# TABLE OF CONTENTS

## 1. Introduction
- 1.1. Interlisp as a Programming Language  1.1
- 1.2. Interlisp as an Interactive Environment  1.3
- 1.3. Interlisp Philosophy  1.5
- 1.4. How to Use this Manual  1.7
- 1.5. References  1.8

## 2. Litatoms
- 2.1. Using Litatoms as Variables  2.2
- 2.2. Function Definition Cells  2.5
- 2.3. Property Lists  2.5
- 2.4. Print Names  2.7
- 2.5. Characters and Character Codes  2.12

## 3. Lists
- 3.1. Creating Lists  3.4
- 3.2. Building Lists From Left to Right  3.6
- 3.3. Copying Lists  3.8
- 3.4. Extracting Tails of Lists  3.9
- 3.5. Counting List Cells  3.10
- 3.6. Logical Operations  3.11
- 3.7. Searching Lists  3.12
- 3.8. Substitution Functions  3.13
- 3.9. Association Lists and Property Lists  3.15
- 3.10. Sorting Lists  3.17
- 3.11. Other List Functions  3.19

## 4. Strings

## 5. Arrays

## 6. Hash Arrays
- 6.1. Hash Overflow  6.3
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.2</td>
<td>User-Specified Hashing Functions</td>
<td>6.4</td>
</tr>
<tr>
<td>7</td>
<td>Numbers and Arithmetic Functions</td>
<td>7.1</td>
</tr>
<tr>
<td>7.1</td>
<td>Generic Arithmetic</td>
<td>7.3</td>
</tr>
<tr>
<td>7.2</td>
<td>Integer Arithmetic</td>
<td>7.4</td>
</tr>
<tr>
<td>7.3</td>
<td>Logical Arithmetic Functions</td>
<td>7.8</td>
</tr>
<tr>
<td>7.4</td>
<td>Floating Point Arithmetic</td>
<td>7.11</td>
</tr>
<tr>
<td>7.5</td>
<td>Other Arithmetic Functions</td>
<td>7.13</td>
</tr>
<tr>
<td>8</td>
<td>Record Package</td>
<td>8.1</td>
</tr>
<tr>
<td>8.1</td>
<td>FETCH and REPLACE</td>
<td>8.2</td>
</tr>
<tr>
<td>8.2</td>
<td>CREATE</td>
<td>8.3</td>
</tr>
<tr>
<td>8.3</td>
<td>TYPE?</td>
<td>8.5</td>
</tr>
<tr>
<td>8.4</td>
<td>WITH</td>
<td>8.5</td>
</tr>
<tr>
<td>8.5</td>
<td>Record Declarations</td>
<td>8.6</td>
</tr>
<tr>
<td>8.5.1</td>
<td>Record Types</td>
<td>8.7</td>
</tr>
<tr>
<td>8.5.2</td>
<td>Optional Record Specifications</td>
<td>8.14</td>
</tr>
<tr>
<td>8.6</td>
<td>Defining New Record Types</td>
<td>8.15</td>
</tr>
<tr>
<td>8.7</td>
<td>Record Manipulation Functions</td>
<td>8.16</td>
</tr>
<tr>
<td>8.8</td>
<td>Changetran</td>
<td>8.17</td>
</tr>
<tr>
<td>8.9</td>
<td>Built-In and User Data Types</td>
<td>8.20</td>
</tr>
<tr>
<td>9</td>
<td>Conditionals and Iterative Statements</td>
<td>9.1</td>
</tr>
<tr>
<td>9.1</td>
<td>Data Type Predicates</td>
<td>9.1</td>
</tr>
<tr>
<td>9.2</td>
<td>Equality Predicates</td>
<td>9.2</td>
</tr>
<tr>
<td>9.3</td>
<td>Logical Predicates</td>
<td>9.3</td>
</tr>
<tr>
<td>9.4</td>
<td>The COND Conditional Function</td>
<td>9.4</td>
</tr>
<tr>
<td>9.5</td>
<td>The IF Statement</td>
<td>9.5</td>
</tr>
<tr>
<td>9.6</td>
<td>Selection Functions</td>
<td>9.6</td>
</tr>
<tr>
<td>9.7</td>
<td>PROG and Associated Control Functions</td>
<td>9.7</td>
</tr>
<tr>
<td>9.8</td>
<td>The Iterative Statement</td>
<td>9.9</td>
</tr>
<tr>
<td>9.8.1</td>
<td>I.s.types</td>
<td>9.10</td>
</tr>
<tr>
<td>9.8.2</td>
<td>Iteration Variable I.s.oprs</td>
<td>9.12</td>
</tr>
<tr>
<td>9.8.3</td>
<td>Condition I.s.oprs</td>
<td>9.15</td>
</tr>
<tr>
<td>9.8.4</td>
<td>Other I.s.oprs</td>
<td>9.16</td>
</tr>
<tr>
<td>9.8.5</td>
<td>Miscellaneous Hints on I.S.Oprs</td>
<td>9.17</td>
</tr>
<tr>
<td>9.8.6</td>
<td>Errors in Iterative Statements</td>
<td>9.19</td>
</tr>
<tr>
<td>Section</td>
<td>Title</td>
<td>Page</td>
</tr>
<tr>
<td>---------</td>
<td>--------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>9.8.7</td>
<td>Defining New Iterative Statement Operators</td>
<td>9.20</td>
</tr>
<tr>
<td>10.</td>
<td>Function Definition, Manipulation, and Evaluation</td>
<td>10.1</td>
</tr>
<tr>
<td>10.1</td>
<td>Function Types</td>
<td>10.2</td>
</tr>
<tr>
<td>10.1.1.</td>
<td>Lambda-Spread Functions</td>
<td>10.3</td>
</tr>
<tr>
<td>10.1.2.</td>
<td>Nlambda-Spread Functions</td>
<td>10.4</td>
</tr>
<tr>
<td>10.1.3.</td>
<td>Lambda-Nospread Functions</td>
<td>10.5</td>
</tr>
<tr>
<td>10.1.4.</td>
<td>Nlambda-Nospread Functions</td>
<td>10.6</td>
</tr>
<tr>
<td>10.1.5.</td>
<td>Compiled Functions</td>
<td>10.6</td>
</tr>
<tr>
<td>10.1.6.</td>
<td>Function Type Functions</td>
<td>10.6</td>
</tr>
<tr>
<td>10.2</td>
<td>Defining Functions</td>
<td>10.9</td>
</tr>
<tr>
<td>10.3</td>
<td>Function Evaluation</td>
<td>10.11</td>
</tr>
<tr>
<td>10.4</td>
<td>Iterating and Mapping Functions</td>
<td>10.14</td>
</tr>
<tr>
<td>10.5</td>
<td>Functional Arguments</td>
<td>10.18</td>
</tr>
<tr>
<td>10.6</td>
<td>Macros</td>
<td>10.21</td>
</tr>
<tr>
<td>10.6.1.</td>
<td>DEFMACRO</td>
<td>10.24</td>
</tr>
<tr>
<td>10.6.2.</td>
<td>Interpreting Macros</td>
<td>10.28</td>
</tr>
<tr>
<td>11.</td>
<td>Variable Bindings and the Interlisp Stack</td>
<td>11.1</td>
</tr>
<tr>
<td>11.1</td>
<td>The Spaghetti Stack</td>
<td>11.2</td>
</tr>
<tr>
<td>11.2</td>
<td>Stack Functions</td>
<td>11.4</td>
</tr>
<tr>
<td>11.2.1.</td>
<td>Searching the Stack</td>
<td>11.5</td>
</tr>
<tr>
<td>11.2.2.</td>
<td>Variable Bindings in Stack Frames</td>
<td>11.6</td>
</tr>
<tr>
<td>11.2.3.</td>
<td>Evaluating Expressions in Stack Frames</td>
<td>11.7</td>
</tr>
<tr>
<td>11.2.4.</td>
<td>Altering Flow of Control</td>
<td>11.8</td>
</tr>
<tr>
<td>11.2.5.</td>
<td>Releasing and Reusing Stack Pointers</td>
<td>11.9</td>
</tr>
<tr>
<td>11.2.6.</td>
<td>Backtrace Functions</td>
<td>11.11</td>
</tr>
<tr>
<td>11.2.7.</td>
<td>Other Stack Functions</td>
<td>11.13</td>
</tr>
<tr>
<td>11.3</td>
<td>The Stack and the Interpreter</td>
<td>11.14</td>
</tr>
<tr>
<td>11.4</td>
<td>Generators</td>
<td>11.16</td>
</tr>
<tr>
<td>11.5</td>
<td>Coroutines</td>
<td>11.18</td>
</tr>
<tr>
<td>11.6</td>
<td>Possibilities Lists</td>
<td>11.20</td>
</tr>
<tr>
<td>12.</td>
<td>Miscellaneous</td>
<td>12.1</td>
</tr>
<tr>
<td>12.1</td>
<td>Greeting and Initialization Files</td>
<td>12.1</td>
</tr>
<tr>
<td>12.2</td>
<td>Idle Mode</td>
<td>12.4</td>
</tr>
<tr>
<td>12.3</td>
<td>Saving Virtual Memory State</td>
<td>12.6</td>
</tr>
</tbody>
</table>
### 12.4. System Version Information

12.11

### 12.5. Date And Time Functions

12.13

### 12.6. Timers and Duration Functions

12.16

### 12.7. Resources

12.19

- 12.7.1. A Simple Example

12.20

- 12.7.2. Trade-offs in More Complicated Cases

12.22

- 12.7.3. Macros for Accessing Resources

12.23

- 12.7.4. Saving Resources in a File

12.23

### 12.8. Pattern Matching

12.24

- 12.8.1. Pattern Elements

12.25

- 12.8.2. Element Patterns

12.25

- 12.8.3. Segment Patterns

12.27

- 12.8.4. Assignments

12.28

- 12.8.5. Place-Markers

12.29

- 12.8.6. Replacements

12.29

- 12.8.7. Reconstruction

12.30

- 12.8.8. Examples

12.31

### 13. Interlisp Executive

13.1

### 13.1. Input Formats

13.3

### 13.2. Programmer’s Assistant Commands

13.5

- 13.2.1. Event Specification

13.6

- 13.2.2. Commands

13.8

- 13.2.3. P.A. Commands Applied to P.A. Commands

13.20

### 13.3. Changing The Programmer’s Assistant

13.21

### 13.4. Undoing

13.26

- 13.4.1. Undoing Out of Order

13.27

- 13.4.2. SAVESET

13.28

- 13.4.3. UNDONLSETQ and RESETUNDO

13.29

### 13.5. Format and Use of the History List

13.31

### 13.6. Programmer’s Assistant Functions

13.35

### 13.7. The Editor and the Programmer’s Assistant

13.43

### 14. Errors and Breaks

14.1

### 14.1. Breaks

14.1

### 14.2. Break Windows

14.3
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.3. Break Commands</td>
<td>14.5</td>
</tr>
<tr>
<td>14.5. Break Window Variables</td>
<td>14.14</td>
</tr>
<tr>
<td>14.6. Creating Breaks with BREAK1</td>
<td>14.16</td>
</tr>
<tr>
<td>14.7. Signalling Errors</td>
<td>14.19</td>
</tr>
<tr>
<td>14.8. Catching Errors</td>
<td>14.21</td>
</tr>
<tr>
<td>14.10. Error List</td>
<td>14.27</td>
</tr>
<tr>
<td>15. Breaking, Tracing, and Advising</td>
<td>15.1</td>
</tr>
<tr>
<td>15.1. Breaking Functions and Debugging</td>
<td>15.1</td>
</tr>
<tr>
<td>15.2. Advising</td>
<td>15.9</td>
</tr>
<tr>
<td>15.2.1. Implementation of Advising</td>
<td>15.10</td>
</tr>
<tr>
<td>15.2.2. Advise Functions</td>
<td>15.10</td>
</tr>
<tr>
<td>16. List Structure Editor</td>
<td>16.1</td>
</tr>
<tr>
<td>16.1. DEdit</td>
<td>16.1</td>
</tr>
<tr>
<td>16.1.1. Calling DEdit</td>
<td>16.2</td>
</tr>
<tr>
<td>16.1.2. Selecting Objects and Lists</td>
<td>16.4</td>
</tr>
<tr>
<td>16.1.3. Typing Characters to DEdit</td>
<td>16.5</td>
</tr>
<tr>
<td>16.1.4. Copy-Selection</td>
<td>16.5</td>
</tr>
<tr>
<td>16.1.5. DEdit Commands</td>
<td>16.6</td>
</tr>
<tr>
<td>16.1.6. Multiple Commands</td>
<td>16.10</td>
</tr>
<tr>
<td>16.1.7. DEdit Idioms</td>
<td>16.10</td>
</tr>
<tr>
<td>16.1.8. DEdit Parameters</td>
<td>16.12</td>
</tr>
<tr>
<td>16.2. Local Attention-Changing Commands</td>
<td>16.13</td>
</tr>
<tr>
<td>16.3. Commands That Search</td>
<td>16.18</td>
</tr>
<tr>
<td>16.3.1. Search Algorithm</td>
<td>16.20</td>
</tr>
<tr>
<td>16.3.2. Search Commands</td>
<td>16.21</td>
</tr>
<tr>
<td>16.3.3. Location Specification</td>
<td>16.23</td>
</tr>
<tr>
<td>16.4. Commands That Save and Restore the Edit Chain</td>
<td>16.27</td>
</tr>
<tr>
<td>16.5. Commands That Modify Structure</td>
<td>16.29</td>
</tr>
<tr>
<td>16.5.1. Implementation</td>
<td>16.30</td>
</tr>
<tr>
<td>16.5.2. The A, B, and : Commands</td>
<td>16.31</td>
</tr>
<tr>
<td>16.5.3. Form Oriented Editing and the Role of UP</td>
<td>16.34</td>
</tr>
<tr>
<td>16.5.4. Extract and Embed</td>
<td>16.35</td>
</tr>
<tr>
<td>Section</td>
<td>Page</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>16.5.5. The MOVE Command</td>
<td>16.37</td>
</tr>
<tr>
<td>16.5.6. Commands That Move Parentheses</td>
<td>16.40</td>
</tr>
<tr>
<td>16.5.7. TO and THRU</td>
<td>16.42</td>
</tr>
<tr>
<td>16.5.8. The R Command</td>
<td>16.45</td>
</tr>
<tr>
<td>16.6. Commands That Print</td>
<td>16.47</td>
</tr>
<tr>
<td>16.7. Commands for Leaving the Editor</td>
<td>16.49</td>
</tr>
<tr>
<td>16.8. Nested Calls to Editor</td>
<td>16.51</td>
</tr>
<tr>
<td>16.9. Manipulating the Characters of an Atom or String</td>
<td>16.52</td>
</tr>
<tr>
<td>16.10. Manipulating Predicates and Conditional Expressions</td>
<td>16.53</td>
</tr>
<tr>
<td>16.11. History commands in the editor</td>
<td>16.54</td>
</tr>
<tr>
<td>16.12. Miscellaneous Commands</td>
<td>16.55</td>
</tr>
<tr>
<td>16.13. Commands That Evaluate</td>
<td>16.57</td>
</tr>
<tr>
<td>16.15. Edit Macros</td>
<td>16.62</td>
</tr>
<tr>
<td>16.16. Undo</td>
<td>16.64</td>
</tr>
<tr>
<td>16.17. EDITDEFAULT</td>
<td>16.66</td>
</tr>
<tr>
<td>16.18. Editor Functions</td>
<td>16.68</td>
</tr>
<tr>
<td>16.19. Time Stamps</td>
<td>16.76</td>
</tr>
<tr>
<td><strong>17. File Package</strong></td>
<td>17.1</td>
</tr>
<tr>
<td>17.1. Loading Files</td>
<td>17.5</td>
</tr>
<tr>
<td>17.2. Storing Files</td>
<td>17.10</td>
</tr>
<tr>
<td>17.3. Remaking a Symbolic File</td>
<td>17.15</td>
</tr>
<tr>
<td>17.4. Loading Files in a Distributed Environment</td>
<td>17.16</td>
</tr>
<tr>
<td>17.5. Marking Changes</td>
<td>17.17</td>
</tr>
<tr>
<td>17.6. Noticing Files</td>
<td>17.19</td>
</tr>
<tr>
<td>17.7. Distributing Change Information</td>
<td>17.21</td>
</tr>
<tr>
<td>17.8. File Package Types</td>
<td>17.21</td>
</tr>
<tr>
<td>17.8.1. Functions for Manipulating Typed Definitions</td>
<td>17.24</td>
</tr>
<tr>
<td>17.8.2. Defining New File Package Types</td>
<td>17.29</td>
</tr>
<tr>
<td>17.9. File Package Commands</td>
<td>17.32</td>
</tr>
<tr>
<td>17.9.1. Functions and Macros</td>
<td>17.34</td>
</tr>
<tr>
<td>17.9.2. Variables</td>
<td>17.35</td>
</tr>
<tr>
<td>17.9.3. Litatom Properties</td>
<td>17.37</td>
</tr>
<tr>
<td>17.9.4. Miscellaneous File Package Commands</td>
<td>17.38</td>
</tr>
</tbody>
</table>
# Master Table of Contents

## 17.9.5. DECLARE:
- 17.40

## 17.9.6. Exporting Definitions
- 17.42

## 17.9.7. FileVars
- 17.44

## 17.9.8. Defining New File Package Commands
- 17.45

## 17.10. Functions for Manipulating File Command Lists
- 17.48

## 17.11. Symbolic File Format
- 17.50

### 17.11.1. Copyright Notices
- 17.52

### 17.11.2. Functions Used Within Source Files
- 17.54

### 17.11.3. File Maps
- 17.55

## 18. Compiler

### 18.1. Compiler Printout
- 18.3

### 18.2. Global Variables
- 18.4

### 18.3. Local Variables and Special Variables
- 18.5

### 18.4. Constants
- 18.7

### 18.5. Compiling Function Calls
- 18.8

### 18.6. FUNCTION and Functional Arguments
- 18.10

### 18.7. Open Functions
- 18.11

### 18.8. COMPILETYPELST
- 18.11

### 18.9. Compiling CLISP
- 18.11

### 18.10. Compiler Functions
- 18.13

### 18.11. Block Compiling
- 18.17

#### 18.11.1. Block Declarations
- 18.17

#### 18.11.2. Block Compiling Functions
- 18.20

### 18.12. Compiler Error Messages
- 18.22

## 19. Masterscope

### 19.1. Command Language
- 19.3

#### 19.1.1. Commands
- 19.4

#### 19.1.2. Relations
- 19.7

#### 19.1.3. Set Specifications
- 19.10

#### 19.1.4. Set Determiners
- 19.13

#### 19.1.5. Set Types
- 19.13

#### 19.1.6. Conjunctions of Sets
- 19.14

### 19.2. SHOW PATHS
- 19.15

### 19.3. Error Messages
- 19.17
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.4. Macro Expansion</td>
<td>19.17</td>
</tr>
<tr>
<td>19.5. Affecting Masterscope Analysis</td>
<td>19.18</td>
</tr>
<tr>
<td>19.6. Data Base Updating</td>
<td>19.22</td>
</tr>
<tr>
<td>19.7. Masterscope Entries</td>
<td>19.22</td>
</tr>
<tr>
<td>19.8. Noticing Changes that Require Recompiling</td>
<td>19.25</td>
</tr>
<tr>
<td>19.9. Implementation Notes</td>
<td>19.25</td>
</tr>
<tr>
<td>20. DWIM</td>
<td>20.1</td>
</tr>
<tr>
<td>20.1. Spelling Correction Protocol</td>
<td>20.4</td>
</tr>
<tr>
<td>20.2. Parentheses Errors Protocol</td>
<td>20.5</td>
</tr>
<tr>
<td>20.3. Undefined Function T Errors</td>
<td>20.6</td>
</tr>
<tr>
<td>20.4. DWIM Operation</td>
<td>20.7</td>
</tr>
<tr>
<td>20.4.1. DWIM Correction: Unbound Atoms</td>
<td>20.8</td>
</tr>
<tr>
<td>20.4.2. Undefined CAR of Form</td>
<td>20.9</td>
</tr>
<tr>
<td>20.4.3. Undefined Function in APPLY</td>
<td>20.10</td>
</tr>
<tr>
<td>20.5. DWIMUSERFORMS</td>
<td>20.11</td>
</tr>
<tr>
<td>20.6. DWIM Functions and Variables</td>
<td>20.13</td>
</tr>
<tr>
<td>20.7. Spelling Correction</td>
<td>20.15</td>
</tr>
<tr>
<td>20.7.1. Synonyms</td>
<td>20.16</td>
</tr>
<tr>
<td>20.7.2. Spelling Lists</td>
<td>20.16</td>
</tr>
<tr>
<td>20.7.3. Generators for Spelling Correction</td>
<td>20.19</td>
</tr>
<tr>
<td>20.7.4. Spelling Corrector Algorithm</td>
<td>20.19</td>
</tr>
<tr>
<td>20.7.5. Spelling Corrector Functions and Variables</td>
<td>20.21</td>
</tr>
<tr>
<td>21. CLISP</td>
<td>21.1</td>
</tr>
<tr>
<td>21.1. CLISP Interaction with User</td>
<td>21.6</td>
</tr>
<tr>
<td>21.2. CLISP Character Operators</td>
<td>21.7</td>
</tr>
<tr>
<td>21.3. Declarations</td>
<td>21.12</td>
</tr>
<tr>
<td>21.4. CLISP Operation</td>
<td>21.14</td>
</tr>
<tr>
<td>21.5. CLISP Translations</td>
<td>21.17</td>
</tr>
<tr>
<td>21.6. DWIMIFY</td>
<td>21.18</td>
</tr>
<tr>
<td>21.7. CLISPIFY</td>
<td>21.22</td>
</tr>
<tr>
<td>21.8. Miscellaneous Functions and Variables</td>
<td>21.25</td>
</tr>
<tr>
<td>21.9. CLISP Internal Conventions</td>
<td>21.27</td>
</tr>
<tr>
<td>22. Performance Issues</td>
<td>22.1</td>
</tr>
<tr>
<td>22.1. Storage Allocation and Garbage Collection</td>
<td>22.1</td>
</tr>
<tr>
<td>Section</td>
<td>Page</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>22.2. Variable Bindings</td>
<td>22.5</td>
</tr>
<tr>
<td>22.3. Performance Measuring</td>
<td>22.7</td>
</tr>
<tr>
<td>22.3.1. BREAKDOWN</td>
<td>22.9</td>
</tr>
<tr>
<td>22.4. GAINSPACE</td>
<td>22.11</td>
</tr>
<tr>
<td>22.5. Using Data Types Instead of Records</td>
<td>22.13</td>
</tr>
<tr>
<td>22.6. Using Incomplete File Names</td>
<td>22.13</td>
</tr>
<tr>
<td>22.7. Using &quot;Fast&quot; and &quot;Destructive&quot; Functions</td>
<td>22.14</td>
</tr>
<tr>
<td><strong>23. Processes</strong></td>
<td></td>
</tr>
<tr>
<td>23.1. Creating and Destroying Processes</td>
<td>23.2</td>
</tr>
<tr>
<td>23.2. Process Control Constructs</td>
<td>23.5</td>
</tr>
<tr>
<td>23.3. Events</td>
<td>23.7</td>
</tr>
<tr>
<td>23.4. Monitors</td>
<td>23.8</td>
</tr>
<tr>
<td>23.5. Global Resources</td>
<td>23.10</td>
</tr>
<tr>
<td>23.6. Type in and the TTY Process</td>
<td>23.11</td>
</tr>
<tr>
<td>23.6.1. Switching the TTY Process</td>
<td>23.12</td>
</tr>
<tr>
<td>23.6.2. Handling of Interrupts</td>
<td>23.14</td>
</tr>
<tr>
<td>23.7. Keeping the Mouse Alive</td>
<td>23.15</td>
</tr>
<tr>
<td>23.8. Process Status Window</td>
<td>23.16</td>
</tr>
<tr>
<td>23.9. Non-Process Compatibility</td>
<td>23.17</td>
</tr>
<tr>
<td><strong>24. Streams and Files</strong></td>
<td></td>
</tr>
<tr>
<td>24.1. Opening and Closing File Streams</td>
<td>24.2</td>
</tr>
<tr>
<td>24.2. File Names</td>
<td>24.5</td>
</tr>
<tr>
<td>24.3. Incomplete File Names</td>
<td>24.9</td>
</tr>
<tr>
<td>24.4. Version Recognition</td>
<td>24.11</td>
</tr>
<tr>
<td>24.5. Using File Names Instead of Streams</td>
<td>24.13</td>
</tr>
<tr>
<td>24.5.1. File Name Efficiency Considerations</td>
<td>24.14</td>
</tr>
<tr>
<td>24.5.2. Obsolete File Opening Functions</td>
<td>24.14</td>
</tr>
<tr>
<td>24.5.3. Converting Old Programs</td>
<td>24.15</td>
</tr>
<tr>
<td>24.6. Using Files with Processes</td>
<td>24.16</td>
</tr>
<tr>
<td>24.7. File Attributes</td>
<td>24.17</td>
</tr>
<tr>
<td>24.8. Closing and Reopening Files</td>
<td>24.20</td>
</tr>
<tr>
<td>24.9. Local Hard Disk Device</td>
<td>24.21</td>
</tr>
<tr>
<td>24.10. Floppy Disk Device</td>
<td>24.24</td>
</tr>
<tr>
<td>24.11. I/O Operations to and from Strings</td>
<td>24.28</td>
</tr>
</tbody>
</table>
24.12. Temporary Files and the CORE Device 24.29
24.13. NULL Device 24.30
24.15. Deleting, Copying, and Renaming Files 24.31
24.16. Searching File Directories 24.31
24.17. Listing File Directories 24.33
24.18. File Servers 24.36
    24.18.1. Pup File Server Protocols 24.36
    24.18.2. Xerox NS File Server Protocols 24.37
    24.18.3. Operating System Designations 24.38
    24.18.4. Logging In 24.39
    24.18.5. Abnormal Conditions 24.41

25. Input/Output Functions 25.1
    25.1. Specifying Streams for Input/Output Functions 25.1
    25.2. Input Functions 25.2
    25.3. Output Functions 25.7
        25.3.1. PRINTLEVEL 25.11
        25.3.2. Printing numbers 25.13
        25.3.3. User Defined Printing 25.16
        25.3.4. Printing Unusual Data Structures 25.17
    25.4. Random Access File Operations 25.18
    25.5. Input/Output Operations with Characters and Bytes 25.22
    25.6. PRINTOUT 25.23
        25.6.1. Horizontal Spacing Commands 25.25
        25.6.2. Vertical Spacing Commands 25.26
        25.6.3. Special Formatting Controls 25.27
        25.6.4. Printing Specifications 25.27
        25.6.4.1. Paragraph Format 25.28
        25.6.4.2. Right-Flushing 25.29
        25.6.4.3. Centering 25.29
        25.6.4.4. Numbering 25.29
        25.6.5. Escaping to Lisp 25.30
        25.6.6. User-Defined Commands 25.31
        25.6.7. Special Printing Functions 25.32
    25.7. READFILE and WRITEFILE 25.33
## 25.8. Read Tables

- **25.8.1. Read Table Functions** 25.34
- **25.8.2. Syntax Classes** 25.35
- **25.8.3. Read Macros** 25.39

## 26. User Input/Output Packages

### 26.1. Inspector

- **26.1.1. Calling the Inspector** 26.2
- **26.1.2. Multiple Ways of Inspecting** 26.2
- **26.1.3. Inspect Windows** 26.3
- **26.1.4. Inspect Window Commands** 26.4
- **26.1.5. Interaction With Break Windows** 26.5
- **26.1.6. Controlling the Amount Displayed During Inspection** 26.5
- **26.1.7. Inspect Macros** 26.6
- **26.1.8. INSPECTWs** 26.6

### 26.2. PROMPTFORWORD

### 26.3. ASKUSER

- **26.3.1. Format of KEYLST** 26.13
- **26.3.2. Options** 26.15
- **26.3.3. Operation** 26.17
- **26.3.4. Completing a Key** 26.18
- **26.3.5. Special Keys** 26.19
- **26.3.6. Startup Protocol and Typeahead** 26.20

### 26.4. TTYIN Display Typein Editor

- **26.4.1. Entering Input With TTYIN** 26.22
- **26.4.2. Mouse Commands [Interlisp-D Only]** 26.24
- **26.4.3. Display Editing Commands** 26.25
- **26.4.4. Using TTYIN for Lisp Input** 26.28
- **26.4.5. Useful Macros** 26.29
- **26.4.6. Programming With TTYIN** 26.29
- **26.4.7. Using TTYIN as a General Editor** 26.32
- **26.4.8. = Handler** 26.33
- **26.4.9. Read Macros** 26.34
- **26.4.10. Assorted Flags** 26.36
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>26.4.11. Special Responses</td>
<td>26.38</td>
</tr>
<tr>
<td>26.4.12. Display Types</td>
<td>26.38</td>
</tr>
<tr>
<td>26.5. Prettyprint</td>
<td>26.39</td>
</tr>
<tr>
<td>26.5.1. Comment Feature</td>
<td>26.42</td>
</tr>
<tr>
<td>26.5.2. Comment Pointers</td>
<td>26.44</td>
</tr>
<tr>
<td>26.5.3. Converting Comments to Lower Case</td>
<td>26.46</td>
</tr>
<tr>
<td>26.5.4. Special Prettyprint Controls</td>
<td>26.47</td>
</tr>
<tr>
<td>27. Graphics Output Operations</td>
<td>27.1</td>
</tr>
<tr>
<td>27.1. Primitive Graphics Concepts</td>
<td>27.1</td>
</tr>
<tr>
<td>27.1.1. Positions</td>
<td>27.1</td>
</tr>
<tr>
<td>27.1.2. Regions</td>
<td>27.1</td>
</tr>
<tr>
<td>27.1.3. Bitmaps</td>
<td>27.3</td>
</tr>
<tr>
<td>27.1.4. Textures</td>
<td>27.6</td>
</tr>
<tr>
<td>27.2. Opening Image Streams</td>
<td>27.8</td>
</tr>
<tr>
<td>27.3. Accessing Image Stream Fields</td>
<td>27.10</td>
</tr>
<tr>
<td>27.5. Moving Bits Between Bitmaps With BITBLT</td>
<td>27.14</td>
</tr>
<tr>
<td>27.6. Drawing Lines</td>
<td>27.17</td>
</tr>
<tr>
<td>27.7. Drawing Curves</td>
<td>27.18</td>
</tr>
<tr>
<td>27.8. Miscellaneous Drawing and Printing Operations</td>
<td>27.20</td>
</tr>
<tr>
<td>27.9. Drawing and Shading Grids</td>
<td>27.22</td>
</tr>
<tr>
<td>27.10. Display Streams</td>
<td>27.23</td>
</tr>
<tr>
<td>27.12. Fonts</td>
<td>27.25</td>
</tr>
<tr>
<td>27.13. Font Files and Font Directories</td>
<td>27.31</td>
</tr>
<tr>
<td>27.15. Font Profiles</td>
<td>27.32</td>
</tr>
<tr>
<td>27.16. Image Objects</td>
<td>27.35</td>
</tr>
<tr>
<td>27.16.1. IMAGEFNS Methods</td>
<td>27.36</td>
</tr>
<tr>
<td>27.16.2. Registering Image Objects</td>
<td>27.39</td>
</tr>
<tr>
<td>27.16.3. Reading and Writing Image Objects on Files</td>
<td>27.40</td>
</tr>
<tr>
<td>27.16.4. Copying Image Objects Between Windows</td>
<td>27.41</td>
</tr>
<tr>
<td>27.17. Implementation of Image Streams</td>
<td>27.42</td>
</tr>
<tr>
<td>28. Windows and Menus</td>
<td>28.1</td>
</tr>
<tr>
<td>28.2. Changing Window Command Menus</td>
<td>28.7</td>
</tr>
<tr>
<td>Section</td>
<td>Subsection</td>
</tr>
<tr>
<td>---------</td>
<td>------------</td>
</tr>
<tr>
<td>28.3.</td>
<td>Interactive Display Functions</td>
</tr>
<tr>
<td>28.4.1.</td>
<td>Window Properties</td>
</tr>
<tr>
<td>28.4.2.</td>
<td>Creating Windows</td>
</tr>
<tr>
<td>28.4.3.</td>
<td>Opening and Closing Windows</td>
</tr>
<tr>
<td>28.4.4.</td>
<td>Redisplaying Windows</td>
</tr>
<tr>
<td>28.4.5.</td>
<td>Reshaping Windows</td>
</tr>
<tr>
<td>28.4.6.</td>
<td>Moving Windows</td>
</tr>
<tr>
<td>28.4.7.</td>
<td>Exposing and Burying Windows</td>
</tr>
<tr>
<td>28.4.8.</td>
<td>Shrinking Windows Into Icons</td>
</tr>
<tr>
<td>28.4.9.</td>
<td>Coordinate Systems, Extents, And Scrolling</td>
</tr>
<tr>
<td>28.4.10.</td>
<td>Mouse Activity in Windows</td>
</tr>
<tr>
<td>28.4.11.</td>
<td>Terminal I/O and Page Holding</td>
</tr>
<tr>
<td>28.4.12.</td>
<td>The TTY Process and the Caret</td>
</tr>
<tr>
<td>28.4.13.</td>
<td>Miscellaneous Window Functions</td>
</tr>
<tr>
<td>28.4.15.</td>
<td>Example: A Scrollable Window</td>
</tr>
<tr>
<td>28.5.</td>
<td>Menus</td>
</tr>
<tr>
<td>28.5.1.</td>
<td>Menu Fields</td>
</tr>
<tr>
<td>28.5.2.</td>
<td>Miscellaneous Menu Functions</td>
</tr>
<tr>
<td>28.5.3.</td>
<td>Examples of Menu Use</td>
</tr>
<tr>
<td>28.6.</td>
<td>Attached Windows</td>
</tr>
<tr>
<td>28.6.1.</td>
<td>Attaching Menus To Windows</td>
</tr>
<tr>
<td>28.6.2.</td>
<td>Attached Prompt Windows</td>
</tr>
<tr>
<td>28.6.3.</td>
<td>Window Operations And Attached Windows</td>
</tr>
<tr>
<td>28.6.4.</td>
<td>Window Properties Of Attached Windows</td>
</tr>
<tr>
<td>29.</td>
<td>Hardcopy Facilities</td>
</tr>
<tr>
<td>29.1.</td>
<td>Low-level Hardcopy Variables</td>
</tr>
<tr>
<td>30.</td>
<td>Terminal Input/Output</td>
</tr>
<tr>
<td>30.1.</td>
<td>Interrupt Characters</td>
</tr>
<tr>
<td>30.2.</td>
<td>Terminal Tables</td>
</tr>
<tr>
<td>30.2.1.</td>
<td>Terminal Syntax Classes</td>
</tr>
<tr>
<td>30.2.2.</td>
<td>Terminal Control Functions</td>
</tr>
<tr>
<td>30.2.3.</td>
<td>Line-Buffering</td>
</tr>
</tbody>
</table>
MASTER TABLE OF CONTENTS

30.3. Dribble Files  30.12
30.4. Cursor and Mouse  30.13
   30.4.1. Changing the Cursor Image  30.13
   30.4.2. Flashing Bars on the Cursor  30.16
   30.4.3. Cursor Position  30.17
   30.4.4. Mouse Button Testing  30.17
   30.4.5. Low Level Mouse Functions  30.18
30.5. Keyboard Interpretation  30.19
30.6. Display Screen  30.22
30.7. Miscellaneous Terminal I/O  30.24

31. Ethernet  31.1
   31.1. Ethernet Protocols  31.1
      31.1.1. Protocol Layering  31.1
      31.1.2. Level Zero Protocols  31.2
      31.1.3. Level One Protocols  31.3
      31.1.4. Higher Level Protocols  31.4
      31.1.5. Connecting Networks: Routers and Gateways  31.4
      31.1.6. Addressing Conflicts with Level Zero Mediums  31.5
      31.1.7. References  31.5
   31.2. Higher-level PUP Protocol Functions  31.6
   31.3. Higher-level NS Protocol Functions  31.7
      31.3.1. Name and Address Conventions  31.7
      31.3.2. Clearinghouse Functions  31.9
      31.3.3. NS Printing  31.12
      31.3.4. SPP Stream Interface  31.12
      31.3.5. Courier Remote Procedure Call Protocol  31.15
         31.3.5.1. Defining Courier Programs  31.15
         31.3.5.2. Courier Type Definitions  31.17
         31.3.5.2.1. Pre-defined Types  31.17
         31.3.5.2.2. Constructed Types  31.18
         31.3.5.2.3. User Extensions to the Type Language  31.19
         31.3.5.3. Performing Courier Transactions  31.20
         31.3.5.3.1. Expedited Procedure Call  31.22
         31.3.5.3.2. Expanding Ring Broadcast  31.23
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>31.3.5.3.3</td>
<td>Using Bulk Data Transfer</td>
<td>31.24</td>
</tr>
<tr>
<td>31.3.5.3.4</td>
<td>Courier Subfunctions for Data Transfer</td>
<td>31.25</td>
</tr>
<tr>
<td>31.4</td>
<td>Level One Ether Packet Format</td>
<td>31.26</td>
</tr>
<tr>
<td>31.5</td>
<td>PUP Level One Functions</td>
<td>31.28</td>
</tr>
<tr>
<td>31.5.1</td>
<td>Creating and Managing Pups</td>
<td>31.28</td>
</tr>
<tr>
<td>31.5.2</td>
<td>Sockets</td>
<td>31.28</td>
</tr>
<tr>
<td>31.5.3</td>
<td>Sending and Receiving Pups</td>
<td>31.29</td>
</tr>
<tr>
<td>31.5.4</td>
<td>Pup Routing Information</td>
<td>31.30</td>
</tr>
<tr>
<td>31.5.5</td>
<td>Miscellaneous PUP Utilities</td>
<td>31.31</td>
</tr>
<tr>
<td>31.5.6</td>
<td>PUP Debugging Aids</td>
<td>31.32</td>
</tr>
<tr>
<td>31.6</td>
<td>NS Level One Functions</td>
<td>31.36</td>
</tr>
<tr>
<td>31.6.1</td>
<td>Creating and Managing XIPs</td>
<td>31.36</td>
</tr>
<tr>
<td>31.6.2</td>
<td>NS Sockets</td>
<td>31.37</td>
</tr>
<tr>
<td>31.6.3</td>
<td>Sending and Receiving XIPs</td>
<td>31.37</td>
</tr>
<tr>
<td>31.6.4</td>
<td>NS Debugging Aids</td>
<td>31.38</td>
</tr>
<tr>
<td>31.7</td>
<td>Support for Other Level One Protocols</td>
<td>31.38</td>
</tr>
<tr>
<td>31.8</td>
<td>The SYSQUEUE mechanism</td>
<td>31.41</td>
</tr>
<tr>
<td>Section</td>
<td>Page</td>
<td></td>
</tr>
<tr>
<td>-----------------------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td><strong>1. Introduction</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1. Interlisp as a Programming Language</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>1.2. Interlisp as an Interactive Environment</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>1.3. Interlisp Philosophy</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>1.4. How to Use this Manual</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>1.5. References</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td><strong>2. Litatoms</strong></td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td>2.1. Using Litatoms as Variables</td>
<td>2.2</td>
<td></td>
</tr>
<tr>
<td>2.2. Function Definition Cells</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>2.3. Property Lists</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>2.4. Print Names</td>
<td>2.7</td>
<td></td>
</tr>
<tr>
<td>2.5. Characters and Character Codes</td>
<td>2.12</td>
<td></td>
</tr>
<tr>
<td><strong>3. Lists</strong></td>
<td>3.1</td>
<td></td>
</tr>
<tr>
<td>3.1. Creating Lists</td>
<td>3.4</td>
<td></td>
</tr>
<tr>
<td>3.2. Building Lists From Left to Right</td>
<td>3.6</td>
<td></td>
</tr>
<tr>
<td>3.3. Copying Lists</td>
<td>3.8</td>
<td></td>
</tr>
<tr>
<td>3.4. Extracting Tails of Lists</td>
<td>3.9</td>
<td></td>
</tr>
<tr>
<td>3.5. Counting List Cells</td>
<td>3.10</td>
<td></td>
</tr>
<tr>
<td>3.6. Logical Operations</td>
<td>3.11</td>
<td></td>
</tr>
<tr>
<td>3.7. Searching Lists</td>
<td>3.12</td>
<td></td>
</tr>
<tr>
<td>3.8. Substitution Functions</td>
<td>3.13</td>
<td></td>
</tr>
<tr>
<td>3.9. Association Lists and Property Lists</td>
<td>3.15</td>
<td></td>
</tr>
<tr>
<td>3.10. Sorting Lists</td>
<td>3.17</td>
<td></td>
</tr>
<tr>
<td>3.11. Other List Functions</td>
<td>3.19</td>
<td></td>
</tr>
<tr>
<td><strong>4. Strings</strong></td>
<td>4.1</td>
<td></td>
</tr>
<tr>
<td><strong>5. Arrays</strong></td>
<td>5.1</td>
<td></td>
</tr>
<tr>
<td><strong>6. Hash Arrays</strong></td>
<td>6.1</td>
<td></td>
</tr>
<tr>
<td>6.1. Hash Overflow</td>
<td>6.3</td>
<td></td>
</tr>
</tbody>
</table>
# TABLE OF CONTENTS

6.2. User-Specified Hashing Functions 6.4

7. Numbers and Arithmetic Functions 7.1

7.1. Generic Arithmetic 7.3
7.2. Integer Arithmetic 7.4
7.3. Logical Arithmetic Functions 7.8
7.4. Floating Point Arithmetic 7.11
7.5. Other Arithmetic Functions 7.13

8. Record Package 8.1

8.1. FETCH and REPLACE 8.2
8.2. CREATE 8.3
8.3. TYPE? 8.5
8.4. WITH 8.5
8.5. Record Declarations 8.6
  8.5.1. Record Types 8.7
  8.5.2. Optional Record Specifications 8.14
8.6. Defining New Record Types 8.15
8.7. Record Manipulation Functions 8.16
8.8. Changetran 8.17
8.9. Built-In and User Data Types 8.20

9. Conditionals and Iterative Statements 9.1

9.1. Data Type Predicates 9.1
9.2. Equality Predicates 9.2
9.3. Logical Predicates 9.3
9.4. The COND Conditional Function 9.4
9.5. The IF Statement 9.5
9.6. Selection Functions 9.6
9.7. PROG and Associated Control Functions 9.7
9.8. The Iterative Statement 9.9
  9.8.1. l.s.types 9.10
  9.8.2. Iteration Variable l.s.oprs 9.12
  9.8.3. Condition l.s.oprs 9.15
  9.8.4. Other l.s.oprs 9.16
  9.8.5. Miscellaneous Hints on l.S.Oprs 9.17
  9.8.6. Errors in Iterative Statements 9.19
# 9.8.7. Defining New Iterative Statement Operators

## 10. Function Definition, Manipulation, and Evaluation

### 10.1. Function Types

- **10.1.1. Lambda-Spread Functions**
- **10.1.2. Nlambda-Spread Functions**
- **10.1.3. Lambda-Nospread Functions**
- **10.1.4. Nlambda-Nospread Functions**
- **10.1.5. Compiled Functions**
- **10.1.6. Function Type Functions**

### 10.2. Defining Functions

### 10.3. Function Evaluation

### 10.4. Iterating and Mapping Functions

### 10.5. Functional Arguments

### 10.6. Macros

- **10.6.1. DEFMACRO**
- **10.6.2. Interpreting Macros**

## 11. Variable Bindings and the Interlisp Stack

### 11.1. The Spaghetti Stack

### 11.2. Stack Functions

- **11.2.1. Searching the Stack**
- **11.2.2. Variable Bindings in Stack Frames**
- **11.2.3. Evaluating Expressions in Stack Frames**
- **11.2.4. Altering Flow of Control**
- **11.2.5. Releasing and Reusing Stack Pointers**
- **11.2.6. Backtrace Functions**
- **11.2.7. Other Stack Functions**

### 11.3. The Stack and the Interpreter

### 11.4. Generators

### 11.5. Coroutines

### 11.6. Possibilities Lists

## 12. Miscellaneous

### 12.1. Greeting and Initialization Files

### 12.2. Idle Mode

### 12.3. Saving Virtual Memory State
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.4</td>
<td>System Version Information</td>
<td>12.11</td>
</tr>
<tr>
<td>12.5</td>
<td>Date And Time Functions</td>
<td>12.13</td>
</tr>
<tr>
<td>12.6</td>
<td>Timers and Duration Functions</td>
<td>12.16</td>
</tr>
<tr>
<td>12.7</td>
<td>Resources</td>
<td>12.19</td>
</tr>
<tr>
<td></td>
<td>12.7.1. A Simple Example</td>
<td>12.20</td>
</tr>
<tr>
<td></td>
<td>12.7.2. Trade-offs in More Complicated Cases</td>
<td>12.22</td>
</tr>
<tr>
<td></td>
<td>12.7.3. Macros for Accessing Resources</td>
<td>12.23</td>
</tr>
<tr>
<td></td>
<td>12.7.4. Saving Resources in a File</td>
<td>12.23</td>
</tr>
<tr>
<td>12.8</td>
<td>Pattern Matching</td>
<td>12.24</td>
</tr>
<tr>
<td></td>
<td>12.8.1. Pattern Elements</td>
<td>12.25</td>
</tr>
<tr>
<td></td>
<td>12.8.2. Element Patterns</td>
<td>12.25</td>
</tr>
<tr>
<td></td>
<td>12.8.3. Segment Patterns</td>
<td>12.27</td>
</tr>
<tr>
<td></td>
<td>12.8.4. Assignments</td>
<td>12.28</td>
</tr>
<tr>
<td></td>
<td>12.8.5. Place-Markers</td>
<td>12.29</td>
</tr>
<tr>
<td></td>
<td>12.8.6. Replacements</td>
<td>12.29</td>
</tr>
<tr>
<td></td>
<td>12.8.7. Reconstruction</td>
<td>12.30</td>
</tr>
<tr>
<td></td>
<td>12.8.8. Examples</td>
<td>12.31</td>
</tr>
</tbody>
</table>
A Brief History of Interlisp

Interlisp began with an implementation of the Lisp programming language for the PDP-1 at Bolt, Beranek and Newman in 1966. It was followed in 1967 by 940 Lisp for the SDS-940 computer, which was the first Lisp system to use software paging techniques and a large virtual memory in conjunction with a list-processing system [Bobrow & Murphy, 1967]. DWIM, the Do-What-I-Mean error correction facility, was introduced into this system in 1968 by Warren Teitelman [Teitelman, 1969].

In 1970 BBN-Lisp, an upward compatible Lisp system for the PDP-10, was implemented under the Tenex operating system [Teitelman, et al., 1972]. With the hardware paging and 256K of virtual memory provided by Tenex, it was practical to provide more extensive and sophisticated user support facilities, and a library of such facilities began to evolve. In 1972, the name of the system was changed to Interlisp, and its development became a joint effort of the Xerox Palo Alto Research Center and Bolt, Beranek and Newman. The next few years saw a period of rapid growth and development of the language, the system and the user support facilities, including the record package, the file package, and Masterscope.

In 1974, an implementation of Interlisp was begun for the Xerox Alto, an experimental microprogrammed personal computer [Thacker et al., 1979]. AltoLisp [Deutsch, 1973] introduced the idea of providing a specialized, microcoded instruction set that modelled the basic operations of Lisp more closely than a general-purpose instruction set could -- and as such was the first true "Lisp machine". AltoLisp also served as a departure point for Interlisp-D, the implementation of Interlisp for the Xerox 1100 Series of personal computers, which was begun in 1979 [Sheil & Masinter, 1983].

In 1976, partially as a result of the AltoLisp effort, a specification for the Interlisp "virtual machine" was published [Moore, 1976]. This attempted to specify a small set of "primitive" operations...
which would support all of the higher level user facilities, which were nearly all written in Lisp. Although incomplete and written at a level which preserved too many of the details of the Tenex operating system, this document proved to be a watershed in the development of Interlisp, since it gave a clear definition of a (relatively) small kernel whose implementation would suffice to port Interlisp to a new environment. This was decisive in enabling many subsequent implementations.

Most recently, the implementation of Interlisp on personal workstations has extended Interlisp in major ways. Most striking has been the incorporation of interactive graphics and local area network facilities. Not only have these extensions expanded the range of applications for which Interlisp is being used, but the personal machine capabilities have had a major impact on the Interlisp programming system itself. Whereas the original Interlisp user interface assumed a very limited (teletype) channel to the user, the use of interactive graphics and the "mouse" pointing device has radically expanded the bandwidth of communication between the user and the machine. This has enabled completely new styles of interaction with the user (e.g., the use of multiple windows to provide several different interaction channels with the user) and these have provided both new programming tools and new ways of viewing and using the existing ones. In addition, the increased use of local area networks (such as the Ethernet) has expanded the horizon of the Interlisp user beyond the local machine to a whole community of machines, processes and services. Large portions of this manual are devoted to documenting the enhanced environment that has resulted from these developments.

## 2 Interlisp Implementations

Development of Interlisp for the PDP-10 was, until approximately 1978, funded by the Advanced Research Projects Administration of the Department of Defence (DARPA). Subsequent developments, which have emphasized the personal workstation facilities, have been sponsored by the Xerox Corporation, with contributions from members of the Interlisp user community.

Although there are a variety of implementations of Interlisp in use, this manual is a reference manual for the Interlisp-D implementation. Notes may occasionally be included on other implementations, but there is no guarantee that this information is complete for implementations other than Interlisp-D. For some implementations, there is a "Users Guide" which documents features which are completely unique to that...
machine; for example, how to turn on the system, logging on, and unique facilities which link Interlisp to the host environment or operating system.

3 Acknowledgements

The Interlisp system is the work of many people -- after nearly twenty years, too many even to list, much less detail their contributions. Nevertheless, some individuals cannot go unacknowledged:

Warren Teitelman, more than anyone else, made Interlisp "happen". Warren designed and implemented large parts of several generations of Interlisp, including the initial versions of most of the user facilities, coordinated the system development and assembled and edited the first four editions of the Interlisp reference manual.

Larry Masinter is a principal architect of the current Interlisp system, has contributed extensively to several implementations, and has designed and developed major extensions to both the Interlisp language and the programming environment.

Dan Bobrow was a principal designer of Interlisp's predecessors, has contributed to the implementation of several generations of Interlisp, and (in collaboration with others) made major advances in the underlying architecture, including the spaghetti stack, the transaction garbage collector, and the block compiler.

Ron Kaplan has decisively shaped many of the programming language extensions and user facilities of Interlisp, has played a key role in two implementations and has contributed extensively to the design and content of the Interlisp reference manual.

Peter Deutsch designed the Alto Lisp implementation of Interlisp which developed several key design insights on which the current generation of personal machine implementations depends.

No matter where one ends this list, one is tempted to continue. Many others who contributed to particular implementations or revisions are acknowledged in the documentation for those systems. Following that tradition, this manual, which primarily documents the Interlisp-D implementation, acknowledges, in addition to those listed above, the work of:

Bill van Melle, who designed and implemented most of the local area network facilities, the process mechanism, and much of the run time support system.

Richard Burton, who designed and implemented a great deal of the interactive display facilities.
and the contributions of Alan Bell, Don Charnley, Mitch Lichtenberg, Steve Purcell, Eric Schoen, Beau Sheil, John Sybalsky, and the many others who have helped and contributed to the development of Interlisp-D.

Like Interlisp itself, the Interlisp Reference Manual is the work of many people, some of whom are acknowledged above. This edition was substantially rewritten, designed, edited and produced by Michael Sannella of Xerox Artificial Intelligence Systems. It is a major revision of the previous edition --- it has been completely reorganized, updated in most sections, and extended with a large amount of new material.

Interlisp is not designed by a formal committee. It grows and changes in response to the needs of those who use it. Contributions and discussion from the user community remain, as they always have been, warmly welcome.

4 References


# 1. Introduction

1.1. Interlisp as a Programming Language 1.1
1.2. Interlisp as an Interactive Environment 1.3
1.3. Interlisp Philosophy 1.5
1.4. How to Use this Manual 1.7
1.5. References 1.8
Interlisp is a programming system. A programming system consists of a programming language, a large number of predefined programs (or functions, to use the Lisp terminology) that can be used either as direct user commands or as subroutines in user programs, and an environment that supports the programmer by providing a variety of specialized programming tools. The language and predefined functions of Interlisp are rich, but similar to those of other modern programming languages. The Interlisp programming environment, on the other hand, is very distinctive. Its most salient characteristic is an integrated set of programming tools which know enough about Interlisp programming so that they can act as semi-autonomous, intelligent "assistants" to the programmer. In addition, the environment provides a completely self-contained world for creating, debugging and maintaining Interlisp programs.

This manual describes all three components of the Interlisp system. There are discussions about the content and structure of the language, about the pieces of the system that can be incorporated into user programs, and about the environment. The line between user code and the environment is thin and changing. Most users extend the environment with some special features of their own. Because Interlisp is so easily extended, the system has grown over time to incorporate many different ideas about effective and useful ways to program. This gradual accumulation over many years has resulted in a rich and diverse system. That is the reason this manual is so large.

Whereas the rest of this manual describes the individual pieces of the Interlisp system, this chapter attempts to describe the whole system---language, environment, tools, and the otherwise unstated philosophies that tie it all together. It is intended to give a global view of Interlisp to readers approaching it for the first time.

1.1 Interlisp as a Programming Language

This manual does not contain an introduction to programming in Lisp. In this section, we simply highlight a few key points about Lisp on which much of the later material depends.
The Lisp family of languages shares a common structure in which large programs (or functions) are built up by composing the results of smaller ones. Although Interlisp, like most modern Lisps, allows programming in almost any style one can imagine, the natural style of Lisp is functional and recursive, in that each function computes its result by selecting from or building upon the values given to it and then passing that result back to its caller (rather than by producing "side-effects" on external data structures, for example). A great many applications can be written in Lisp in this purely functional style, which is encouraged by the simplicity with which Lisp functions can be composed together.

Lisp is also a list-manipulation language. The essential primitive data objects of any Lisp are "atoms" (symbols or identifiers) and "lists" (sequences of atoms or lists), rather than the "characters" or "numbers" of more conventional programming languages (although these are also present in all modern Lisps). Each Lisp dialect has a set of operations that act on atoms and lists, and these operations comprise the core of the language.

Invisible in the programs, but essential to the Lisp style of programming, is an automatic memory management system (an "allocator" and a "garbage collector"). Allocation of new storage occurs automatically whenever a new data object is created. Conversely, that storage is automatically reclaimed for reuse when no other object makes reference to it. Automatic allocation and deallocation of memory is essential for rapid, large scale program development because it frees the programmer from the task of maintaining the details of memory administration, which change constantly during rapid program evolution.

A key property of Lisp is that it can represent Lisp function definitions as pieces of Lisp list data. Each subfunction "call" (or function application) is written as a list in which the function is written first, followed by its arguments. Thus, (PLUS 1 2) is a list structure representation of the expression 1 + 2. Each program can be written as a list of such function applications. This representation of program as data allows one to apply the same operations to programs that one uses to manipulate data, which makes it very straightforward to write Lisp programs which look at and change other Lisp programs. This, in turn, makes it easy to develop programming tools and translators, which was essential in enabling the development of the Interlisp environment.

One result of this ability to have one program examine another is that one can extend the Lisp programming language itself. If some desired programming idiom is not supported, it can be added simply by defining a function that translates the desired expression into simpler Lisp. Interlisp provides extensive facilities for users to make this type of language extension. Using this...
ability to extend itself, Interlisp has incorporated many of the constructs that have been developed in other modern programming languages (e.g. if-then-else, do loops, etc.).

1.2 Interlisp as an Interactive Environment

Interlisp programs should not be thought of as autonomous, external files of source code. All Interlisp programming takes place within the Interlisp environment, which is a completely self-sufficient environment for developing and using Interlisp programs. Not only does the environment contain the obvious programming facilities (e.g., program editors, compilers, debuggers, etc.), but it also contains a variety of tools which assist the user by "keeping track" of what happens, so the user doesn’t have to. For example, the Interlisp file package notices when programs or data have been changed, so that the system will know what needs to be saved at the end of the session. The "residential" style, where one stays within the environment throughout the development, from initial program definition through final debugging, is essential for these tools to operate. Furthermore, this same environment is available to support the final production version, some parts providing run time support and other parts being ignored until the need arises for further debugging or development.

For terminal interaction with the user, Interlisp provides a top level "Read-Eval-Print" executive, which reads whatever the user types in, evaluates it, and prints the result. (This interaction is also recorded by the programmer's assistant, described below, so the user can ask to do an action again, or even to undo the effects of a previous action.) Although each interactive executive defines a few specialized commands, most of the interaction will consist of simple evaluations of ordinary Lisp expressions. Thus, instead of specialized terminal commands for operations like manipulating the user's files, actions like this are carried out simply by typing the same expressions that one would use to accomplish them inside a Lisp program. This creates a very rich, simple and uniform set of interactive commands, since any Lisp expression can be typed at a command executive and evaluated immediately.

In normal use, one writes a program (or rather, "defines a function") simply by typing in an expression that invokes the "function defining" function (DEFINEQ), giving it the name of the function being defined and its new definition. The newly defined function can be executed immediately, simply by using it in a Lisp expression. Although most Interlisp code is normally run compiled (for reasons of efficiency), the initial versions of most
programs, and all of the user's terminal interactions, will be run interpreted. Eventually, as a function gets larger or is used in many places, it becomes more effective to compile it. Usually, by that stage, the function has been stored on a file and the whole file (which may contain many functions) is compiled at once. DEFINEQ, the compiler (COMPILE), and the interpreter (EVAL), are all themselves Lisp functions that use the ability to treat other Lisp expressions and programs as data.

In addition to these basic programming tools, Interlisp also provides a wide variety of programming support mechanisms:

**List structure editor**

Since Interlisp programs are represented as list structure, Interlisp provides an editor which allows one to change the list structure of a function's definition directly. See page 16.1.

**Pretty-printer**

The pretty printer is a function that prints Lisp function definitions so that their syntactic structure is displayed by the indentation and fonts used. See page 26.40.

**Break Package**

When errors occur, the break package is called, allowing the user to examine and modify the context at the point of the error. Often, this enables execution to continue without starting over from the beginning. Within a break, the full power of Interlisp is available to the user. Thus, the broken function can be edited, data structures can be inspected and changed, other computations carried out, and so on. All of this occurs in the context of the suspended computation, which will remain available to be resumed. See page 14.1.

**DWIM**

The "Do What I Mean" package automatically fixes the user's misspellings and errors in typing. See page 20.1.

**Programmer's Assistant**

Interlisp keeps track of the user's actions during a session and allows each one to be replayed, undone, or altered. See page 13.1.

**Masterscope**

Masterscope is a program analysis and management tool which can analyze users' functions and build (and automatically maintain) a data base of the results. This allows the user to ask questions like "WHO CALLS ARCTAN" or "WHO USES COEF1 FREELY" or to request systematic changes like "EDIT WHERE ANY (function) FETCHES ANY FIELD OF (the data structure) FOO". See page 19.1.

**Record/Datatype Package**

Interlisp allows a programmer to define new data structures. This enables one to separate the issues of data access from the details of how the data is actually stored. See page 8.1.

**File Package**

Files in Interlisp are managed by the system, removing the problem of ensuring timely file updates from the user. The file package can be modified and extended to accommodate new types of data. See page 17.1.

**Performance Analysis**

These tools allow statistics on program operation to be collected and analyzed. See page 22.1.
These facilities are tightly integrated, so they know about and use each other, just as they can be used by user programs. For example, Masterscope uses the structural editor to make systematic changes. By combining the program analysis features of Masterscope with the features of the structural editor, large scale system changes can be made with a single command. For example, when the lowest-level interface of the Interlisp-D I/O system was changed to a new format, the entire edit was made by a single call to Masterscope of the form `EDIT WHERE ANY CALLS '(BIN BOUT ...)'. [Burton et al., 1980] This caused Masterscope to invoke the editor at each point in the system where any of the functions in the list `(BIN BOUT ...)` were called. This ensured that no functions used in input or output were overlooked during the modification.

The personal machine implementations of Interlisp, such as Interlisp-D, provide some additional facilities, and interactive graphic interfaces to some of the older Interlisp programming tools:

### Multiple Processes
Multiple and independent processes simplify problems which require logically separate pieces of code to operate in parallel. See page 23.1.

### Windows
The ability to have multiple, independent windows on the display allows many different processes or activities to be active on the screen at once. See page 28.2.

### Inspector
The inspector is a display tool for examining complex data structures encountered during debugging. See page 26.1.

Interlisp-D has embedded within it an entire operating system written in Interlisp. For the most part, that is of no concern to the user (although it is nice to know that one can write programs of this complexity and performance within Interlisp!). However, some of the facilities provided by this low level code allow the use of Interlisp for applications that would previously have been forced into a relatively impoverished system programming environment. In particular, Interlisp-D provides complete facilities for experimenting with distributed machines and services on a local area network, plus access to all the services that such networks provide (e.g., mail, printing, filing, etc.).

### 1.3 Interlisp Philosophy
The extensive environmental support that the Interlisp system provides has developed over the years in order to support a particular style of programming called "exploratory programming" [Sheil, 1983]. For many complex programming problems, the task of program creation is not simply one of
writing a program to fulfill pre-identified specifications. Instead, it is a matter of exploring the problem (trying out various solutions expressed as partial programs) until one finds a good solution (or sometimes, any solution at all!). Such programs are by their very nature evolutionary; they are transformed over time from one realization into another in response to a growing understanding of the problem. This point of view has lead to an emphasis on having the tools available to analyze, alter, and test programs easily. One important aspect of this is that the tools be designed to work together in an integrated fashion, so that knowledge about the user's programs, once gained, is available throughout the environment.

The development of programming tools to support exploratory programming is itself an exploration. No one knows all the tools that will eventually be found useful, and not all programmers want all of the tools to behave the same way. In response to this diversity, Interlisp has been shaped, by its implementors and by its users, to be easily extensible in several different ways. First, there are many places in the system where its behavior can be adjusted by the user. One way that this can be done is by changing the value of various "flags" or variables whose values are examined by system code to enable or suppress certain behavior. The other is where the user can provide functions or other behavioral specifications of what is to happen in certain contexts. For example, the format used for each type of list structure when it is printed by the pretty-printer is determined by specifications that are found on the list PRETTYPRINTMACROS. Thus, this format can be changed for a given type simply by putting a printing specification for it on that list.

Another way in which users can effect Interlisp's behavior is by redefining or changing system functions. The "Advise" capability, for instance, permits the user to modify the operation of virtually any function in the system by wrapping user code "around" the selected function. (This same philosophy extends to the break package and tracing, so almost any function in the system can be broken or traced.) Experimentation is thus encouraged and actively facilitated, which allows the user to find useful pieces of the Interlisp system which can be configured to assist with application development. Since the entire system is implemented in Interlisp, there are extremely few places where the system's behavior depends on anything that the user cannot modify (such as a low level system implementation language).

While these techniques provide a fair amount of tailorability, the price paid is that Interlisp presents an overall appearance of complexity. There are many flags, parameters and controls that affect the behavior one sees. Because of this complexity, Interlisp tends to be more comfortable for experts, rather than casual users. Beginning users of Interlisp should depend on the
default settings of parameters until they learn what dimensions of flexibility are available. At that point, they can begin to "tune" the system to their preferences.

Appropriately enough, even Interlisp's underlying philosophy was itself discovered during Interlisp's development, rather than laid out beforehand. The Interlisp environment and its interactive style were first analyzed in Sandewall's excellent paper [Sandewall, 1978]. The notion of "exploratory programming" and the genesis of the Interlisp programming tools in terms of the characteristic demands of this style of programming was developed in [Sheil, 1983]. The evolution and structure of the Interlisp programming environment are discussed in greater depth in [Teitelman & Masinter, 1981].

1.4 How to Use this Manual

This document is a reference manual, not a primer. We have tried to provide a manual that is complete, and that allows users to find particular items as easily as possible. Sometimes, these goals have been achieved at the expense of simplicity. For example, many functions have a number of arguments that are rarely used. In the interest of providing a complete reference, these arguments are fully explained, even though they would normally be defaulted. There is a lot of information in this manual that is only of interest to experts.

Users should not try to read straight through this manual, like a novel. In general, the chapters are organized with overview explanations and the most useful functions at the beginning of the chapter, and implementation details towards the end. If you are interested in becoming acquainted with Interlisp using this manual, the best way would be to skim through the whole book, reading the beginning of each chapter.

A few comments about the notational conventions used in this manual:

**Lisp object notation:** All Interlisp objects in this manual are printed in the same font: Functions (AND, PLUS, DEFINEQ, LOAD); Variables (MAX.INTEGER, FILELIST, DFNFAG); and arbitrary Interlisp expressions: (PLUS 2 3), (PROG ((A 1)) ...), etc.

**Case is significant:** An important piece of information, often missed by newcomers to Interlisp, is that upper and lower case is significant. The variable FOO is not the same as the variable foo or the variable Foo. By convention, most Interlisp system functions and variables are all uppercase, but users are free to use upper and lower case for their own functions and variables as they wish.
One exception to the case-significance rule is provided by the Interlisp CLISP facility, which allows iterative statement operators and record operations to be typed in either all uppercase or all lowercase letters: (for X from 1 to 5 ...) is the same as (FOR X FROM 1 TO 5 ...). The few situations where this is the case are explicitly mentioned in the manual. Generally, one should assume that case is significant.

This manual contains a large number of descriptions of functions, variables, commands, etc, which are printed in the following standard format:

**(FOO BAR BAZ —)**

This is a description for the function named FOO. FOO has two arguments, BAR and BAZ. Some system functions have extra optional arguments that are not documented and should not be used. These extra arguments are indicated by "—".

The descriptor [Function] indicates that this is a function, rather than a [Variable], [Macro], etc. For function definitions only, this can also indicate the "function type" (see page 10.2): [NLambda Function], [NoSpread Function], or [NLambda NoSpread Function], which describes whether the function takes a fixed or variable number of arguments, and whether the arguments are evaluated or not. [Function] indicates a lambda spread function (the most common function type).

### 1.5 References


## 2. Litatoms

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1. Using Litatoms as Variables</td>
<td>2.2</td>
</tr>
<tr>
<td>2.2. Function Definition Cells</td>
<td>2.5</td>
</tr>
<tr>
<td>2.3. Property Lists</td>
<td>2.5</td>
</tr>
<tr>
<td>2.4. Print Names</td>
<td>2.7</td>
</tr>
<tr>
<td>2.5. Characters and Character Codes</td>
<td>2.12</td>
</tr>
</tbody>
</table>
[This page intentionally left blank]
A "litatom" (for "literal atom") is an object which conceptually consists of a print name, a value, a function definition, and a property list. In some Lisp dialects, litatoms are also known as "symbols."

A litatom is read as any string of non-delimiting characters that cannot be interpreted as a number. The syntactic characters that delimit litatoms are called separator or break characters (see page 25.33) and normally are space, end-of-line, line-feed, ( (left paren), ) (right paren), " (double quote), [ (left bracket), and ] (right bracket). However, any character may be included in a litatom by preceding it with the character %. Here are some examples of litatoms:

A wxyz 23SKIDDOO [%] 3.1415 + 17

Long% Litatom% With% Embedded% Spaces

\begin{verbatim}
(LITATOM X) \hspace{1cm} [Function]
\end{verbatim}

Returns T if X is a litatom, NIL otherwise. Note that a number is not a litatom.

(LITATOM NIL) = T.

\begin{verbatim}
(ATOM X) \hspace{1cm} [Function]
\end{verbatim}

Returns T if X is an atom (i.e. a litatom or a number); NIL otherwise.

Warning: (ATOM X) is NIL if X is an array, string, etc. In many dialects of Lisp, the function ATOM is defined equivalent to the Interlisp function NLISTP.

(ATOM NIL) = T.

Litatoms are printed by PRINT and PRIN2 as a sequence of characters with %’s inserted before all delimiting characters (so that the litatom will read back in properly). Litatoms are printed by PRIN1 as a sequence of characters without these extra %’s. For example, the litatom consisting of the five characters A, B, C, (, and D will be printed as ABC%(D by PRINT and ABC(D by PRIN1.

Litatoms can also be constructed by PACK, PACK*, SUBATOM, MKATOM, and GENSYM (which uses MKATOM).
Litatoms are unique. In other words, if two litatoms print the same, they will always be EQ. Note that this is not true for strings, large integers, floating point numbers, and lists; they all can print the same without being EQ. Thus if PACK or MKATOM is given a list of characters corresponding to a litatom that already exists, they return a pointer to that litatom, and do not make a new litatom. Similarly, if the read program is given as input a sequence of characters for which a litatom already exists, it returns a pointer to that litatom. Note: Interlisp is different from other Lisp dialects which allow “uninterned” litatoms.

Note: Litatoms are limited to 255 characters in Interlisp-D; 127 characters in Interlisp-10. Attempting to create a larger litatom either via PACK or by typing one in (or reading from a file) will cause an error, ATOM TOO LONG.

2.1 Using Litatoms as Variables

Litatoms are commonly used as variables. Each litatom has a "top level" variable binding, which can be an arbitrary Interlisp object. Litatoms may also be given special variable bindings within PROGS or function calls, which only exist for the duration of the function. When a litatom is evaluated, the "current" variable binding is returned. This is the most recent special variable binding, or the top level binding if the litatom has not been rebound. SETQ is used to change the current binding. For more information on variable bindings in Interlisp, see page 11.1.

Note: The compiler (page 18.1) treats variables somewhat differently than the interpreter, and the user has to be aware of these differences when writing functions that will be compiled. For example, variable references in compiled code are not checked for NOBIND, so compiled code will not generate unbound atom errors. In general, it is better to debug interpreted code, before compiling it for speed. The compiler offers some facilities to increase the efficiency of variable use in compiled functions. Global variables (page 18.4) can be defined so that the entire stack is not searched at each variable reference. Local variables (page 18.5) allow compiled functions to access variable bindings which are not on the stack, which reduces variable conflicts, and also makes variable lookup faster.

By convention, a litatom whose top level binding is to the litatom NOBIND is considered to have no top level binding. If a litatom has no local variable bindings, and its top level value is NOBIND, attempting to evaluate it will cause an unbound atom error.
The two litatoms T and NIL always evaluate to themselves. Attempting to change the binding of T or NIL with the functions below will generate the error ATTEMPT TO SET T or ATTEMPT TO SET NIL.

The following functions (except BOUNDP) will also generate the error ARG NOT LITATOM, if not given a litatom.

(BOUNDP VAR) [Function]
Returns T if VAR has a special variable binding (even if bound to NOBIND), or if VAR has a top level value other than NOBIND; otherwise NIL. In other words, if X is a litatom, (EVAL X) will cause an UNBOUND ATOM error if and only if (BOUNDP X) returns NIL.

(SET VAR VALUE) [Function]
Sets the "current" variable binding of VAR to VALUE, and returns VALUE.

Note that SET is a normal lambda spread function, so both VAR and VALUE are evaluated before it is called. Thus, if the value of X is B, and the value of Y is C, then (SET X Y) would result in B being set to C, and C being returned as the value of SET.

(SETQ VAR VALUE) [NLambda NoSpread Function]
Nlambda version of SET; VAR is not evaluated, VALUE is. Thus if the value of X is B and the value of Y is C, (SETQ X Y) would result in X (not B) being set to C, and C being returned.

Note: Since SETQ is an nlambda, neither argument is evaluated during the calling process. However, SETQ itself calls EVAL on its second argument. As a result, typing (SETQ VAR FORM) and SETQ(VAR FORM) to the Interlisp executive is equivalent: in both cases VAR is not evaluated, and FORM is.

(SETQQ VAR VALUE) [NLambda Function]
Like SETQ except that neither argument is evaluated, e.g., (SETQQ X (A B C)) sets X to (A B C).

(PSETQ VAR1 VALUE1 ... VARN VALUEN) [Macro]
Does a multiple SETQ of VAR1 (unevaluated) to the value of VALUE1, VAR2 to the value of VALUE2, etc. All of the VALUES terms are evaluated before any of the assignments. Therefore, (PSETQ A B B A) can be used to swap the values of the variables A and B.
(GETTOPVAL VAR) [Function]
Returns the top level value of VAR (even if NOBIND), regardless of any intervening local bindings.

(SETTOPVAL VAR VALUE) [Function]
Sets the top level value of VAR to VALUE, regardless of any intervening bindings, and returns VALUE.

A major difference between various Interlisp implementations is the way that variable bindings are implemented. Interlisp-10 and Interlisp-Jerico use what is called "shallow" binding. Interlisp-D and Interlisp-VAX use what is called "deep" binding.

In a deep binding system, a variable is bound by saving on the stack the variable's new value. When a variable is accessed, its value is found by searching the stack for the most recent binding. If the variable is not found on the stack, the top level binding is retrieved from a "value cell" associated with the variable.

In a "shallow" binding system, a variable is bound by saving on the stack the variable name and the variable's old value and putting the new value in the variable's value cell. When a variable is accessed, its value is always found in its value cell.

GETTOPVAL and SETTOPVAL are less efficient in a shallow binding system, because they have to search the stack for rebindings; it is more economical to simply rebind variables. In a deep binding system, GETTOPVAL and SETTOPVAL are very efficient since they do not have to search the stack, but can simply access the value cell directly.

GETATOMVAL and SETATOMVAL can be used to access a variable's value cell, in either a shallow or deep binding system.

(GETATOMVAL VAR) [Function]
Returns the value in the value cell of VAR. In a shallow binding system, this is the same as (EVAL ATM), or simply VAR. In a deep binding system, this is the same as (GETTOPVAL VAR).

(SETATOMVAL VAR VALUE) [Function]
Sets the value cell of VAR to VALUE. In a shallow binding system, this is the same as SET; in a deep binding system, this is the same as SETTOPVAL.
2.2 Function Definition Cells

Each litatom has a function definition cell, which is accessed when a litatom is used as a function. The mechanism for accessing and setting the function definition cell of a litatom is described on page 10.9.

2.3 Property Lists

Each litatom has an associated property list, which allows a set of named objects to be associated with the litatom. A property list associates a name, known as a "property name" or "property", with an arbitrary object, the "property value" or simply "value". Sometimes the phrase "to store on the property X" is used, meaning to place the indicated information on a property list under the property name X.

Property names are usually litatoms or numbers, although no checks are made. However, the standard property list functions all use EQ to search for property names, so they may not work with non-atomic property names. Note that the same object can be used as both a property name and a property value.

Note: Many litatoms in the system already have property lists, with properties used by the compiler, the break package, DWIM, etc. Be careful not to clobber such system properties. The variable SYSPROPS is a list of property names used by the system.

The functions below are used to manipulate the property lists of litatoms. Except when indicated, they generate the error ARG NOT LITATOM, if given an object that is not a litatom.

(GETPROP ATM PROP) [Function]
Returns the property value for PROP from the property list of ATM. Returns NIL if ATM is not a litatom, or PROP is not found. Note that GETPROP also returns NIL if there is an occurrence of PROP but the corresponding property value is NIL; this can be a source of program errors.

Note: GETPROP used to be called GETP.

(PUTPROP ATM PROP VAL) [Function]
Puts the property PROP with value VAL on the property list of ATM. VAL replaces any previous value for the property PROP on this property list. Returns VAL.
(ADDPROP ATM PROP NEW FLG)  [Function]
Adds the value NEW to the list which is the value of property PROP on the property list of ATM. If FLG is T, NEW is CONSed onto the front of the property value of PROP, otherwise it is NCONCed on the end (using NCONC1). If ATM does not have a property PROP, or the value is not a list, then the effect is the same as (PUTPROP ATM PROP (LIST NEW)). ADDPROP returns the (new) property value. Example:

←(PUTPROP 'POCKET 'CONTENTS NIL)
NIL
←(ADDPROP 'POCKET 'CONTENTS 'COMB)
(COMB)
←(ADDPROP 'POCKET 'CONTENTS 'WALLET)
(COMB WALLET)

(REMPROP ATM PROP)  [Function]
Removes all occurrences of the property PROP (and its value) from the property list of ATM. Returns PROP if any were found, otherwise NIL.

(REMROPLIST ATM PROPS)  [Function]
Removes all occurrences of all properties on the list PROPS (and their corresponding property values) from the property list of ATM. Returns NIL.

(CHANCEPROP X PROP1 PROP2)  [Function]
Changes the property name of property PROP1 to PROP2 on the property list of X, (but does not affect the value of the property). Returns X, unless PROP1 is not found, in which case it returns NIL.

PROPNAMES ATM)  [Function]
Returns a list of the property names on the property list of ATM.

(DEFLIST L PROP)  [Function]
Used to put values under the same property name on the property lists of several litatoms. L is a list of two-element lists. The first element of each is a litatom, and the second element is the property value for the property PROP. Returns NIL. For example,

(DEFLIST '( (FOO MA) (BAR CA) (BAZ RI) ) 'STATE)
puts MA on FOO's STATE property, CA on BAR's STATE property, and RI on BAZ's STATE property.

Property lists are conventionally implemented as lists of the form

(NAME1 VALUE1 NAME2 VALUE2 ...)
although the user can store anything as the property list of a litatom. However, the functions which manipulate property lists observe this convention by searching down the property lists two CDRs at a time. Most of these functions also generate an error, ARG NOT LITATOM, if given an argument which is not a litatom, so they cannot be used directly on lists. (LISTPUT, LISTPUT1, LISTGET, and LISTGET1 are functions similar to PUTPROP and GETPROP that work directly on lists. See page 316.) The property lists of litatoms can be directly accessed with the following functions:

(GETPROPLIST ATM) [Function]
Returns the property list of ATM.

(SETPROPLIST ATM LST) [Function]
If ATM is a litatom, sets the property list of ATM to be LST, and returns LST as its value.

(GETLIS X PROPS) [Function]
Searches the property list of X, and returns the property list as of the first property on PROPS that it finds. For example,

\[
\begin{align*}
\text{\texttt{\textasciitilde (GETPROPLIST 'X)}} \\
\text{\texttt{(PROP1 A PROP3 B A C)}} \\
\text{\texttt{\textasciitilde (GETLIS 'X '(PROP2 PROP3))}} \\
\text{\texttt{(PROP3 B A C)}}
\end{align*}
\]
Returns NIL if no element on PROPS is found. X can also be a list itself, in which case it is searched as described above. If X is not a litatom or a list, returns NIL.

2.4 Print Names

Each litatom has a print name, a string of characters that uniquely identifies that litatom. The term "print name" has been extended, however, to refer to the characters that are output when any object is printed. In Interlisp, all objects have print names, although only litatoms and strings have their print name explicitly stored. This section describes a set of functions which can be used to access and manipulate the print names of any object, though they are primarily used with the print names of litatoms.

The print name of an object is those characters that are output when the object is printed using PRIN1, e.g., the print name of the litatom ABC%(D consists of the five characters ABC(D. The
print name of the list (A B C) consists of the seven characters (A B C) (two of the characters are spaces).

Sometimes we will have occasion to refer to a "PRIN2-name." The PRIN2-name of an object is those characters output when the object is printed using PRIN2. Thus the PRIN2-name of the litatom ABC%(D is the six characters ABC%(D. Note that the PRIN2-name depends on what readtable is being used (see page 25.33), since this determines where %'s will be inserted. Many of the functions below allow either print names or PRIN2-names to be used, as specified by FLG and RDTBL arguments. If FLG is NIL, print names are used. Otherwise, PRIN2-names are used, computed with respect to the readable RDTBL (or the current readable, if RDTBL = NIL).

Note: The print name of an integer depends on the setting of RADIX (page 25.13). The functions described in this section (UNPACK, NCHARS, etc.) define the print name of an integer as though the radix was 10, so that (PACK (UNPACK 'X9)) will always be X9 (and not X11, if RADIX is set to 8). However, integers will still be printed by PRIN1 using the current radix. The user can force these functions to use print names in the current radix by changing the setting of the variable PRXFLG (page 25.14).

(MKATOM X) [Function]
Creates and returns an atom whose print name is the same as that of the string X or, if X isn't a string, the same as that of (MKSTRING X). Examples:

(MKATOM '(A B C)) ➞ %(A% B% C%)
(MKATOM "1.5") ➞ 1.5

Note that the last example returns a number, not a litatom. It is a deeply-ingrained feature of Interlisp that no litatom can have the print name of a number.

(SUBATOM X N M) [Function]
Equivalent to (MKATOM (SUBSTRING X N M)), but does not make a string pointer (see page 4.3). Returns an atom made from the Nth through Mth characters of the print name of X. If N or M are negative, they specify positions counting backwards from the end of the print name. Examples:

(SUBATOM "FOO1.SBAR" 4 6) ➞ 1.5
(SUBATOM '(A B C) 2 -2) ➞ A% B% C

(PACK X) [Function]
If X is a list of atoms, PACK returns a single atom whose print name is the concatenation of the print names of the atoms in X.
If the concatenated print name is the same as that of a number, PACK will return that number. For example,

(PACK 'A BC DEF G) => ABCDEFG
(PACK '(1 3.4)) => 13.4
(PACK '(1 E -2)) => .01

Although X is usually a list of atoms, it can be a list of arbitrary Interlisp objects. The value of PACK is still a single atom whose print name is the concatenation of the print names of all the elements of X, e.g.,

(PACK '((A B) "CD")) => %(A % B%)CD

If X is not a list or NIL, PACK generates an error, ILLEGAL ARG.

(PACK* X1 X2 ... XN) [NoSpread Function]
Nospread version of PACK that takes an arbitrary number of arguments, instead of a list. Examples:

(PACK* 'A 'BC 'DEF 'G) => ABCDEFG
(PACK* 1 3.4) => 13.4

(UNPACK X FLG RDTBL) [Function]
Returns the print name of X as a list of single-characters atoms, e.g.,

(UNPACK 'ABC5D) => (A B C 5 D)
(UNPACK "ABC(D") => (A B C %( D)
If FLG = T, the PRIN2-name of X is used (computed with respect to RDTBL), e.g.,

(UNPACK "ABC(D" T) => (%" A B C %%( D %")
(UNPACK 'ABC%(D" T) => (A B C %%( D)

Note: (UNPACK X) performs N CONSes, where N is the number of characters in the print name of X.

(DUNPACK X SCRATCHLIST FLG RDTBL) [Function]
A destructive version of UNPACK that does not perform any CONSes but instead reuses the list SCRATCHLIST. If the print name is too long to fit in SCRATCHLIST, DUNPACK will extend it. If SCRATCHLIST is not a list, DUNPACK returns (UNPACK X FLG RDTBL).

(NCHARS X FLG RDTBL) [Function]
Returns the number of characters in the print name of X. If FLG = T, the PRIN2-name is used. For example,

(NCHARS 'ABC) => 3
(NCHARS "ABC" T) = > 5
Note: NCHARS works most efficiently on litatoms and strings, but can be given any object.

(NTHCHAR X N FLG RDTBL)  [Function]
Returns the Nth character of the print name of X as an atom. N can be negative, in which case it counts from the end of the print name, e.g., -1 refers to the last character, -2 next to last, etc. If N is greater than the number of characters in the print name, or less than minus that number, or 0, NTHCHAR returns NIL. Examples:

(NTHCHAR 'ABC 2) = > B
(NTHCHAR 15.6 2) = > 5
(NTHCHAR 'ABC%(D -3 T) = > %%
(NTHCHAR "ABC" 2) = > B
(NTHCHAR "ABC" 2 T) = > A

Note: NTHCHAR and NCHARS work much faster on objects that actually have an internal representation of their print name, i.e., litatoms and strings, than they do on numbers and lists, as they do not have to simulate printing.

(L-CASE X FLG)  [Function]
Returns a lower case version of X. If FLG is T, the first letter is capitalized. If X is a string, the value of L-CASE is also a string. If X is a list, L-CASE returns a new list in which L-CASE is computed for each corresponding element and non-NIL tail of the original list. Examples:

(L-CASE 'FOO) = > foo
(L-CASE 'FOO T) = > Foo
(L-CASE "FILE NOT FOUND" T) = > "File not found"
(L-CASE 'JANUARY FEBRUARY (MARCH "APRIL")) T)
= > '(January February (March "April"))

(U-CASE X)  [Function]
Similar to L-CASE, except returns the upper case version of X.

(U-CASEP X)  [Function]
Returns T if X contains no lower case letters; NIL otherwise.

(GENSYM PREFIX — — —)  [Function]
Returns a litatom of the form Xnnnn, where X = PREFIX (or A if PREFIX is NIL) and nnnn is an integer. Thus, the first one
generated is A0001, the second A0002, etc. The integer suffix is always at least four characters long, but it can grow beyond that. For example, the next litatom produced after A9999 would be A10000. GENSYM provides a way of generating litatoms for various uses within the system.

**GENNUM**

The value of GENNUM, initially 0, determines the next GENSYM, e.g., if GENNUM is set to 23, (GENSYM) = A0024.

The term "gensym" is used to indicate a litatom that was produced by the function GENSYM. Litatoms generated by GENSYM are the same as any other litatoms: they have property lists, and can be given function definitions. Note that the litatoms are not guaranteed to be new. For example, if the user has previously created A0012, either by typing it in, or via PACK or GENSYM itself, then if GENNUM is set to 11, the next litatom returned by GENSYM will be the A0012 already in existence.

**MAPATOMS FN**

 Applies FN (a function or lambda expression) to every litatom in the system. Returns NIL

For example,

(MAPATOMS (FUNCTION (LAMBDA(X)
   (if (GETD X) then (PRINT X)

will print every litatom with a function definition.

Note: In some implementations of Interlisp, unused litatoms may be garbage collected, which can effect the action of MAPATOMS.

**APROPOS STRING ALLFLG QUIETFLG OUTPUT**

APROPOS scans all litatoms in the system for those which have STRING as a substring and prints them on the terminal along with a line for each relevant item defined for each selected atom. Relevant items are (1) function definitions, for which only the arglist is printed, (2) dynamic variable values, and (3) non-null property lists. PRINTLEVEL (page 25.11) is set to (3 . 5) when APROPOS is printing.

If ALLFLG is NIL, then atoms with no relevant items and "internal" atoms are omitted ("internal" currently means those litatoms whose print name begins with a \ or those litatoms produced by GENSYM). If ALLFLG is a function (i.e., (FNTYP ALLFLG) is non-NIL), then it is used as a predicate on atoms selected by the substring match, with value NIL meaning to omit the atom. If ALLFLG is any other non-NIL value, then no atoms are omitted.
If $QUIETFLG$ is non-NIL, then no printing at all is done, but instead a list of the selected atoms is returned.

If $OUTPUT$ is non-NIL, the printing will be directed to $OUTPUT$ (which should be a stream open for output) instead of to the terminal stream.

### 2.5 Characters and Character Codes

Characters may be represented in two ways: as single-character atoms, or as integer character codes. In many situations, it is more efficient to use character codes, so Interlisp provides parallel functions for both representations.

Interlisp-D uses the 16-bit NS character set, described in the document *Character Code Standard* [Xerox System Integration Standards, XSIS 058404, April 1984]. Legal character codes range from 0 to 65535. The NS (Network Systems) character encoding encompasses a much wider set of available characters than the 8-bit character standards (such as ASCII), including characters comprising many foreign alphabets and special symbols. For instance, Interlisp-D supports the display and printing of the following:

Le système d'information Xerox 11xx est remarquablement polyglotte.

Das Xerox 11xx Kommunikationssystem bietet merkwürdige multilinguale Nutzmöglichkeiten.

$M \equiv \square[w] \equiv \forall v \text{ with } Rwv: M \equiv [v]$

These characters can be used in strings, litatom print names, symbolic files, or anywhere else 8-bit characters could be used. All of the standard string and print name functions (RPLSTRING, GNC, NCHARS, STRPOS, etc.) accept litatoms and strings containing NS characters. For example:

```lisp
\rightarrow (STRPOS "char" "this is an 8-bit character string")
18
\rightarrow (STRPOS "char" "celui-ci comporte des caractères NS")
23
```

In almost all cases, a program does not have to distinguish between NS characters or 8-bit characters. The exception to this rule is the handling of input/output operations (see page 25.22).

The function CHARCODE (page 2.13) provides a simple way to create individual NS characters codes. The VirtualKeyboards library package provides a set of virtual keyboards that allow keyboard or mouse entry of NS characters.
(PACKC X) [Function]
Similar to PACK except X is a list of character codes. For example,

(PACKC '(70 79 79)) = > FOO

(CHCON X FLG RDTBL) [Function]
Like UNPACK, except returns the print name of X as a list of character codes. If FLG = T, the PRIN2-name is used. For example,

(CHCON 'FOO) = > (70 79 79)

(DCHCON X SCRATCHLIST FLG RDTBL) [Function]
Similar to DUNPACK.

(NTHCHARCODE X N FLG RDTBL) [Function]
Similar to NTHCHAR, except returns the character code of the Nth character of the print name of X. If N is negative, it is interpreted as a count backwards from the end of X. If the absolute value of N is greater than the number of characters in X, or 0, then the value of NTHCHARCODE is NIL.

If FLG is T, then the PRIN2-name of X is used, computed with respect to the readtable RDTBL.

(CHCON1 X) [Function]
Returns the character code of the first character of the print name of X; equal to (NTHCHARCODE X 1).

(CHARACTER N) [Function]
N is a character code. Returns the atom having the corresponding single character as its print name.

(CHARACTER 70) = > F

(FCHARACTER N) [Function]
Fast version of CHARACTER that compiles open.

The following function makes it possible to gain the efficiency that comes from dealing with character codes without losing the symbolic advantages of character atoms:

(CHARCODE CHAR) [NLambda Function]
Returns the character code specified by CHAR (unevaluated). If CHAR is a one-character atom or string, the corresponding character code is simply returned. Thus, (CHARCODE A) is 65, (CHARCODE 0) is 48. If CHAR is a multi-character litatom or string, it specifies a character code as described below. If CHAR is NIL, CHARCODE simply returns NIL. Finally, if CHAR is a list
structure, the value is a copy of CHAR with all the leaves replaced by the corresponding character codes. For instance, \((\text{CHARCODE (A (B C)))} = > (65 \ 66 \ 67))\).

If a character is specified by a multi-character litatom or string, `CHARCODE` interprets it as follows:

- **CR, SPACE, etc.**

  The variable `CHARACTERNAMES` contains an association list mapping special litatoms to character codes. Among the characters defined this way are CR (13), LF (10), SPACE or SP (32), ESCAPE or ESC (27), BELL (7), BS (8), TAB (9), NULL (0), and DEL (127). The litatom `EOL` maps into the appropriate End-Of-Line character code in the different Interlisp implementations (31 in Interlisp-10, 13 in Interlisp-D, 10 in Interlisp-VAX). Examples:

  \[(\text{CHARCODE SPACE}) = > 32\]

  \[(\text{CHARCODE CR}) = > 13\]

- **CHARSET,CHARNUM**

  If the character specification is a litatom or string of the form `CHARSET,CHARNUM` or `CHARSET-CHARNUM`, the character code for the character number `CHARNUM` in the character set `CHARSET` is returned.

  The 16-bit NS character encoding is divided into a large number of "character sets." Each 16-bit character can be decoded into a character set (an integer from 0 to 254 inclusive) and a character number (also an integer from 0 to 254 inclusive). `CHARSET` is either an octal number, or a litatom in the association list `CHARACTERSETNAMES` (which defines the character sets for GREEK, CYRILLIC, etc.).

  `CHARNUM` is either an octal number, a single-character litatom, or a litatom from the association list `CHARACTERNAMES`. Note that if `CHARNUM` is a single-digit number, it is interpreted as the character "2", rather than as the octal number 2. Examples:

  \[(\text{CHARCODE 12,6}) = > 2566\]

  \[(\text{CHARCODE 12,SPACE}) = > 2592\]

  \[(\text{CHARCODE GREEK,A}) = > 9793\]

- \(\uparrow\) **CHARSPEC (control chars)**

  If the character specification is a litatom or string of one of the forms above, preceded by the character \("\uparrow\"\), this indicates a "control character," derived from the normal character code by clearing the seventh bit of the character code (normally set). Examples:

  \[(\text{CHARCODE \(\uparrow\) A}) = > 1\]

  \[(\text{CHARCODE \(\uparrow\) GREEK,A}) = > 9729\]

- \#**CHARSPEC (meta chars)**

  If the character specification is a litatom or string of one of the forms above, preceded by the character \("\#\"\), this indicates a "meta character," derived from the normal character code by
setting the eighth bit of the character code (normally cleared). ↑ and # can both be set at once.

Examples:

(CHARCODE #A) = > 193

(CHARCODE # ↑ GREEK,A) = > 9857

A CHARCODE form can be used wherever a structure of character codes would be appropriate. For example:

(FMEMB (NTHCHARCODE X 1) (CHARCODE (CR LF SPACE ↑ A)))

(EQ (READCCODE FOO) (CHARCODE GREEK,A))

There is a macro for CHARCODE which causes the character-code structure to be constructed at compile-time. Thus, the compiled code for these examples is exactly as efficient as the less readable:

(FMEMB (NTHCHARCODE X 1) (QUOTE (13 10 32 1)))

(EQ (READCCODE FOO) 9793)

(SELCHARQ E CLAUSE₁ ... CLAUSEₙ DEFAULT) [Macro]

Similar to SELECTQ (page 9.6), except that the selection keys are determined by applying CHARCODE (instead of QUOTE) to the key-expressions. If the value of E is a character code or NIL and it is EQ or MEMB to the result of applying CHARCODE to the first element of a clause, the remaining forms of that clause are evaluated. Otherwise, the default is evaluated.

Thus

(SELCHARQ (BIN FOO)
  ((SPACE TAB) (FUM))
  ((↑ D NIL) (BAR))
  (a (BAZ))
  (ZIP))

is exactly equivalent to

(SELECTQ (BIN FOO)
  ((32 9) (FUM))
  ((4 NIL) (BAR))
  (97 (BAZ))
  (ZIP))

Furthermore, SELCHARQ has a macro definition such that it always compiles as an equivalent SELECTQ.
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3. Lists

<table>
<thead>
<tr>
<th>3.1. Creating Lists</th>
<th>3.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2. Building Lists From Left to Right</td>
<td>3.6</td>
</tr>
<tr>
<td>3.3. Copying Lists</td>
<td>3.8</td>
</tr>
<tr>
<td>3.4. Extracting Tails of Lists</td>
<td>3.9</td>
</tr>
<tr>
<td>3.5. Counting List Cells</td>
<td>3.10</td>
</tr>
<tr>
<td>3.6. Logical Operations</td>
<td>3.11</td>
</tr>
<tr>
<td>3.7. Searching Lists</td>
<td>3.12</td>
</tr>
<tr>
<td>3.8. Substitution Functions</td>
<td>3.13</td>
</tr>
<tr>
<td>3.9. Association Lists and Property Lists</td>
<td>3.15</td>
</tr>
<tr>
<td>3.10. Sorting Lists</td>
<td>3.17</td>
</tr>
<tr>
<td>3.11. Other List Functions</td>
<td>3.19</td>
</tr>
</tbody>
</table>
One of the most useful datatypes in Interlisp is the list cell, a data structure which contains pointers to two other objects, known as the CAR and the CDR of the list cell (after the accessing functions). Very complicated structures can be built out of list cells, including lattices and trees, but list cells are most frequently used for representing simple linear lists of objects.

The following functions are used to manipulate list cells:

**(CONS X Y)**  
*Function*  
CONS is the primary list construction function. It creates and returns a new list cell containing pointers to X and Y. If Y is a list, this returns a list with X added at the beginning of Y.

**(LISTP X)**  
*Function*  
Returns X if X is a list cell, e.g., something created by CONS; NIL otherwise.  
**(LISTP NIL) = NIL.**

**(NLISTP X)**  
*Function*  
(NOT (LISTP X)). Returns T if X is not a list cell, NIL otherwise.  
**(NLISTP NIL) = T.**

**(CAR X)**  
*Function*  
Returns the first element of the list X. CAR of NIL is always NIL. For all other nonlists (e.g., litatoms, numbers, strings, arrays), the value returned is controlled by CAR/CDRERR (below).

**(CDR X)**  
*Function*  
Returns all but the first element of the list X. CDR of NIL is always NIL. The value of CDR for other nonlists is controlled by CAR/CDRERR (below).

**CAR/CDRERR**  
*Variable*  
The variable CAR/CDRERR controls the behavior of CAR and CDR when they are passed non-lists (other than NIL).  
If CAR/CDRERR = NIL (the current default), then CAR or CDR of a non-list (other than NIL) return the string "{car of non-list}" or
"(cdr of non-list)". If CAR/CDRERR = T, then CAR and CDR of a non-list (other than NIL) causes an error.

If CAR/CDRERR = ONCE, then CAR or CDR of a string causes an error, but CAR or CDR of anything else returns the string "(car of non-list)" or "(cdr of non-list)" as above. This catches loops which repeatedly take CAR or CDR of an object, but it allows one-time errors to pass undetected.

If CAR/CDRERR = CDR, then CAR of a non-list returns "(car of non-list)" as above, but CDR of a non-list causes an error. This setting is based on the observation that nearly all infinite loops involving non-lists occur from taking CDRs, but a fair amount of careless code takes CAR of something it has not tested to be a list.

Often, combinations of the CAR and CDR functions are used to extract various components of complex list structures. Functions of the form C...R may be used for some of these combinations:

(CAAR X) = => (CAR (CAR X))
(CADR X) = => (CAR (CDR X))
(CDDDDR X) = => (CDR (CDR (CDR (CDR X))))

All 30 combinations of nested CARs and CDRs up to 4 deep are included in the system.

(RPLACD X Y) [Function]
Replaces the CDR of the list cell X with Y. This physically changes the internal structure of X, as opposed to CONS, which creates a new list cell. It is possible to construct a circular list by using RPLACD to place a pointer to the beginning of a list in a spot at the end of the list.

The value of RPLACD is X. An attempt to RPLACD NIL will cause an error, ATTEMPT TO RPLAC NIL (except for (RPLACD NIL NIL)). An attempt to RPLACD any other non-list will cause an error, ARG NOT LIST.

(RPLACA X Y) [Function]
Similar to RPLACD, but replaces the CAR of X with Y. The value of RPLACA is X. An attempt to RPLACA NIL will cause an error, ATTEMPT TO RPLAC NIL, (except for (RPLACA NIL NIL)). An attempt to RPLACA any other non-list will cause an error, ARG NOT LIST.

(RPLNODE X A D) [Function]
Performs (RPLACA X A), (RPLACD X D), and returns X.
(RPLNODE2 X Y)  
Performs (RPLACA X (CAR Y)), (RPLACD X (CDR Y)) and returns X.

(FRPLACD X Y)  
(Function)

(FRPLACA X Y)  
(Function)

(FRPLNODE X A D)  
(Function)

(FRPLNODE2 X Y)  
(Faster versions of RPLACD, etc.)

Usually, single list cells are not manipulated in isolation, but in structures known as "lists". By convention, a list is represented by a list cell whose CAR is the first element of the list, and whose CDR is the rest of the list (usually another list cell or the "empty list," NIL). List elements may be any Interlisp objects, including other lists.

The input syntax for a list is a sequence of Interlisp data objects (litatoms, numbers, other lists, etc.) enclosed in parentheses or brackets. Note that () is read as the litatom NIL. A right bracket can be used to match all left parenthesis back to the last left bracket, or terminate the lists, e.g. (A (B C) ...).

If there are two or more elements in a list, the final element can be preceded by a period delimited on both sides, indicating that CDR of the final list cell in the list is to be the element immediately following the period, e.g. (A . B) or (A B C . D), otherwise CDR of the last list cell in a list will be NIL. Note that a list does not have to end in NIL. It is simply a structure composed of one or more list cells. The input sequence (A B C . NIL) is equivalent to (A B C), and (A B . (C D)) is equivalent to (A B C D). Note however that (A B . C D) will create a list containing the five litatoms A, B, %, C, and D.

Lists are printed by printing a left parenthesis, and then printing the first element of the list, then printing a space, then printing the second element, etc. until the final list cell is reached. The individual elements of a list are printed by PRIN1 if the list is being printed by PRIN1, and by PRIN2 if the list is being printed by PRINT or PRIN2. Lists are considered to terminate when CDR of some node is not a list. If CDR of this terminal node is NIL (the usual case), CAR of the terminal node is printed followed by a right parenthesis. If CDR of the terminal node is not NIL, CAR of the terminal node is printed, followed by a space, a period, another space, CDR of the terminal node, and then the right parenthesis. Note that a list input as (A B C . NIL) will print as (A B C), and a list input as (A B . (C D)) will print as (A B C D). Note also
that PRINTLEVEL affects the printing of lists (page 25.11), and that carriage returns may be inserted where dictated by LINELENGTH (page 25.11).

Note: One must be careful when testing the equality of list structures. EQ will be true only when the two lists are the exact same list. For example,

\[
\begin{align*}
\text{\texttt{\textbackslash (SETQ A '(1 2))}} & \Rightarrow (1 2) \\
\text{\texttt{\textbackslash (SETQ B A)}} & \Rightarrow (1 2) \\
\text{\texttt{\textbackslash (EQ A B)}} & \Rightarrow T \\
\text{\texttt{\textbackslash (SETQ C '(1 2))}} & \Rightarrow (1 2) \\
\text{\texttt{\textbackslash (EQ A C)}} & \Rightarrow \text{NIL} \\
\text{\texttt{\textbackslash (EQUAL A C)}} & \Rightarrow T
\end{align*}
\]

In the example above, the values of A and B are the exact same list, so they are EQ. However, the value of C is a totally different list, although it happens to have the same elements. EQUAL should be used to compare the elements of two lists. In general, one should notice whether list manipulation functions use EQ or EQUAL for comparing lists. This is a frequent source of errors.

Interlisp provides an extensive set of list manipulation functions, described in the following sections.

## 3.1 Creating Lists

### (MKLIST X) [Function]

"Make List." If X is a list or NIL, returns X; Otherwise, returns (LIST X).

### (LIST X₁ X₂ ... Xₙ) [NoSpread Function]

Returns a list of its arguments, e.g.

\[
\text{(LIST 'A 'B '(C D))} = > (A B (C D))
\]

### (LIST* X₁ X₂ ... Xₙ) [NoSpread Function]

Returns a list of its arguments, using the last argument for the tail of the list. This is like an iterated CONS: (LIST* A B C) = (CONS A (CONS B C)). For example,

\[
\text{(LIST* 'A 'B 'C)} = > (A B . C)
\]
(APPEND $X_1 X_2 ... X_N$)  

Copies the top level of the list $X_1$ and appends this to a copy of the top level of the list $X_2$ appended to ... appended to $X_N$, e.g.,

$$(\text{APPEND } '(A B) '(C D E) '(F G)) = (A B C D E F G)$$

Note that only the first $N-1$ lists are copied. However $N=1$ is treated specially; (APPEND $X$) copies the top level of a single list. To copy a list to all levels, use COPY.

The following examples illustrate the treatment of non-lists:

$$(\text{APPEND } '(A B C) 'D) = (A B C . D)$$

$$(\text{APPEND } 'A ' (B C D)) = (B C D)$$

$$(\text{APPEND } '(A B C . D) '(E F G)) = (A B C E F G)$$

$$(\text{APPEND } '(A B C . D)) = (A B C . D)$$

(NCONC $X_1 X_2 ... X_N$)  

Returns the same value as APPEND, but actually modifies the list structure of $X_1 ... X_{N-1}$.

Note that NCONC cannot change NIL to a list:

$$\langle\langle\text{SETQ FOO NIL}\rangle\rangle$$

$$\langle\langle\text{NCONC FOO } '(A B C)\rangle\rangle$$

$$\langle\langle\langle\text{A B C}\rangle\rangle\rangle$$

$$\langle\langle\text{FOO}\rangle\rangle$$

$$\langle\langle\text{NIL}\rangle\rangle$$

Although the value of the NCONC is $(A B C)$, FOO has not been changed. The "problem" is that while it is possible to alter list structure with RPLACA and RPLACD, there is no way to change the non-list NIL to a list.

(NCONC1 LST $X$)  

(NCONC LST (LIST $X$))

[Function]

(ATTACH $X$ $L$)  

"Attaches" $X$ to the front of $L$ by doing a RPLACA and RPLACD. The value is EQUAL to (CONS $X$ $L$), but EQ to $L$, which it physically changes (except if $L$ is NIL). (ATTACH $X$ NIL) is the same as (CONS $X$ NIL). Otherwise, if $L$ is not a list, an error is generated, ARG NOT LIST.
3.2 Building Lists From Left to Right

(TCONC PTR X)  [Function]

TCONC is similar to NCONC1; it is useful for building a list by adding elements one at a time at the end. Unlike NCONC1, TCONC does not have to search to the end of the list each time it is called. Instead, it keeps a pointer to the end of the list being assembled, and updates this pointer after each call. This can be considerably faster for long lists. The cost is an extra list cell, PTR. (CAR PTR) is the list being assembled, (CDR PTR) is (LAST (CAR PTR)). TCONC returns PTR, with its CAR and CDR appropriately modified.

PTR can be initialized in two ways. If PTR is NIL, TCONC will create and return a PTR. In this case, the program must set some variable to the value of the first call to TCONC. After that, it is unnecessary to reset the variable, since TCONC physically changes its value. Example:

\[
\text{~SETQ} FOO \text{(TCONC NIL 1)}
\]

\[
(((1) 1)
\]

\[
\text{~for I from 2 to 5 do (TCONC FO0 I)}
\]

NIL

\[
\text{~FOO}
\]

\[
((1 2 3 4 5) 5)
\]

If PTR is initially (NIL), the value of TCONC is the same as for PTR = NIL, but TCONC changes PTR. This method allows the program to initialize the TCONC variable before adding any elements to the list. Example:

\[
\text{~SETQ} FOO \text{(CONS)}
\]

\[
(\text{NIL})
\]

\[
\text{~for I from 1 to 5 do (TCONC FO0 I)}
\]

NIL

\[
\text{~FOO}
\]

\[
((1 2 3 4 5) 5)
\]

(LCONC PTR X)  [Function]

Where TCONC is used to add elements at the end of a list, LCONC is used for building a list by adding lists at the end, i.e., it is similar to NCONC instead of NCONC1. Example:

\[
\text{~SETQ} FOO \text{(CONS)}
\]

\[
(\text{NIL})
\]

\[
\text{~LCONC FO0 '((1 2))}
\]

\[
((1 2) 2)
\]

\[
\text{~LCONC FO0 '((3 4 5))}
\]

\[
((1 2 3 4 5) 5)
\]

\[
\text{~LCONC FO0 NIL}
\]

\[
((1 2 3 4 5) 5)
\]
LCONC uses the same pointer conventions as TCONC for eliminating searching to the end of the list, so that the same pointer can be given to TCONC and LCONC interchangeably. Therefore, continuing from above,

\[
\begin{align*}
\langle & (TCONC \text{ FOO NIL}) \\
& (1 \ 2 \ 3 \ 4 \ 5 \ \text{NIL}) \ \text{NIL} \\
\langle & (TCONC \text{ FOO } '(3 \ 4 \ 5)) \\
& (1 \ 2 \ 3 \ 4 \ 5 \ \text{NIL} (3 \ 4 \ 5)) \ (3 \ 4 \ 5)
\end{align*}
\]

The functions DOCOLLECT and ENDCOLLECT also permit building up lists from left-to-right like TCONC, but without the overhead of an extra list cell. The list being maintained is kept as a circular list. DOCOLLECT adds items; ENDCOLLECT replaces the tail with its second argument, and returns the full list.

**DOCOLLECT ITEM LST**

\[\text{"Adds" ITEM to the end of LST. Returns the new circular list. Note that LST is modified, but it is not EQ to the new list. The new list should be stored and used as LST to the next call to DOCOLLECT."}\]

**ENDCOLLECT LST TAIL**

\[\text{Takes LST, a list returned by DOCOLLECT, and returns it as a non-circular list, adding TAIL as the terminating CDR.}\]

Here is an example using DOCOLLECT and ENDCOLLECT. HPRINT is used to print the results because they are circular lists. Notice that FOO has to be set to the value of DOCOLLECT as each element is added.

\[
\begin{align*}
\langle & (\text{SETQ FOO NIL}) \\
& \text{NIL} \\
\langle & (\text{HPRINT (SETQ FOO (DOCOLLECT 1 FOO) \uparrow (1 . \{1\})})} \\
\langle & (\text{HPRINT (SETQ FOO (DOCOLLECT 2 FOO) \uparrow (2 \ 1 . \{1\})})} \\
\langle & (\text{HPRINT (SETQ FOO (DOCOLLECT 3 FOO) \uparrow (3 \ 1 \ 2 . \{1\})})} \\
\langle & (\text{HPRINT (SETQ FOO (DOCOLLECT 4 FOO) \uparrow (4 \ 1 \ 2 \ 3 . \{1\})})} \\
\langle & (\text{SETQ FOO (ENDCOLLECT FOO 5) \ (1 \ 2 \ 3 \ 4 . \ 5))}
\end{align*}
\]

The following two functions are useful writing programs that wish to reuse a scratch list to collect together some result (Both of these compile open):
(SCRATCHLIST LST X₁ X₂ ... Xₙ)  
[ NLambda NoSpread Function ]

SCRATCHLIST sets up a context in which the value of LST is used as a "scratch" list. The expressions X₁, X₂, ... Xₙ are evaluated in turn. During the course of evaluation, any value passed to ADDTOSCRATCHLIST will be saved, reusing CONS cells from the value of LST. If the value of LST is not long enough, new CONS cells will be added onto its end. If the value of LST is NIL, the entire value of SCRATCHLIST will be "new" (i.e. no CONS cells will be reused).

(ADDTOSCRATCHLIST VALUE)  
[ Function ]
For use under calls to SCRATCHLIST. VALUE is added on to the end of the value being collected by SCRATCHLIST. When SCRATCHLIST returns, its value is a list containing all of the things that ADDTOSCRATCHLIST has added.

3.3 Copying Lists

(COPY X)  
[ Function ]
Creates and returns a copy of the list X. All levels of X are copied down to non-lists, so that if X contains arrays and strings, the copy of X will contain the same arrays and strings, not copies. COPY is recursive in the CAR direction only, so very long lists can be copied.

Note: To copy just the top level of X, do (APPEND X).

(COPYALL X)  
[ Function ]
Like COPY except copies down to atoms. Arrays, hash-arrays, strings, user data types, etc., are all copied. Analogous to EQUALALL (page 9.3). Note that this will not work if given a data structure with circular pointers; in this case, use HCOPYALL.

(HCOPYALL X)  
[ Function ]
Similar to COPYALL, except that it will work even if the data structure contains circular pointers.
3.4 Extracting Tails of Lists

(TAILP X Y)  [Function]

Returns X, if X is a tail of the list Y; otherwise NIL. X is a tail of Y if it is EQ to 0 or more CDRs of Y.

Note: If X is EQ to 1 or more CDRs of Y, X is called a "proper tail."

(NTH X N)  [Function]

Returns the tail of X beginning with the Nth element. Returns NIL if X has fewer than N elements. Examples:

(NTH '(A B C D) 1) = > (A B C D)
(NTH '(A B C D) 3) = > (C D)
(NTH '(A B C D) 9) = > .NIL
(NTH '(A . B) 2) = > B

For consistency, if N = 0, NTH returns (CONS NIL X):

(NTH '(A B) 0) = > (NIL A B)

(FNTH X N)  [Function]

Faster version of NTH that terminates on a null-check.

(LAST X)  [Function]

Returns the last list cell in the list X. Returns NIL if X is not a list. Examples:

(LAST '(A B C) ) = > (C)
(LAST '(A B . C) ) = > (B . C)
(LAST 'A) = > NIL

(FLAST X)  [Function]

Faster version of LAST that terminates on a null-check.

(NLEFT L N TAIL)  [Function]

NLEFT returns the tail of L that contains N more elements than TAIL. If L does not contain N more elements than TAIL, NLEFT returns NIL. If TAIL is NIL or not a tail of L, NLEFT returns the last N list cells in L. NLEFT can be used to work backwards through a list. Example:

~SETQ FOO ' (A B C D E)~
(A B C D E)
~(NLEFT FOO 2)~
(D E)
~(NLEFT FOO 1 (CDDR FOO))~
(B C D E)


\[ \text{LASTN} \; L \; N \] [Function]

Returns \((\text{CONS} \; X \; Y)\), where \(Y\) is the last \(N\) elements of \(L\), and \(X\) is the initial segment, e.g.,

\[
\text{LASTN} \; (\text{\textbf{A B C D E}}) \; 2 \; \to \; ((\text{\textbf{A B C}}) \; \text{\textbf{D E}}) \\
\text{LASTN} \; (\text{\textbf{A B}}) \; 2 \; \to \; (\text{\textbf{NIL A B}}) 
\]

Returns \text{NIL} if \(L\) is not a list containing at least \(N\) elements.

### 3.5 Counting List Cells

\[ \text{LENGTH} \; X \] [Function]

Returns the length of the list \(X\), where "length" is defined as the number of CDRs required to reach a non-list. Examples:

\[
\text{LENGTH} \; (\text{\textbf{A B C}}) \; \Rightarrow \; 3 \\
\text{LENGTH} \; (\text{\textbf{A B . C} . D}) \; \Rightarrow \; 3 \\
\text{LENGTH} \; \text{\textbf{A}} \; \Rightarrow \; 0 
\]

\[ \text{FLENGTH} \; X \] [Function]

Faster version of \text{LENGTH} that terminates on a null-check.

\[ \text{EQLENGTH} \; X \; N \] [Function]

Equivalent to \((\text{EQUAL} \; (\text{LENGTH} \; X) \; N)\), but more efficient, because \text{EQLENGTH} stops as soon as it knows that \(X\) is longer than \(N\). Note that \text{EQLENGTH} is safe to use on (possibly) circular lists, since it is "bounded" by \(N\).

\[ \text{COUNT} \; X \] [Function]

Returns the number of list cells in the list \(X\). Thus, \text{COUNT} is like a \text{LENGTH} that goes to all levels. \text{COUNT} of a non-list is 0. Examples:

\[
\text{COUNT} \; (\text{\textbf{A}}) \; \Rightarrow \; 1 \\
\text{COUNT} \; (\text{\textbf{A . B}}) \; \Rightarrow \; 1 \\
\text{COUNT} \; (\text{\textbf{A (B C)}}) \; \Rightarrow \; 4 
\]

In this last example, the value is 4 because the list \((\text{\textbf{A X C}})\) uses 3 list cells for any object \(X\), and \(\text{\textbf{B}}\) uses another list cell.
### COUNTDOWN X N

Counts the number of list cells in X, decrementing N for each one. Stops and returns N when it finishes counting, or when N reaches 0. COUNTDOWN can be used on circular structures since it is "bounded" by N. Examples:

- `(COUNTDOWN '(A) 100) = > 99`
- `(COUNTDOWN '(A . B) 100) = > 99`
- `(COUNTDOWN '(A (B) C) 100) = > 96`
- `(COUNTDOWN (DOCOLLECT 1 NIL) 100) = > 0`

### EQUALN X Y DEPTH

Similar to EQUAL, for use with (possibly) circular structures. Whenever the depth of CAR recursion plus the depth of CDR recursion exceeds DEPTH, EQUALN does not search further along that chain, and returns the litatom ?. If recursion never exceeds DEPTH, EQUALN returns T if the expressions X and Y are EQUAL; otherwise NIL.

- `(EQUALN '(((A)) B) '(((Z)) B) 2) = > ?`
- `(EQUALN '(((A)) B) '(((Z)) B) 3) = > NIL`
- `(EQUALN '(((A)) B) '(((A)) B) 3) = > T`

### 3.6 Logical Operations

#### LDIFFERENCE X Y

"List Difference." Returns a list of those elements in X that are not members of Y (using EQUAL to compare elements).

Note: If X and Y share no elements, LDIFFERENCE returns a copy of X.

#### INTERSECTION X Y

Returns a list whose elements are members of both lists X and Y (using EQUAL to compare elements).

Note that (INTERSECTION X X) gives a list of all members of X without any duplications.

#### UNION X Y

Returns a (new) list consisting of all elements included on either of the two original lists (using EQUAL to compare elements). It is more efficient to make X be the shorter list.
The value of UNION is \( Y \) with all elements of \( X \) not in \( Y \) CONSed on the front of it. Therefore, if an element appears twice in \( Y \), it will appear twice in \((\text{UNION } X \ Y)\). Since \((\text{UNION } '(A) \ '(A \ A)) = (A \ A)\), while \((\text{UNION } '(A \ A) \ '(A)) = (A)\), UNION is non-commutative.

**FUNCTION**

**TAIL** must be a tail of \( LST \), i.e., EQ to the result of applying some number of CDRs to \( LST \). (LDIFF \( LST \ TAIL \)) returns a list of all elements in \( LST \) up to \( TAIL \).

If \( ADD \) is not NIL, the value of LDIFF is effectively \((\text{NCONC } ADD \ (\text{LDIFF } LST \ TAIL))\), i.e., the list difference is added at the end of \( ADD \).

If \( TAIL \) is not a tail of \( LST \), LDIFF generates an error, LDIFF: NOT A TAIL. LDIFF terminates on a null-check, so it will go into an infinite loop if \( LST \) is a circular list and \( TAIL \) is not a tail.

Example:

\[
\begin{align*}
\text{~SETQ FOO} & \ '({\text{A B C D E F}}) \\
\text{(A B C D E F)} & \rightarrow \text{(CDDR FOO)} \\
\text{(C D E F)} & \rightarrow \text{(LDIFF FOO (CDDR FOO))} \\
\text{(A B)} & \rightarrow \text{(LDIFF FOO (CDDR FOO) }'(1 \ 2)) \\
\text{(1 2 A B)} & \rightarrow \text{(LDIFF FOO }'(C D E F)) \\
\text{LDIFF: not a tail} & \\
\text{(C D E F)} &
\end{align*}
\]

Note that the value of LDIFF is always new list structure unless \( TAIL = \text{NIL} \), in which case the value is \( LST \) itself.

### 3.7 Searching Lists

**FUNCTION**

Determines if \( X \) is a member of the list \( Y \). If there is an element of \( Y \) EQ to \( X \), returns the tail of \( Y \) starting with that element. Otherwise, returns NIL. Examples:

\[
\begin{align*}
\text{(MEMB 'A }'(A \ W \ C D)) & = > \ (A \ W \ C D) \\
\text{(MEMB 'C }'(A \ W \ C D)) & = > \ (C \ D) \\
\text{(MEMB 'W }'(A \ W \ C D)) & = > \ \text{NIL} \\
\text{(MEMB 'W )}'(A \ W \ C D)) & = > \ \text{NIL}
\end{align*}
\]
3.8 Substitution Functions

**(FMEMBX Y)**

Faster version of MEMB that terminates on a null-check.

**(MEMBERX Y)**

Identical to MEMB except that it uses EQUAL instead of EQ to check membership of X in Y. Examples:

- `(MEMBER 'C '(A (W) C D)) = > (C D)
- `(MEMBER 'W '(A (W) C D)) = > NIL
- `(MEMBER '(W) '(A (W) C D)) = > ((W) C D)

**(EQMEMBX Y)**

Returns T if either X is EQ to Y, or else Y is a list and X is an FMEMB of Y.

3.8 Substitution Functions

**(SUBST NEW OLD EXPR)**

Returns the result of substituting NEW for all occurrences of OLD in the expression EXPR. Substitution occurs whenever OLD is EQUAL to CAR of some subexpression of EXPR, or when OLD is atomic and EQ to a non-NIL CDR of some subexpression of EXPR. For example:

- `(SUBST 'A 'B '(C B (X . B))) = > (C A (X . A))
- `(SUBST 'A '(B C) '(B C D B C)) = > (A D B C) not (A D . A)

SUBST returns a copy of EXPR with the appropriate changes. Furthermore, if NEW is a list, it is copied at each substitution.

**(DSUBST NEW OLD EXPR)**

Similar to SUBST, except it does not copy EXPR, but changes the list structure EXPR itself. Like SUBST, DSUBST substitutes with a copy of NEW. More efficient than SUBST.

**(LSUBST NEW OLD EXPR)**

Like SUBST except NEW is substituted as a segment of the list EXPR rather than as an element. For instance,

- `(LSUBST '(A B) 'Y '(X Y Z)) = > (X A B Z)

Note that if NEW is not a list, LSUBST returns a copy of EXPR with all OLD's deleted:

- `(LSUBST NIL 'Y '(X Y Z)) = > (X Z)
(SUBLIST ALST EXPR FLG)  

ALST is a list of pairs:

\[ ((\text{OLD}_1 \cdot \text{NEW}_1) \cdot (\text{OLD}_2 \cdot \text{NEW}_2) \ldots (\text{OLD}_N \cdot \text{NEW}_N)) \]

Each OLD\(_i\) is an atom. SUBLIS returns the result of substituting each NEW\(_i\) for the corresponding OLD\(_i\) in EXPR, e.g.,

\[ \text{SUBLIS}'((\text{A} \cdot \text{X}) \cdot (\text{C} \cdot \text{Y}))'((\text{A} \cdot \text{B} \cdot \text{C} \cdot \text{D})) = > (\text{X} \cdot \text{B} \cdot \text{Y} \cdot \text{D}) \]

If FLG = NIL, new structure is created only if needed, so if there are no substitutions, the value is EQ to EXPR. If FLG = T, the value is always a copy of EXPR.

(DSUBLIS ALST EXPR FLG)  

Similar to SUBLIS, except it changes the list structure EXPR itself instead of copying it.

(SUBPAIR OLD NEW EXPR FLG)  

Similar to SUBLIS, except that elements of NEW are substituted for corresponding atoms of OLD in EXPR, e.g.,

\[ \text{SUBPAIR}'((\text{A} \cdot \text{C}) \cdot (\text{X} \cdot \text{Y}))'((\text{A} \cdot \text{B} \cdot \text{C} \cdot \text{D})) = > (\text{X} \cdot \text{B} \cdot \text{Y} \cdot \text{D}) \]

As with SUBLIS, new structure is created only if needed, or if FLG = T, e.g., if FLG = NIL and there are no substitutions, the value is EQ to EXPR.

If OLD ends in an atom other than NIL, the rest of the elements on NEW are substituted for that atom. For example, if OLD = (A B . C) and NEW = (U V X Y Z), U is substituted for A, V for B, and (X Y Z) for C. Similarly, if OLD itself is an atom (other than NIL), the entire list NEW is substituted for it. Examples:

\[ \text{SUBPAIR}'((\text{A} \cdot \text{B} \cdot \text{C}) \cdot (\text{W} \cdot \text{X} \cdot \text{Y} \cdot \text{Z}))'((\text{C} \cdot \text{A} \cdot \text{B} \cdot \text{B} \cdot \text{Y})) = > ((\text{Y} \cdot \text{Z}) \cdot \text{W} \cdot \text{X} \cdot \text{X} \cdot \text{Y}) \]

Note that SUBST, DSUBST, and LSUBST all substitute copies of the appropriate expression, whereas SUBLIS, and DSUBLIS, and SUBPAIR substitute the identical structure (unless FLG = T). For example:

\[ \text{E} \leftarrow (\text{SETQ FOO}'((\text{A} \cdot \text{B})) \right) \leftarrow (\text{SETQ BAR}'((\text{X} \cdot \text{Y} \cdot \text{Z})) \right) \leftarrow (\text{DSUBLIS} (\text{LIST} (\text{CONS}'\text{X} \cdot \text{FOO})) \cdot \text{BAR}) \right) \leftarrow (\text{DSUBLIS} (\text{LIST} (\text{CONS}'\text{Y} \cdot \text{FOO})) \cdot \text{BAR} \cdot \text{T}) \right) \leftarrow (\text{EQ} (\text{CAR} \cdot \text{BAR}) \cdot \text{FOO}) \right) \leftarrow (\text{EQ} (\text{CDAR} \cdot \text{BAR}) \cdot \text{FOO}) \right) \text{NIL} \]
3.9 Association Lists and Property Lists

A commonly-used data structure is one that associates an arbitrary set of property names \((NAME1, NAME2, \text{etc.})\), with a set of property values \((VALUE1, VALUE2, \text{etc.})\). Two list structures commonly used to store such associations are called "property lists" and "association lists." A list in "association list" format is a list where each element is a dotted pair whose CAR is a property name, and whose CDR is the value:

\[
((\text{NAME1 . VALUE1}) (\text{NAME2 . VALUE2}) \ldots)
\]

A list in "property list" format is a list where the first, third, etc. elements are the property names, and the second, forth, etc. elements are the associated values:

\[
(\text{NAME1 VALUE1 NAME2 VALUE2} \ldots)
\]

The functions below provide facilities for searching and changing lists in property list or association list format.

Note: Property lists are contained within many Interlisp-D system datatypes. There are special functions that can be used to set and retrieve values from the property lists of litatoms (see page 2.5), from properties of windows (see page 28.13), etc.

Note: Another data structure that offers some of the advantages of association lists and property lists is the hash array data type (see page 6.1).

\begin{itemize}
\item \textbf{(ASSOC KEY ALST)}
\begin{itemize}
\item \textit{ALST} is a list of lists. ASSOC returns the first sublist of \textit{ALST} whose CAR is EQ to \textit{KEY}. If such a list is not found, ASSOC returns NIL. Example:
\begin{verbatim}
(ASSOC 'B '((A . 1) (B . 2) (C . 3))) = > (B . 2)
\end{verbatim}
\end{itemize}
\item \textbf{(FASSOC KEY ALST)}
\begin{itemize}
\item Faster version of ASSOC that terminates on a null-check.
\end{itemize}
\item \textbf{(SASSOC KEY ALST)}
\begin{itemize}
\item Same as ASSOC but uses EQUAL instead of EQ when searching for \textit{KEY}.
\end{itemize}
\item \textbf{(PUTASSOC KEY VAL ALST)}
\begin{itemize}
\item Searches \textit{ALST} for a sublist CAR of which is EQ to \textit{KEY}. If one is found, the CDR is replaced (using RPLACD) with \textit{VAL}. If no such sublist is found, \textbf{(CONS KEY VAL)} is added at the end of \textit{ALST}. Returns \textit{VAL}. If \textit{ALST} is not a list, generates an error, \textbf{ARG NOT LIST}.
\end{itemize}
\end{itemize}
Note that the argument order for ASSOC, PUTASSOC, etc. is different from that of LISTGET, LISTPUT, etc.

**LISTGET LST PROP**

Searches LST two elements at a time, by CDDR, looking for an element EQ to PROP. If one is found, returns the next element of LST, otherwise NIL. Returns NIL if LST is not a list. Example:

(LISTGET '(A 1 B 2 C 3) 'B) = 2
(LISTGET '(A 1 B 2 C 3) 'W) = NIL

**LISTPUT LST PROP VAL**

Searches LST two elements at a time, by CDDR, looking for an element EQ to PROP. If PROP is found, replaces the next element of LST with VAL. Otherwise, PROP and VAL are added to the end of LST. If LST is a list with an odd number of elements, or ends in a non-list other than NIL, PROP and VAL are added at its beginning. Returns VAL. If LST is not a list, generates an error, ARG NOT LIST.

**LISTGET1 LST PROP**

Like LISTGET, but searches LST one CDR at a time, i.e., looks at each element. Returns the next element after PROP. Examples:

(LISTGET1 '(A 1 B 2 C 3) 'B) = 2
(LISTGET1 '(A 1 B 2 C 3) '1) = B
(LISTGET1 '(A 1 B 2 C 3) 'W) = NIL

Note: LISTGET1 used to be called GET.

**LISTPUT1 LST PROP VAL**

Like LISTPUT, except searches LST one CDR at a time. Returns the modified LST. Example:

(SETQ FOO '(A 1 B 2))
(A 1 B 2)
(SETQ FOO 'B 3)
(A 1 B 3)
(SETQ FOO 'C 4)
(A 1 B 3 C 4)
(SETQ FOO 'W)
(A 1 W 3 C 4)
(FOO)
(A 1 W 3 C 4)

Note that if LST is not a list, no error is generated. However, since a non-list cannot be changed into a list, LST is not modified. In this case, the value of LISTPUT1 should be saved. Example:

(SETQ FOO NIL)
3.10 Sorting Lists

**(SORT DATA COMPAREFN)**  [Function]

DATA is a list of items to be sorted using COMPAREFN, a predicate function of two arguments which can compare any two items on DATA and return T if the first one belongs before the second. If COMPAREFN is NIL, ALPHORDER is used; thus (SORT DATA) will alphabetize a list. If COMPAREFN is T, CAR's of items that are lists are given to ALPHORDER, otherwise the items themselves; thus (SORT A-LIST T) will alphabetize an assoc list by the CAR of each item. (SORT X 'ILESSP) will sort a list of integers.

The value of SORT is the sorted list. The sort is destructive and uses no extra storage. The value returned is EQ to DATA but elements have been switched around. Interrupting with control D, E, or B may cause loss of data, but control H may be used at any time, and SORT will break at a clean state from which † or control characters are safe. The algorithm used by SORT is such that the maximum number of compares is $N^2 \log_2 N$, where $N$ is (LENGTH DATA).

Note: if (COMPAREFN A B) = (COMPAREFN B A), then the ordering of A and B may or may not be preserved.

For example, if (FOO . FIE) appears before (FOO . FUM) in X, (SORT X T) may or may not reverse the order of these two elements. Of course, the user can always specify a more precise COMPAREFN.

**(MERGE A B COMPAREFN)**  [Function]

A and B are lists which have previously been sorted using SORT and COMPAREFN. Value is a destructive merging of the two lists. It does not matter which list is longer. After merging both A and B are equal to the merged list. (In fact, (CDR A) is EQ to (CDR B)). MERGE may be aborted after control-H.

**(ALPHORDER A B CASEARRAY)**  [Function]

A predicate function of two arguments, for alphabetizing. Returns a non-NIL value if its arguments are in lexicographic order, i.e., if B does not belong before A. Numbers come before
literal atoms, and are ordered by magnitude (using `GREATERP`). Literal atoms and strings are ordered by comparing the character codes in their print names. Thus `(ALPHORDER 23 123)` is `T`, whereas `(ALPHORDER 'A23 'A123)` is `NIL`, because the character code for the digit 2 is greater than the code for 1.

Atoms and strings are ordered before all other data types. If neither `A` nor `B` are atoms or strings, the value of `ALPHORDER` is `T`, i.e., in order.

If `CASEARRAY` is non-`NIL`, it is a casearray (page 25.21) that the characters of `A` and `B` are translated through before being compared. Note that numbers are not passed through `CASEARRAY`.

Note: If either `A` or `B` is a number, the value returned in the "true" case is `T`. Otherwise, `ALPHORDER` returns either `EQUAL` or `LESSP` to discriminate the cases of `A` and `B` being equal or unequal strings/atoms.

Note: `ALPHORDER` does no `UNPACKs`, `CHCONs`, `CONSes` or `NTHCHARs`. It is several times faster for alphabetizing than anything that can be written using these other functions.

```
(UALPHORDER A B)
```

Defined as `(ALPHORDER A B UPPERCASEARRAY)`. `UPPERCASEARRAY` (page 25.22) is a casearray that maps every lowercase character into the corresponding uppercase character.

```
(MERGEINSERT NEW LST ONEFLG)
```

`LST` is `NIL` or a list of partially sorted items. `MERGEINSERT` tries to find the "best" place to (destructively) insert `NEW`, e.g.,

```
(MERGEINSERT 'FIE2 '(FOO FOO1 FIE FUM))
```

= > `(FOO FOO1 FIE FIE2 FUM)`

Returns `LST`. `MERGEINSERT` is undoable.

If `ONEFLG = T` and `NEW` is already a member of `LST`, `MERGEINSERT` does nothing and returns `LST`.

`MERGEINSERT` is used by `ADDTOFILE` (page 17.48) to insert the name of a new function into a list of functions. The algorithm is essentially to look for the item with the longest common leading sequence of characters with respect to `NEW`, and then merge `NEW` in starting at that point.
3.11 Other List Functions

(REMOVE X L) [Function]
Removes all top-level occurrences of X from list L, returning a copy of L with all elements EQUAL to X removed. Example:

(REMOVE 'A '(A B C A)) = > (B C A)
(REMOVE '(A)'(A B C (A) A)) = > (A B C A)

(DREMOVE X L) [Function]
Similar to REMOVE, but uses EQ instead of EQUAL, and actually modifies the list L when removing X, and thus does not use any additional storage. More efficient than REMOVE.

Note that DREMOVE cannot change a list to NIL:

←(SETQ FOO '(A))
(A)
←(DREMOVE 'A FOO)
NIL
←FOO
(A)

The DREMOVE above returns NIL, and does not perform any CONSes, but the value of FOO is still (A), because there is no way to change a list to a non-list. See NCONC.

(REVERSE L) [Function]
Reverses (and copies) the top level of a list, e.g.,

(REVERSE '(A B (C D))) = > ((C D) B A)

If L is not a list, REVERSE just returns L.

(DREVERSE L) [Function]
Value is the same as that of REVERSE, but DREVERSE destroys the original list L and thus does not use any additional storage. More efficient than REVERSE.

(COMPARELISTS X Y) [Function]
Compares the list structures X and Y and prints a description of any differences to the terminal. If X and Y are EQUAL lists, COMPARELISTS simply prints out SAME. Returns NIL.

COMPARELISTS prints a terse description of the differences between the two list structures, highlighting the items that have changed. This printout is not a complete and perfect comparison. If X and Y are radically different list structures, the printout will not be very useful. COMPARELISTS is meant to be
used as a tool to help users isolate differences between similar structures.

When a single element has been changed for another, COMPARELISTS prints out items such as \( (A \rightarrow B) \), for example:

\[
\leftarrow \text{COMPARELISTS} '(A B C D) '(X B E D)) \\
(A \rightarrow X) (C \rightarrow E) \\
\text{NIL}
\]

When there are more complex differences between the two lists, COMPARELISTS prints \( X \) and \( Y \), highlighting differences and abbreviating similar elements as much as possible. "&" is used to signal a single element that is present in the same place in the two lists; "--" signals an arbitrary number of elements in one list but not in the other; "-2-", "-3-," etc signal a sequence of two, three, etc. elements that are the same in both lists. Examples:

\[
\begin{align*}
\text{(COMPARELISTS} '&&(A B C D) '(A D)) \\
&&(A B C --) \\
&&(A D) \\
\leftarrow \text{COMPARELISTS} '&&(A B C D E F G H) '&&(A B C D X)) \\
&&(A -3- E F --) \\
&&(A -3- X) \\
\leftarrow \text{COMPARELISTS} '&&(A B C (D E F G) H) '(A B (G) C (D E F H) I)) \\
&&(A \& \& (D -2- (G) \& \&) \\
&&(A \& (G) \& (D -2- \& \&) \&)
\end{align*}
\]

\[
\text{(NEGATE X)} \hspace{1cm} \text{[Function]}
\]

For a form \( X \), returns a form which computes the negation of \( X \). For example:

\[
\begin{align*}
\text{(NEGATE} '(\text{MEMBER} X Y)) &= \text{> (NOT} (\text{MEMBER} X Y)) \\
\text{(NEGATE} '(\text{EQ} X Y)) &= \text{> (NEQ} X Y) \\
\text{(NEGATE} '(\text{AND} X (\text{NIL} X) )\)) &= \text{> (OR} (\text{NULL} X) (\text{LIST} X)\)) \\
\text{(NEGATE} \text{NIL}) &= \text{> T}
\end{align*}
\]
4. Strings
41
A string is an object which represents a sequence of characters. Interlisp provides functions for creating strings, concatenating strings, and creating sub-strings of a string.

The input syntax for a string is a double quote ("), followed by a sequence of any characters except double quote and %, terminated by a double quote. The % and double quote characters may be included in a string by preceding them with the character %.

Strings are printed by PRINT and PRIN2 with initial and final double quotes, and %s inserted where necessary for it to read back in properly. Strings are printed by PRIN1 without the delimiting double quotes and extra %s.

A "null string" containing no characters is input as "". The null string is printed by PRINT and PRIN2 as "". (PRIN1 "") doesn't print anything.

Internally a string is stored in two parts; a "string pointer" and the sequence of characters. Several string pointers may reference the same character sequence, so a substring can be made by creating a new string pointer, without copying any characters. Functions that refer to "strings" actually manipulate string pointers. Some functions take an "old string" argument, and re-use the string pointer.

(STRINGP X)  [Function]
Returns X if X is a string, NIL otherwise.

(STREQUAL X Y)  [Function]
Returns T if X and Y are both strings and they contain the same sequence of characters, otherwise NIL. EQUAL uses STREQUAL. Note that strings may be STREQUAL without being EQ. For instance,

(STREQUAL "ABC" "ABC")  =>  T

(EQ "ABC" "ABC")  =>  NIL

STREQUAL returns T if X and Y are the same string pointer, or two different string pointers which point to the same character sequence, or two string pointers which point to different character sequences which contain the same characters. Only in the first case would X and Y be EQ.
(STRING-EQUAL X Y) [Function]
Returns T if X and Y are either strings or litatoms, and they contain the same sequence of characters, ignoring case. For instance,

(STRING-EQUAL "FOO" "Foo") => T
(STRING-EQUAL "FOO" 'Foo) => T

This is useful for comparing things that might want to be considered “equal” even though they’re not both litatoms in a consistent case, such as file names and user names.

(ALLOCSTRING N INITCHAR OLD FATFLG) [Function]
Creates a string of length N characters of INITCHAR (which can be either a character code or something coercible to a character). If INITCHAR is NIL, it defaults to character code 0. If OLD is supplied, it must be a string pointer, which is modified and returned.

If FATFLG is non-NIL, the string is allocated using full 16-bit NS characters (see page 2.12) instead of 8-bit characters. This can speed up some string operations if NS characters are later inserted into the string. This has no other effect on the operation of the string functions.

(MKSTRING X FLG RDTBL) [Function]
If X is a string, returns X. Otherwise, creates and returns a string containing the print name of X. Examples:

(MKSTRING "ABC") => "ABC"
(MKSTRING 'A B C) => "(A B C)"
(MKSTRING NIL) => "NIL"

Note that the last example returns the string "NIL", not the atom NIL.

If FLG is T, then the PRIN2-name of X is used, computed with respect to the readtable RDTBL. For example,

(MKSTRING "ABC" T) => "%"ABC%"

(NCHARS X FLG RDTBL) [Function]
Returns the number of characters in the print name of X. If FLG = T, the PRIN2-name is used. For example,

(NCHARS 'ABC) => 3
(NCHARS "ABC" T) => 5

Note: NCHARS works most efficiently on litatoms and strings, but can be given any object.
(FUNCTION SUBSTRING X N M OLDPTR)

Returns the substring of X consisting of the Nth through Mth characters of X. If M is NIL, the substring contains the Nth character thru the end of X. N and M can be negative numbers, which are interpreted as counts back from the end of the string, as with NTHCHAR (page 2.10). SUBSTRING returns NIL if the substring is not well defined, e.g., N or M specify character positions outside of X, or N corresponds to a character in X to the right of the character indicated by M). Examples:

(SUBSTRING "ABCDEFG" 4 6) = > "DEF"
(SUBSTRING "ABCDEFG" 3 3) = > "C"
(SUBSTRING "ABCDEFG" 3 NIL) = > "CDEFG"
(SUBSTRING "ABCDEFG" 4 -2) = > "DEF"
(SUBSTRING "ABCDEFG" 6 4) = > NIL
(SUBSTRING "ABCDEFG" 4 9) = > NIL

If X is not a string, it is converted to one. For example,

(SUBSTRING '(A B C) 4 6) = > "BC"

SUBSTRING does not actually copy any characters, but simply creates a new string pointer to the characters in X. If OLDPTR is a string pointer, it is modified and returned.

(FUNCTION GNC X)

"Get Next Character." Returns the next character of the string X (as an atom); also removes the character from the string, by changing the string pointer. Returns NIL if X is the null string. If X isn’t a string, a string is made. Used for sequential access to characters of a string. Example:

←(SETQ FOO "ABCDEFG")
"ABCDEFG"
←(GNC FOO)
A
←(GNC FOO)
B
←FOO
"CDEFG"

Note that if A is a substring of B, (GNC A) does not remove the character from B.

(FUNCTION GLC X)

"Get Last Character." Returns the last character of the string X (as an atom); also removes the character from the string. Similar to GNC. Example:

←(SETQ FOO "ABCDEFG")
"ABCDEFG"
\begin{align*}
\text{(CONCAT } X_1 X_2 \ldots X_N) &\quad \text{[NoSpread Function]} \\
\text{Returns a new string which is the concatenation of (copies of) its arguments. Any arguments which are not strings are transformed to strings. Examples:} \\
\text{(CONCAT "ABC" 'DEF "GHI")} &= \text{"ABCDGHI"} \\
\text{(CONCAT '(A B C) "ABC")} &= \text{"(A B C)ABC"} \\
\text{(CONCAT)} &\text{returns the null string, "".}
\end{align*}

\text{(CONCATLIST } L) &\quad \text{[Function]} \\
L &\text{is a list of strings and/or other objects. The objects are transformed to strings if they aren't strings. Returns a new string which is the concatenation of the strings. Example:} \\
\text{(CONCATLIST '(A B (C D) "EF")}) &= \text{"AB(C D)EF"}

\text{(RPLSTRING } X N Y) &\quad \text{[Function]} \\
\text{Replaces the characters of string } X \text{ beginning at character position } N \text{ with string } Y. \ X \text{ and } Y \text{ are converted to strings if they aren't already. } N \text{ may be positive or negative, as with SUBSTRING. Characters are smashed into (converted) } X. \ \text{Returns the string } X. \ \text{Examples:} \\
\text{(RPLSTRING "ABCDEF" -3 "END")} &= \text{"ABCEND"} \\
\text{(RPLSTRING "ABCDEFGHIJK" 4 '(A B C))} &= \text{"ABC(A B C)K"}

\text{Generates an error if there is not enough room in } X \text{ for } Y, \text{i.e., the new string would be longer than the original. If } Y \text{ was not a string, } X \text{ will already have been modified since RPLSTRING does not know whether } Y \text{ will "fit" without actually attempting the transfer.}

\text{Warning: In some implementations of Interlisp, if } X \text{ is a substring of } Z, \ Z \text{ will also be modified by the action of RPLSTRING or RPLCHARCODE. However, this is not guaranteed to be true in all cases, so programmers should not rely on RPLSTRING or RPLCHARCODE altering the characters of any string other than the one directly passed as argument to those functions.}
(RPLCHARCODE X N CHAR)  [Function]
Replaces the Nth character of the string X with the character code CHAR. N may be positive or negative. Returns the new X. Similar to RPLSTRING. Example:
(RPLCHARCODE "ABCDE" 3 (CHARCODE F)) = > "ABFDE"

(STRPOS PAT STRING START SKIP ANCHOR TAIL CASEARRAY BACKWARDSFLG)  [Function]
STRPOS is a function for searching one string looking for another. PAT and STRING are both strings (or else they are converted automatically). STRPOS searches STRING beginning at character number START, (or 1 if START is NIL) and looks for a sequence of characters equal to PAT. If a match is found, the character position of the first matching character in STRING is returned, otherwise NIL. Examples:
(STRPOS "ABC" "XYZABCDEF") = > 4
(STRPOS "ABC" "XYZABCDEF" 5) = > NIL
(STRPOS "ABC" "XYZABCDEFABC" 5) = > 10

SKIP can be used to specify a character in PAT that matches any character in STRING. Examples:
(STRPOS "A&C&" "XYZABCDEF" NIL '&) = > 4
(STRPOS "DEF&" "XYZABCDEF" NIL '&) = > NIL

If ANCHOR is T, STRPOS compares PAT with the characters beginning at position START (or 1 if START is NIL). If that comparison fails, STRPOS returns NIL without searching any further down STRING. Thus it can be used to compare one string with some portion of another string. Examples:
(STRPOS "ABC" "XYZABCDEF" NIL NIL T) = > NIL
(STRPOS "ABC" "XYZABCDEF" 4 NIL T) = > 4

If TAIL is T, the value returned by STRPOS if successful is not the starting position of the sequence of characters corresponding to PAT, but the position of the first character after that, i.e., the starting position plus (NCHARS PAT). Examples:
(STRPOS "ABC" "XYZABCDEFABC" NIL NIL T) = > 7
(STRPOS "A" "A" NIL NIL NIL T) = > 2

If TAIL = NIL, STRPOS returns NIL, or a character position within STRING which can be passed to SUBSTRING. In particular, (STRPOS "" "") = > NIL. However, if TAIL = T, STRPOS may return a character position outside of STRING. For instance, note that the second example above returns 2, even though "A" has only one character.

If CASEARRAY is non-NIL, this should be a casearray like that given to FILEPOS (page 25.20). The casearray is used to map the string characters before comparing them to the search string.
If BACKWARDSFLG is non-NIL, the search is done backwards from the end of the string.

(STRPOSL A STRING START NEG BACKWARDSFLG) [Function]

STRING is a string (or else it is converted automatically to a string). A is a list of characters or character codes. STRPOSL searches STRING beginning at character number START (or else 1 if START = NIL) for one of the characters in A. If one is found, STRPOSL returns as its value the corresponding character position, otherwise NIL. Example:

(STRPOSL '(A B C) "XYZBCD") = > 4

If NEG = T, STRPOSL searches for a character not on A. Example:

(STRPOSL '(A B C) "ABCDEF" NIL T) = > 4

If any element of A is a number, it is assumed to be a character code. Otherwise, it is converted to a character code via CHCON1. Therefore, it is more efficient to call STRPOSL with A a list of character codes.

If A is a bit table, it is used to specify the characters (see MAKEBITTABLE below)

If BACKWARDSFLG is non-NIL, the search is done backwards from the end of the string.

STRPOSL uses a "bit table" data structure to search efficiently. If A is not a bit table, it is converted to a bit table using MAKEBITTABLE. If STRPOSL is to be called frequently with the same list of characters, a considerable savings can be achieved by converting the list to a bit table once, and then passing the bit table to STRPOSL as its first argument.

(MAKEBITTABLE L NEG A) [Function]

Returns a bit table suitable for use by STRPOSL. L is a list of characters or character codes, NEG is the same as described for STRPOSL. If A is a bit table, MAKEBITTABLE modifies and returns it. Otherwise, it will create a new bit table.

Note: if NEG = T, STRPOSL must call MAKEBITTABLE whether A is a list or a bit table. To obtain bit table efficiency with NEG = T, MAKEBITTABLE should be called with NEG = T, and the resulting "inverted" bit table should be given to STRPOSL with NEG = NIL.
An array in Interlisp is an object representing a one-dimensional vector of objects. Arrays are generally created by the function \texttt{ARRAY}.

\textbf{Function} \texttt{ARRAY \ SIZE \ TYPE \ INIT \ ORIG \ →}

Creates and returns a new array capable of containing \texttt{SIZE} objects of type \texttt{TYPE}. If \texttt{TYPE} is \texttt{NIL}, the array can contain any arbitrary Lisp datum. In general, \texttt{TYPE} may be any of the various field specifications which are legal in DATATYPE declarations (see page 8.9): \texttt{POINTER}, \texttt{FIXP}, \texttt{FLOATP}, \texttt{(BITS N)}, etc. The implementation will, if necessary, choose an "enclosing" type if the given one is not supported; for example, an array of \texttt{(BITS 3)} may be represented by an array of \texttt{(BITS 8)}.

\texttt{INIT} is the initial value in each element of the new array. If not specified, the array elements will be initialized with 0 (for number arrays) or \texttt{NIL} (all other types).

Arrays can have either 0-origin or 1-origin indexing, as specified by the \texttt{ORIG} argument; if \texttt{ORIG} is not specified, the default is 1.

Note: Arrays of type \texttt{FLOATP} are stored unboxed. This increases the space and time efficiency of \texttt{FLOATP} arrays. Users who want to use boxed floating point numbers should use an array of type \texttt{POINTER} instead of \texttt{FLOATP}.

\textbf{Function} \texttt{ARRAYP X}

Returns \texttt{X} if \texttt{X} is an array, \texttt{NIL} otherwise.

Note: In some implementations of Interlisp (but not Interlisp-D), \texttt{ARRAYP} may also return \texttt{X} if it is of type \texttt{CCODEP} or \texttt{HARRAYP}.

\textbf{Function} \texttt{ELT ARRAY N}

Returns the \texttt{N}th element of the array \texttt{ARRAY}.

Generates the error \texttt{ARG NOT ARRAY} if \texttt{ARRAY} is not an array.

Generates the error \texttt{ILLEGAL ARG} if \texttt{N} is out of bounds.

\textbf{Function} \texttt{SETA ARRAY N V}

Sets the \texttt{N}th element of the array \texttt{ARRAY} to \texttt{VAL}, and returns \texttt{VAL}.

Generates the error \texttt{ARG NOT ARRAY} if \texttt{ARRAY} is not an array.

Generates the error \texttt{ILLEGAL ARG} if \texttt{N} is out of bounds. Can
generate the error **NON-NUMERIC ARG** if **ARRAY** is an array whose **ARRAYTYP** is **FIXP** or **FLOATP** and **VAL** is non-numeric.

(ARRAYTYP ARRAY) [Function]

Returns the type of the elements in the array **ARRAY**, a value corresponding to the second argument to **ARRAY**.

Note: If **ARRAY** coerced the array type as described above, **ARRAYTYP** will return the new type. For example, (ARRAYTYP (ARRAY 10 '(BITS 3))) will return **BYTE** in Interlisp-D, and **FIXP** in Interlisp-10.

(ARRAYSIZE ARRAY) [Function]

Returns the size of array **ARRAY**. Generates the error, **ARG NOT ARRAY**, if **ARRAY** is not an array.

(ARRAYORIG ARRAY) [Function]

Returns the origin of array **ARRAY**, which may be 0 or 1. Generates an error, **ARG NOT ARRAY**, if **ARRAY** is not an array.

(COPYARRAY ARRAY) [Function]

Returns a new array of the same size and type as **ARRAY**, and with the same contents as **ARRAY**. Generates an **ARG NOT ARRAY** error, if **ARRAY** is not an array.
6. Hash Arrays 6.1

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1. Hash Overflow</td>
<td>6.3</td>
</tr>
<tr>
<td>6.2. User-Specified Hashing Functions</td>
<td>6.4</td>
</tr>
</tbody>
</table>
Hash arrays provide a mechanism for associating arbitrary lisp objects ("hash keys") with other objects ("hash values"), such that the hash value associated with a particular hash key can be quickly obtained. A set of associations could be represented as a list or array of pairs, but these schemes are very inefficient when the number of associations is large. There are functions for creating hash arrays, putting a hash key/value pair in a hash array, and quickly retrieving the hash value associated with a given hash key.

By default, the hash array functions use EQ for comparing hash keys. This means that if non-atoms are used as hash keys, the exact same object (not a copy) must be used to retrieve the hash value. However, the user can override this default for any hash array by specifying the functions used to compare hash keys and to "hash" a hash key to a number. This can be used, for example, to create hash arrays where EQUAL but non-EQ strings will hash to the same value. Specifying alternative hashing algorithms is described below (page 6.4).

In the description of the functions below, the argument HARRAY should be a value of the function HASHARRAY, which is used to create hash arrays. For convenience in interactive program development, it may also be NIL, in which case a hash array provided by the system, SYSHASHARRAY, is used; the user must watch out for confusions if this form is used to associate more than one kind of value with the same key.

Note: For backwards compatibility, the hash array functions will accept a list whose CAR is a hash array, and whose CDR is the "overflow method" for the hash array (see below). However, hash array functions are guaranteed to perform with maximum efficiency only if a direct value of HASHARRAY is given.

(HASHARRAY MINKEYS OVERFLOW HASHBITSFN EQUIVFN) [Function]

Creates a hash array containing at least MINKEYS hash keys, with overflow method OVERFLOW. See discussion of overflow behavior below (page 6.3).

If HASHBITSFN and EQUIVFN are non-NIL, they specify the hashing function and comparison function used to interpret hash keys. This is described in the section on user-specified hashing functions below (page 6.4). If HASHBITSFN and
**Equivfn** are NIL, the default is to hash EQ hash keys to the same value.

**HARRAY Minkeys** [Function]

Provided for backward compatibility, this is equivalent to (HASHARRAY MINKEYS 'ERROR).

**HARRAYP X** [Function]

Returns X if it is a hash array object; otherwise NIL.

Note that **HARRAYP** returns NIL if X is a list whose CAR is an HARRAY, even though this is accepted by the hash array functions.

**HARRAYPROP HARRAY PROP NEWVALUE** [NoSpread Function]

Returns the property PROP of HARRAY; PROP can have the system-defined values SIZE (returns the maximum occupancy of HARRAY), NUMKEYS (number of occupied slots), OVERFLOW (overflow method), HASHBITSFN (hashing function) and EQUIVFN (comparison function). Except for SIZE and NUMKEYS, a new value may be specified as NEWVALUE.

By using other values for PROP, the user may also set and get arbitrary property values, to associate additional information with a hash array.

Note: The **HASHBITSFN** or **EQUIVFN** properties can only be changed if the hash array is empty.

**HARRAYSIZE HARRAY** [Function]

Equivalent to (HARRAYPROP HARRAY 'SIZE); returns the number of slots in HARRAY.

**CLRHASH HARRAY** [Function]

Clears all hash keys/values from HARRAY. Returns HARRAY.

**PUTHASH KEY VAL HARRAY** [Function]

 Associates the hash value VAL with the hash key KEY in HARRAY. Replaces the previous hash value, if any. If VAL is NIL, any old association is removed (hence a hash value of NIL is not allowed). If HARRAY is full when **PUTHASH** is called with a key not already in the hash array, the function **HASHOVERFLOW** is called, and the **PUTHASH** is applied to the value returned (see below). Returns VAL.

**GETHASH KEY HARRAY** [Function]

Returns the hash value associated with the hash key KEY in HARRAY. Returns NIL, if KEY is not found.
(REHASH OLDHARRAY NEWHARRAY)  
[Function]  
Hashes all hash keys and values in OLDHARRAY into NEWHARRAY. The two hash arrays do not have to be (and usually aren't) the same size. Returns NEWHARRAY.

(MAPHASH HARRAY MAPHFN)  
[Function]  
MAPHFN is a function of two arguments. For each hash key in HARRAY, MAPHFN will be applied to (1) the hash value, and (2) the hash key. For example,

[MAPHASH A  
(FUNCTION (LAMBDA (VAL KEY)  
(if (LISTP KEY) then (PRINT VAL)])  
will print the hash value for all hash keys that are lists. MAPHASH returns HARRAY.

(DMPHASH HARRAY_1 HARRAY_2 ... HARRAY_N)  
[NLambda NoSpread Function]  
Prints on the primary output file LOADable forms which will restore the hash-arrays contained as the values of the atoms HARRAY_1, HARRAY_2, ... HARRAY_N. Example: (DMPHASH SYSHASHARRAY) will dump the system hash-array.

Note: all EQ identities except atoms and small integers are lost by dumping and loading because READ will create new structure for each item. Thus if two lists contain an EQ substructure, when they are dumped and loaded back in, the corresponding substructures while EQUAL are no longer EQ. The HORRIBLEVARS file package command (page 17.36) provides a way of dumping hash tables such that these identities are preserved.

6.1 Hash Overflow

When a hash array becomes full, attempting to add another hash key will cause the function HASHOVERFLOW to be called. This will either automatically enlarge the hash array, or cause the error HASH TABLE FULL. How hash overflow is handled is determined by the value of the OVERFLOW property of the hash array (which can be accessed by HARRAYPROP). The possibilities for the overflow method are:

the litatom ERROR  
The error HASH ARRAY FULL is generated when the hash array overflows. This is the default overflow behavior for hash arrays returned by HARRAY.

NIL  
The array is automatically enlarged by 1.5. This is the default overflow behavior for hash arrays returned by HASHARRAY.
a positive integer $N$  
The array is enlarged to include $N$ more slots than it currently has.

a floating point number $F$  
The array is changed to include $F$ times the number of current slots.

a function or lambda expression $FN$  
Upon hash overflow, $FN$ is called with the hash array as its argument. If $FN$ returns a number, that will become the size of the array. Otherwise, the new size defaults to 1.5 times its previous size. $FN$ could be used to print a message, or perform some monitor function.

Note: For backwards compatibility, the hash array functions accept a list whose CAR is the hash array, and whose CDR is the overflow method. In this case, the overflow method specified in the list overrides the overflow method set in the hash array. Note that hash array functions are guaranteed to perform with maximum efficiency only if a direct value of HASHARRAY is given.

### 6.2 User-Specified Hashing Functions

In general terms, when a key is looked up in a hash array, it is converted to an integer, which is used to index into a linear array. If the key is not the same as the one found at that index, other indices are tried until the desired key is found. The value stored with that key is then returned (from GETHASH) or replaced (from PUTHASH).

The important features of this algorithm, for purposes of customizing hash arrays, are (1) the "hashing function" used to convert a key to an integer; and (2) the comparison function used to compare the key found in the array with the key being looked up. In order for hash arrays to work correctly, any two objects which are equal according to the comparison function must "hash" to equal integers.

By default, the Interlisp hash array functions use a hashing function that computes an integer from the internal address of a key, and use EQ for comparing keys. This means that if non-atoms are used as hash keys, the exact same object (not a copy) must be used to retrieve the hash value.

There are some applications for which the EQ constraint is too restrictive. For example, it may be useful to use strings as hash keys, without the restriction that EQUAL but not EQ strings are considered to be different hash keys.

The user can override this default behavior for any hash array by specifying the functions used to compare keys and to "hash" a
key to a number. This can be done by giving the HASHBITSFN and EQUIVFN arguments to HASHARRAY (page 6.1).

The EQUIVFN argument is a function of two arguments that returns non-NIL when its arguments are considered equal. The HASHBITSFN argument is a function of one argument that produces a positive small integer (in the range \([0..2^{16}-1]\)) with the property that objects that are considered equal by the EQUIVFN produce the same hash bits.

For an existing hash array, the function HARRAYPROP (page 6.2) can be used to examine the hashing and equivalence functions as the HASHBITSFN and EQUIVFN hash array properties. These properties are read-only for non-empty hash arrays, as it makes no sense to change the equivalence relationship once some keys have been hashed.

The following function is useful for creating hash arrays that take strings as hash keys:

\[
\text{(STRINGHASHBITS STRING)}
\]

[Function]

Hashes the string STRING into an integer that can be used as a HASHBITSFN for a hash array. Strings which are STREQUAL hash to the same integer.

Example:

\[
\text{(HASHARRAY MINKEYS OVERFLOW 'STRINGHASHBITS 'STREQUAL)}
\]

creates a hash array where you can use strings as hash keys.
# 7. Numbers and Arithmetic Functions

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1. Generic Arithmetic</td>
<td>7.3</td>
</tr>
<tr>
<td>7.2. Integer Arithmetic</td>
<td>7.4</td>
</tr>
<tr>
<td>7.3. Logical Arithmetic Functions</td>
<td>7.8</td>
</tr>
<tr>
<td>7.4. Floating Point Arithmetic</td>
<td>7.11</td>
</tr>
<tr>
<td>7.5. Other Arithmetic Functions</td>
<td>7.13</td>
</tr>
</tbody>
</table>
[This page intentionally left blank]
Numerical atoms, or simply numbers, do not have value cells, function definition cells, property lists, or explicit print names. There are four different types of numbers in Interlisp: small integers, large integers, bignums (arbitrary-size integers), and floating point numbers. Small integers are those integers that can be directly stored within a pointer value (implementation-dependent). Large integers and floating point numbers are full-word quantities that are stored by "boxing" the number (see below). Bignums are "boxed" as a series of words.

Large integers and floating point numbers can be any full word quantity. In order to distinguish between those full word quantities that represent large integers or floating point numbers, and other Interlisp pointers, these numbers are "boxed": When a large integer or floating point number is created (via an arithmetic operation or by READ), Interlisp gets a new word from "number storage" and puts the large integer or floating point number into that word. Interlisp then passes around the pointer to that word, i.e., the "boxed number", rather than the actual quantity itself. Then when a numeric function needs the actual numeric quantity, it performs the extra level of addressing to obtain the "value" of the number. This latter process is called "unboxing". Note that unboxing does not use any storage, but that each boxing operation uses one new word of number storage. Thus, if a computation creates many large integers or floating point numbers, i.e., does lots of boxes, it may cause a garbage collection of large integer space, or of floating point number space.

Note: Different implementations of Interlisp may use different boxing strategies. Thus, while lots of arithmetic operations may lead to garbage collections, this is not necessarily always the case.

The following functions can be used to distinguish the different types of numbers:

\begin{function}
SMALLP X \end{function}

\begin{description}
\item[Returns] X, if X is a small integer; NIL otherwise. Does not generate an error if X is not a number.
\end{description}
### NUMBERS AND ARITHMETIC FUNCTIONS

<table>
<thead>
<tr>
<th>(FIXP X)</th>
<th>[Function]</th>
<th>Returns X, if X is an integer; NIL otherwise. Note that FIXP is true for small integers, large integers, and bignums. Does not generate an error if X is not a number.</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>(FLOATP X)</th>
<th>[Function]</th>
<th>Returns X if X is a floating point number; NIL otherwise. Does not give an error if X is not a number.</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>(NUMBERP X)</th>
<th>[Function]</th>
<th>Returns X, if X is a number of any type (FIXP or FLOATP); NIL otherwise. Does not generate an error if X is not a number. Note that if (NUMBERP X) is true, then either (FIXP X) or (FLOATP X) is true.</th>
</tr>
</thead>
</table>

Each small integer has a unique representation, so EQ may be used to check equality. Note that EQ should not be used for large integers, bignums, or floating point numbers, EQP, IEQP, or EQUAL must be used instead.

<table>
<thead>
<tr>
<th>(EQP X Y)</th>
<th>[Function]</th>
<th>Returns T, if X and Y are EQ, or equal numbers; NIL otherwise. Note that EQ may be used if X and Y are known to be small integers. EQP does not convert X and Y to integers, e.g., (EQP 2000 2000.3) =&gt; NIL, but it can be used to compare an integer and a floating point number, e.g., (EQP 2000 2000.0) =&gt; T. EQP does not generate an error if X or Y are not numbers.</th>
</tr>
</thead>
</table>

Note: EQP can also be used to compare stack pointers (page 11.4) and compiled code objects (page 10.10).

The action taken on division by zero and floating point overflow is determined with the following function:

<table>
<thead>
<tr>
<th>(OVERFLOW FLG)</th>
<th>[Function]</th>
<th>Sets a flag that determines the system response to arithmetic overflow (for floating point arithmetic) and division by zero; returns the previous setting. For integer arithmetic: If FLG = T, an error occurs on division by zero. If FLG = NIL or 0, integer division by zero returns zero. Integer overflow cannot occur, because small integers are converted to bignums (page 7.1). For floating point arithmetic: If FLG = T, an error occurs on floating overflow or floating division by zero. If FLG = NIL or 0, the largest (or smallest) floating point number is returned as the</th>
</tr>
</thead>
</table>
7.1 Generic Arithmetic

The functions in this section are "generic" arithmetic functions. If any of the arguments are floating point numbers (page 7.11), they act exactly like floating point functions, and float all arguments, and return a floating point number as their value. Otherwise, they act like the integer functions (page 7.4). If given a non-numeric argument, they generate an error, NON-NUMERIC ARG.

(PLUS X₁ X₂ ... Xₕ)  [NoSpread Function]
\[ X₁ + X₂ + \ldots + Xₕ \]

(MINUS X)  [Function]
\[ -X \]

DIFFERENCE X Y  [Function]
\[ X - Y \]

(TIMES X₁ X₂ ... Xₕ)  [NoSpread Function]
\[ X₁ \times X₂ \times \ldots \times Xₕ \]

(QUOTIENT X Y)  [Function]
If X and Y are both integers, returns the integer division of X and Y. Otherwise, converts both X and Y to floating point numbers, and does a floating point division.

The results of division by zero and floating point overflow is determined by the function OVERFLOW (page 7.2).

(REMAINDER X Y)  [Function]
If X and Y are both integers, returns (IREMAINDER X Y), otherwise (FREMAINDER X Y).

(GREATERP X Y)  [Function]
\[ T, \text{ if } X > Y, \text{ NIL otherwise.} \]
### GENERIC ARITHMETIC

- **(LESSP X Y)**: [Function] \(T\) if \(X < Y\), \(NIL\) otherwise.

- **(GEQ X Y)**: [Function] \(T\), if \(X \geq Y\), \(NIL\) otherwise.

- **(LEQ X Y)**: [Function] \(T\), if \(X \leq Y\), \(NIL\) otherwise.

- **(ZEROP X)**: [Function] (EQP X 0).

- **(MINUSP X)**: [Function] \(T\), if \(X\) is negative; \(NIL\) otherwise. Works for both integers and floating point numbers.

- **(MIN X_1 X_2 ... X_N)**: [NoSpread Function] Returns the minimum of \(X_1, X_2, ..., X_N\). (MIN) returns the value of MAX.INTEGER (page 7.5).

- **(MAX X_1 X_2 ... X_N)**: [NoSpread Function] Returns the maximum of \(X_1, X_2, ..., X_N\). (MAX) returns the value of MIN.INTEGER (page 7.5).

- **(ABS X)**: [Function] \(X\) if \(X > 0\), otherwise \(-X\). ABS uses GREATERP and MINUS (not IGREATERP and IMINUS).

### 7.2 Integer Arithmetic

The input syntax for an integer is an optional sign (+ or -) followed by a sequence of decimal digits, and terminated by a delimiting character. Integers entered with this syntax are interpreted as decimal integers. Integers in other radices can be entered as follows:

- \(123Q\) If an integer is followed by the letter \(Q\), or proceed by a vertical bar and the letter "o", the digits are interpreted an octal (base 8) integer.

- \(|b10101\) If an integer is proceed by a vertical bar and the letter "b", the digits are interpreted as a binary (base 2) integer.
If an integer is proceeded by a vertical bar and the letter "x", the digits are interpreted as a hexadecimal (base 16) integer. The upper-case letters A through F are used as the digits after 9.

If an integer is proceeded by a vertical bar, a positive decimal integer BASE, and the letter "r", the digits are interpreted as an integer in the base BASE. For example, |8r123 = 123Q, and |16r12A3 = |x12A3. When inputting a number in a radix above ten, the upper-case letters A through Z can be used as the digits after 9 (but there is no digit above Z, so it is not possible to type all base-99 digits).

Note that 77Q and 63 both correspond to the same integers, and in fact are indistinguishable internally since no record is kept of the syntax used to create an integer. The function RADIX (page 25.13), sets the radix used to print integers.

Integers are created by PACK and MKATOM when given a sequence of characters observing the above syntax, e.g. \texttt{(PACK '(1 2 Q))} = 10. Integers are also created as a result of arithmetic operations.

The range of integers of various types is implementation-dependent. This information is accessible to the user through the following variables:

- **MIN.SMALLP** [Variable]  
  The smallest possible small integer.

- **MAX.SMALLP** [Variable]  
  The largest possible small integer.

- **MIN.FIXP** [Variable]  
  The smallest possible large integer.

- **MAX.FIXP** [Variable]  
  The largest possible large integer.

- **MIN.INTEGER** [Variable]  
  The smallest possible integers. For some algorithms, it is useful to have an integer that is larger than any other integer. Therefore, the values of \texttt{MAX.INTEGER} and \texttt{MIN.INTEGER} are two special bignums; the value of \texttt{MAX.INTEGER} is \texttt{GREATERP} than any other integer, and the value of \texttt{MIN.INTEGER} is \texttt{LESSP} than any other integer. Trying to do arithmetic using these special bignums, other than comparison, will cause an error.

All of the functions described below work on integers. Unless specified otherwise, if given a floating point number, they first
convert the number to an integer by truncating the fractional bits, e.g., `(IPLUS 2.3 3.8) = 5`; if given a non-numeric argument, they generate an error, `NON-NUMERIC ARG`.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>(IPLUS X1 X2 ... XN)</code></td>
<td>[NoSpread Function] Returns the sum $X_1 + X_2 + ... + X_N$. <code>(IPLUS) = 0.</code></td>
</tr>
<tr>
<td><code>(IMINUS X)</code></td>
<td>[Function] $-X$</td>
</tr>
<tr>
<td><code>(IDIFFERENCE X Y)</code></td>
<td>[Function] $X - Y$</td>
</tr>
<tr>
<td><code>(ADD1 X)</code></td>
<td>[Function] $X + 1$</td>
</tr>
<tr>
<td><code>(SUB1 X)</code></td>
<td>[Function] $X - 1$</td>
</tr>
<tr>
<td><code>(ITIMES X1 X2 ... XN)</code></td>
<td>[NoSpread Function] Returns the product $X_1 * X_2 * ... * X_N$. <code>(ITIMES) = 1.</code></td>
</tr>
<tr>
<td><code>(IQUOTIENT X Y)</code></td>
<td>[Function] $X / Y$ truncated. Examples:</td>
</tr>
<tr>
<td></td>
<td><code>(IQUOTIENT 3 2) = &gt; 1</code></td>
</tr>
<tr>
<td></td>
<td><code>(IQUOTIENT -3 2) = &gt; -1</code></td>
</tr>
<tr>
<td></td>
<td>If $Y$ is zero, the result is determined by the function <code>OVERFLOW</code> (page 7.2).</td>
</tr>
<tr>
<td><code>(IREMAINDER X Y)</code></td>
<td>[Function] Returns the remainder when $X$ is divided by $Y$. Example:</td>
</tr>
<tr>
<td></td>
<td><code>(IREMAINDER 3 2) = &gt; 1</code></td>
</tr>
<tr>
<td><code>(IMOD X N)</code></td>
<td>[Function] Computes the integer modulus; this differs from <code>IREMAINDER</code> in that the result is always a non-negative integer in the range $[0,N)$.</td>
</tr>
<tr>
<td><code>(IGREATERP X Y)</code></td>
<td>[Function] $T$, if $X &gt; Y$; $NIL$ otherwise.</td>
</tr>
</tbody>
</table>
(ILESSP X Y) [Function]
\[ T, \text{if} \ X < \ Y; \text{NIL otherwise.} \]

(IGEQ X Y) [Function]
\[ T, \text{if} \ X \geq \ Y; \text{NIL otherwise.} \]

(ILEQ X Y) [Function]
\[ T, \text{if} \ X \leq \ Y; \text{NIL otherwise.} \]

(IMIN X₁ X₂ ... Xₙ) [NoSpread Function]
Returns the minimum of \( X₁, X₂, ..., Xₙ \). (IMIN) returns the largest possible large integer, the value of MAX.INTEGER.

(IMAX X₁ X₂ ... Xₙ) [NoSpread Function]
Returns the maximum of \( X₁, X₂, ..., Xₙ \). (IMAX) returns the smallest possible large integer, the value of MIN.INTEGER.

(IEQP X Y) [Function]
Returns \( T \) if \( X \) and \( Y \) are EQ or equal integers; \text{NIL otherwise.} Note that EQ may be used if \( X \) and \( Y \) are known to be small integers. IEQP converts \( X \) and \( Y \) to integers, e.g., \((IEQP 2000 2000.3) \Rightarrow T\). Causes NON-NUMERIC ARG error if either \( X \) or \( Y \) are not numbers.

(FIX N) [Function]
If \( N \) is an integer, returns \( N \). Otherwise, converts \( N \) to an integer by truncating fractional bits. For example, \((FIX 2.3) = 2\), \((FIX -1.7) = -1\).

Note: Since FIX is also a programmer's assistant command (page 13.12), typing FIX directly to Interlisp will not cause the function FIX to be called.

(FIXR N) [Function]
If \( N \) is an integer, returns \( N \). Otherwise, converts \( N \) to an integer by rounding. For example, \((FIXR 2.3) = 2\), \((FIXR -1.7) = -2\), \((FIXR 3.5) = 4\).

(GCD N₁ N₂) [Function]
Returns the greatest common divisor of \( N₁ \) and \( N₂ \), e.g., \((GCD 72 64) = 8\).
### 7.3 Logical Arithmetic Functions

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>(LOGAND X₁ X₂ ... Xₙ)</strong></td>
<td>[NoSpread Function] Returns the logical AND of all its arguments, as an integer. Example: <em>(LOGAND 7 5 6) = &gt; 4</em></td>
</tr>
<tr>
<td><strong>(LOGOR X₁ X₂ ... Xₙ)</strong></td>
<td>[NoSpread Function] Returns the logical OR of all its arguments, as an integer. Example: <em>(LOGOR 1 3 9) = &gt; 11</em></td>
</tr>
<tr>
<td><strong>(LOGXOR X₁ X₂ ... Xₙ)</strong></td>
<td>[NoSpread Function] Returns the logical exclusive OR of its arguments, as an integer. Example: <em>(LOGXOR 11 5) = &gt; 14</em> <em>(LOGXOR 11 5 9) = (LOGXOR 14 9) = &gt; 7</em></td>
</tr>
<tr>
<td><strong>(LSH X N)</strong></td>
<td>(arithmetic) &quot;Left Shift.&quot; Returns X shifted left N places, with the sign bit unaffected. X can be positive or negative. If N is negative, X is shifted right -N places.</td>
</tr>
<tr>
<td><strong>(RSH X N)</strong></td>
<td>(arithmetic) &quot;Right Shift.&quot; Returns X shifted right N places, with the sign bit unaffected, and copies of the sign bit shifted into the leftmost bit. X can be positive or negative. If N is negative, X is shifted left -N places. Warning: Be careful if using RSH to simulate division; RSHing a negative number is not generally equivalent to dividing by a power of two.</td>
</tr>
<tr>
<td><strong>(LLSH X N)</strong></td>
<td></td>
</tr>
<tr>
<td><strong>(LRSH X N)</strong></td>
<td>&quot;Logical Left Shift&quot; and &quot;Logical Right Shift&quot;. The difference between a logical and arithmetic right shift lies in the treatment of the sign bit. Logical shifting treats it just like any other bit; arithmetic shifting will not change it, and will &quot;propagate&quot; rightward when actually shifting rightwards. Note that shifting (arithmetic) a negative number &quot;all the way&quot; to the right yields -1, not 0.</td>
</tr>
</tbody>
</table>
Note: LLSH and LRSH are currently implemented using mod-2 \( \uparrow \) 32 arithmetic. Passing a bignum to either of these will cause an error. LRSH of negative numbers will shift in 0s in the high bits.

(INTEGERLENGTH X)  [Function]
Returns the number of bits needed to represent \( X \) (coerced to an integer). This is equivalent to: \( 1 + \text{floor}\left[\log_2|X|\right] \).
(INTEGERLENGTH 0) = 0.

(PowerOfTwo X)  [Function]
Returns non-NIL if \( X \) (coerced to an integer) is a power of two.

(EVENP X Y)  [NoSpread Function]
If \( Y \) is not given, equivalent to (ZEROP (IMOD X 2)); otherwise equivalent to (ZEROP (IMOD X Y)).

(ODDP N MODULUS)  [NoSpread Function]
Equivalent to (NOT (EVENP N MODULUS)). MODULUS defaults to 2.

(LOGNOT N)  [Macro]
Logical negation of the bits in \( N \). Equivalent to (LOGXOR N -1)

(BITTEST N MASK)  [Macro]
Returns T if any of the bits in \( MASK \) are on in the number \( N \). Equivalent to (NOT (ZEROP (LOGAND N MASK)))

(BITCLEAR N MASK)  [Macro]
Turns off bits from \( MASK \) in \( N \). Equivalent to (LOGAND N (LOGNOT MASK))

(BITSET N MASK)  [Macro]
Turns on the bits from \( MASK \) in \( N \). Equivalent to (LOGOR N MASK)

(MASK.1'S POSITION SIZE)  [Macro]
Returns a bit-mask with \( SIZE \) one-bits starting with the bit at \( POSITION \). Equivalent to (LLSH (SUB1 (EXPT 2 SIZE)) POSITION)

(MASK.0'S POSITION SIZE)  [Macro]
Returns a bit-mask with all one bits, except for \( SIZE \) bits starting at \( POSITION \). Equivalent to (LOGNOT (MASK.1'S POSITION SIZE))
(LOADBYTE N POS SIZE) [Function]
Extracts SIZE bits from N, starting at position POS. Equivalent to
(LOGAND (RSH N POS) (MASK.1'S 0 SIZE))

(DEPOSITBYTE N POS SIZE VAL) [Function]
Insert SIZE bits of VAL at position POS into N, returning the result. Equivalent to
(LOGOR (BITCLEAR N (MASK.1'S POS SIZE))
   (LSH (LOGAND VAL (MASK.1'S 0 SIZE))
      POS))

(ROT X N FIELDSIZE) [Function]
"Rotate bits in field". It performs a bitwise left-rotation of the integer X, by N places, within a field of FIELDSIZE bits wide. Bits being shifted out of the position selected by (EXPT 2 (SUB1 FIELDSIZE)) will flow into the "units" position.

The notions of position and size can be combined to make up a "byte specifier", which is constructed by the macro BYTE [note reversal of arguments as compare with above functions]:

(BYTE SIZE POSITION) [Macro]
Constructs and returns a "byte specifier" containing SIZE and POSITION.

(BYTESIZE BYTESPEC) [Macro]
Returns the SIZE component of the "byte specifier" BYTESPEC.

(BYTEPOSITION BYTESPEC) [Macro]
Returns the POSITION component of the "byte specifier" BYTESPEC.

(LDB BYTESPEC VAL) [Macro]
Equivalent to
(LOADBYTE VAL
   (BYTEPOSITION BYTESPEC)
   (BYTESIZE BYTESPEC))

(DPB N BYTESPEC VAL) [Macro]
Equivalent to
(DEPOSITBYTE VAL
   (BYTEPOSITION BYTESPEC)
   (BYTESIZE BYTESPEC)
   N)
7.4 Floating Point Arithmetic

A floating point number is input as a signed integer, followed by a decimal point, followed by another sequence of digits called the fraction, followed by an exponent (represented by E followed by a signed integer) and terminated by a delimiter.

Both signs are optional, and either the fraction following the decimal point, or the integer preceding the decimal point may be omitted. One or the other of the decimal point or exponent may also be omitted, but at least one of them must be present to distinguish a floating point number from an integer. For example, the following will be recognized as floating point numbers:

- 5. 5.00 5.01 .3
- 5E2 5.1E2 5E-3 -5.2E + 6

Floating point numbers are printed using the format control specified by the function FLTFMT (page 25.13). FLTFMT is initialized to T, or free format. For example, the above floating point numbers would be printed free format as:

- 5.0 5.0 5.01 .3
- 500.0 510.0 .005 -5.2E6

Floating point numbers are created by the read program when a "." or an E appears in a number, e.g., 1000 is an integer, 1000. a floating point number, as are 1E3 and 1.E3. Note that 1000D, 1000F, and 1E3D are perfectly legal literal atoms. Floating point numbers are also created by PACK and MKATOM, and as a result of arithmetic operations.

PRINTNUM (page 25.15) permits greater controls on the printed appearance of floating point numbers, allowing such things as left-justification, suppression of trailing decimals, etc.

The floating point number range is stored in the following variables:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIN.FLOAT</td>
<td>The smallest possible floating point number.</td>
</tr>
<tr>
<td>MAX.FLOAT</td>
<td>The largest possible floating point number.</td>
</tr>
</tbody>
</table>

All of the functions described below work on floating point numbers. Unless specified otherwise, if given an integer, they first convert the number to a floating point number, e.g., (FPLUS 1 2.3) < > (FPLUS 1.0 2.3) = > 3.3; if given a non-numeric argument, they generate an error, NON-NUMERIC ARG.
<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(FPLUS X₁ X₂ ... Xₙ)</td>
<td>[NoSpread Function] $X₁ + X₂ + ... + Xₙ$</td>
</tr>
<tr>
<td>(FMINUS X)</td>
<td>[Function] $-X$</td>
</tr>
<tr>
<td>(FDIFFERENCE X Y)</td>
<td>[Function] $X - Y$</td>
</tr>
<tr>
<td>(FTIMES X₁ X₂ ... Xₙ)</td>
<td>[NoSpread Function] $X₁ * X₂ * ... * Xₙ$</td>
</tr>
<tr>
<td>(FQUOTIENT X Y)</td>
<td>[Function] $X / Y$. The results of division by zero and floating point overflow is determined by the function OVERFLOW (page 7.2).</td>
</tr>
<tr>
<td>(FREMAINDER X Y)</td>
<td>[Function] Returns the remainder when $X$ is divided by $Y$. Equivalent to: (FDIFFERENCE X (FTIMES Y (FIX (FQUOTIENT X Y)))) Example: (FREMAINDER 7.5 2.3) = 0.6</td>
</tr>
<tr>
<td>(FGREATERP X Y)</td>
<td>[Function] T, if $X &gt; Y$, NIL otherwise.</td>
</tr>
<tr>
<td>(FLESSEP X Y)</td>
<td>[Function] T, if $X &lt; Y$, NIL otherwise.</td>
</tr>
<tr>
<td>(FEQP X Y)</td>
<td>[Function] Returns T if $N$ and $M$ are equal floating point numbers; NIL otherwise. FEQP converts $N$ and $M$ to floating point numbers. Causes NON-NUMERIC ARG error if either $N$ or $M$ are not numbers.</td>
</tr>
<tr>
<td>(FMIN X₁ X₂ ... Xₙ)</td>
<td>[NoSpread Function] Returns the minimum of $X₁, X₂, ..., Xₙ$. (FMIN) returns the largest possible floating point number, the value of MAX.FLOT.</td>
</tr>
</tbody>
</table>
(FMAX $X_1, X_2, \ldots, X_N$) [NoSpread Function]

Returns the maximum of $X_1, X_2, \ldots, X_N$. (FMAX) returns the smallest possible floating point number, the value of MIN.FLOT.

(FLOAT $X$) [Function]

Converts $X$ to a floating point number. Example:

(FLOAT 0) => 0.0

7.5 Other Arithmetic Functions

(EXPT $A \ N$) [Function]

Returns $A \uparrow N$. If $A$ is an integer and $N$ is a positive integer, returns an integer, e.g., (EXPT 3 4) => 81, otherwise returns a floating point number. If $A$ is negative and $N$ fractional, an error is generated, ILLEGAL EXPONENTIATION. If $N$ is floating and either too large or too small, an error is generated, VALUE OUT OF RANGE EXPT.

(SQRT $N$) [Function]

Returns the square root of $N$ as a floating point number. $N$ may be fixed or floating point. Generates an error if $N$ is negative.

(LOG $X$) [Function]

Returns the natural logarithm of $X$ as a floating point number. $X$ can be integer or floating point.

(ANTILOG $X$) [Function]

Returns the floating point number whose logarithm is $X$. $X$ can be integer or floating point. Example:

(ANTILOG 1) = $e$ => 2.71828...

(SIN $X$ RADIANSFLG) [Function]

Returns the sine of $X$ as a floating point number. $X$ is in degrees unless RADIANSFLG = T.

(COS $X$ RADIANSFLG) [Function]

Similar to SIN.

(TAN $X$ RADIANSFLG) [Function]

Similar to SIN.
other arithmetic functions

(ARCSIN X RADIANSFLG) [Function]
X is a number between -1 and 1 (or an error is generated). The value of ARCSIN is a floating point number, and is in degrees unless RADIANSFLG = T. In other words, if (ARCSIN X RADIANSFLG) = Z then (SIN Z RADIANSFLG) = X. The range of the value of ARCSIN is -90 to +90 for degrees, -PI/2 to PI/2 for radians.

(ARCCOS X RADIANSFLG) [Function]
Similar to ARCSIN. Range is 0 to 180, 0 to "PI".

(ARCTAN X RADIANSFLG) [Function]
Similar to ARCSIN. Range is 0 to 180, 0 to "PI".

(ARCTAN2 Y X RADIANSFLG) [Function]
Computes (ARCTAN (FQUOTIENT Y X) RADIANSFLG), and returns a corresponding value in the range -180 to 180 (or -"PI" to "PI"), i.e. the result is in the proper quadrant as determined by the signs of X and Y.

(RAND LOWER UPPER) [Function]
Returns a pseudo-random number between LOWER and UPPER inclusive, i.e., RAND can be used to generate a sequence of random numbers. If both limits are integers, the value of RAND is an integer, otherwise it is a floating point number. The algorithm is completely deterministic, i.e. given the same initial state, RAND produces the same sequence of values. The internal state of RAND is initialized using the function RANDSET described below.

(RANDSET X) [Function]
Returns the internal state of RAND. If X = NIL, just returns the current state. If X = T, RAND is initialized using the clocks, and RANDSET returns the new state. Otherwise, X is interpreted as a previous internal state, i.e., a value of RANDSET, and is used to reset RAND. For example,

← (SETQ OLDSTATE (RANDSET))
...
← (for X from 1 to 10 do (PRIN1 (RAND 1 10)))
2847592748NIL
← (RANDSET OLDSTATE)
...
← (for X from 1 to 10 do (PRIN1 (RAND 1 10)))
2847592748NIL

numbers and arithmetic functions
8. Record Package

8.1. FETCH and REPLACE

8.2. CREATE

8.3. TYPE?

8.4. WITH

8.5. Record Declarations

8.5.1. Record Types

8.5.2. Optional Record Specifications

8.6. Defining New Record Types

8.7. Record Manipulation Functions

8.8. Changetran

8.9. Built-In and User Data Types
[This page intentionally left blank]
The advantages of "data abstraction" have long been known: more readable code, fewer bugs, the ability to change the data structure without having to make major modifications to the program, etc. The record package encourages and facilitates this good programming practice by providing a uniform syntax for creating, accessing and storing data into many different types of data structures (arrays, list structures, association lists, etc.) as well as removing from the user the task of writing the various manipulation routines. The user declares (once) the data structures used by his programs, and thereafter indicates the manipulations of the data in a data-structure-independent manner. Using the declarations, the record package automatically computes the corresponding Interlisp expressions necessary to accomplish the indicated access/storage operations. If the data structure is changed by modifying the declarations, the programs automatically adjust to the new conventions.

The user describes the format of a data structure (record) by making a "record declaration" (see page 8.6). The record declaration is a description of the record, associating names with its various parts, or "fields". For example, the record declaration (RECORD MSG (FROM TO . TEXT)) describes a data structure called MSG, which contains three fields: FROM, TO, and TEXT. The user can reference these fields by name, to retrieve their values or to store new values into them, by using the FETCH and REPLACE operators (page 8.2). The CREATE operator (page 8.3) is used for creating new instances of a record, and TYPE? (page 8.5) is used for testing whether an object is an instance of a particular record. (note: all record operators can be in either upper or lower case.)

Records may be implemented in a variety of different ways, as determined by the first element ("record type") of the record declaration. RECORD (used to specify elements and tails of a list structure) is just one of several record types currently implemented. The user can specify a property list format by using the record type PROPRECORD, or that fields are to be associated with parts of a data structure via a specified hash array by using the record type HASHLINK, or that an entirely new data type be allocated (as described on page 8.20) by using the record-type DATATYPE.

The record package is implemented through the DWIM/CLISP facilities, so it contains features such as spelling correction on
field names, record types, etc. Record operations are translated using all CLiSP declarations in effect (standard/fast/undoable); it is also possible to declare local record declarations that override global ones (see page 21.12).

The file package includes a RECORDS file package command for dumping record declarations (page 17.38), and FILES? and CLEANUP will inform the user about records that need to be dumped.

### 8.1 FETCH and REPLACE

The fields of a record are accessed and changed with the FETCH and REPLACE operators. If the record MSG has the record declaration (RECORD MSG (FROM TO . TEXT)), and X is a MSG data structure, (fetch FROM of X) will return the value of the FROM field of X, and (replace FROM of X with Y) will replace this field with the value of Y. In general, the value of a REPLACE operation is the same as the value stored into the field.

Note that the form (fetch FROM of X) implicitly states that X is an instance of the record MSG, or at least it should be treated as such for this particular operation. In other words, the interpretation of (fetch FROM of X) never depends on the value of X. Therefore, if X is not a MSG record, this may produce incorrect results. The TYPE? record operation (page 8.5) may be used to test the types of objects.

If there is another record declaration, (RECORD REPLY (TEXT . RESPONSE)), then (fetch TEXT of X) is ambiguous, because X could be either a MSG or a REPLY record. In this case, an error will occur, AMBIGUOUS RECORD FIELD. To clarify this, FETCH and REPLACE can take a list for their "field" argument: (fetch (MSG TEXT) of X) will fetch the TEXT field of an MSG record.

Note that if a field has an identical interpretation in two declarations, e.g. if the field TEXT occurred in the same location within the declarations of MSG and REPLY, then (fetch TEXT of X) would not be considered ambiguous.

An exception to this rule is that "user" record declarations take precedence over "system" record declarations, in cases where an unqualified field name would be considered ambiguous. System records are declared by including (SYSTEM) in the record declaration (see page 8.15). All of the records defined in the standard Interlisp-D system are defined as system records.

Another complication can occur if the fields of a record are themselves records. The fields of a record can be further broken down into sub-fields by a "subdeclaration" within the record declaration (see page 8.14). For example,
permits the user to access the POSITION field with (fetch POSITION of X), or its subfield XLOC with (fetch XLOC of X).

The user may also elaborate a field by declaring that field name in a separate record declaration (as opposed to an embedded subdeclaration). For instance, the TEXT field in the MSG and REPLY records above may be subdivided with the separate record declaration (RECORD TEXT (HEADER . TXT)). Fields of subfields (to any level of nested subfields) are accessed by specifying the "data path" as a list of record/field names, where there is some path from each record to the next in the list. For instance, (fetch (MSG TEXT HEADER) of X) indicates that X is to be treated as a MSG record, its TEXT field should be accessed, and its HEADER field should be accessed. Only as much of the data path as is necessary to disambiguate it needs to be specified. In this case, (fetch (MSG HEADER) of X) is sufficient. The record package interprets a data path by performing a tree search among all current record declarations for a path from each name to the next, considering first local declarations (page 21.13) and then global ones. The central point of separate declarations is that the (sub)record is not tied to another record (as with embedded declarations), and therefore can be used in many different contexts. If a data-path rather than a single field is ambiguous, (e.g., if there were yet another declaration (RECORD TO (NAME . HEADER)) and the user specified (fetch (MSG HEADER) of X)), the error AMBIGUOUS DATA PATH is generated.

FETCH and REPLACE forms are translated using the CLISP declarations in effect (see page 21.12). FFETCH and FREPLACE are versions which insure fast CLISP declarations will be in effect, /REPLACE insures undoable declarations.

8.2 CREATE

Record operations can be applied to arbitrary structures, i.e., the user can explicitly creating a data structure (using CONS, etc), and then manipulate it with FETCH and REPLACE. However, to be consistent with the idea of data abstraction, new data should be created using the same declarations that define its data paths. This can be done with an expression of the form:

(create RECORD-NAME . ASSIGNMENTS)

A CREATE expression translates into an appropriate Interlisp form using CONS, LIST, PUTHASH, ARRAY, etc., that creates the new datum with the various fields initialized to the appropriate
values. ASSIGNMENTS is optional and may contain expressions of the following form:

- **FIELD-NAME ← FORM**: Specifies initial value for FIELD-NAME.
- **USING FORM**: Specifies that for all fields not explicitly given a value, the value of the corresponding field in FORM is to be used.
- **COPYING FORM**: Similar to USING except the corresponding values are copied (with COPYALL).
- **REUSING FORM**: Similar to USING, except that wherever possible, the corresponding structure in FORM is used.
- **SMASHING FORM**: A new instance of the record is not created at all; rather, the value of FORM is used and smashed.

The record package goes to great pains to insure that the order of evaluation in the translation is the same as that given in the original CREATE expression if the side effects of one expression might affect the evaluation of another. For example, given the declaration (RECORD CONS (CAR, CDR)), the expression (create CONS CDR→X CAR→Y) will translate to (CONS Y X), but (create CONS CDR→(FOO) CAR→(FIE)) will translate to ((LAMBDA ($$1) (CONS (PROGN (SETQ $$1 (FOO)) (FIE)) $$1))) because FOO might set some variables used by FIE.

Note that (create RECORD REUSING FORM ...) does not itself do any destructive operations on the value of FORM. The distinction between USING and REUSING is that (create RECORD reusing FORM ...) will incorporate as much as possible of the old data structure into the new one being created, while (create RECORD using FORM ...) will create a completely new data structure, with only the contents of the fields re-used. For example, REUSING a PROPRECORD just CONSes the new property names and values onto the list, while USING copies the top level of the list. Another example of this distinction occurs when a field is elaborated by a subdeclaration (page 8.14): USING will create a new instance of the sub-record, while REUSING will use the old contents of the field (unless some field of the subdeclaration is assigned in the CREATE expression.)

If the value of a field is neither explicitly specified, nor implicitly specified via USING, COPYING or REUSING, the default value in the declaration is used, if any, otherwise NIL. (Note: For BETWEEN fields in DATATYPE records, N1 is used; for other non-pointer fields zero is used.) For example, following (RECORD A (B C D) D ← 3),

- (create A B←T) = = > (LIST T NIL 3)
- (create A B←T using X) = = > (LIST T (CADR X) (CADDR X))
- (create A B←T copying X)
(create A B~T reusing X)
[CONS T (CDR X)]

8.3 TYPE?

The record package allows the user to test if a given datum "looks like" an instance of a record. This can be done via an expression of the form

(type? RECORD-NAME FORM)

TYPE? is mainly intended for records with a record type of DATATYPE or TYPERECORD. For DATATYPES, the TYPE? check is exact; i.e. the TYPE? expression will return non-NIL only if the value of FORM is an instance of the record named by RECORD-NAME. For TYPERECORDs, the TYPE? expression will check that the value of FORM is a list beginning with RECORD-NAME. For ARRAYRECORDs, it checks that the value is an array of the correct size. For PROPRECORDs and ASSOCRECORDs, a TYPE? expression will make sure that the value of FORM is a property/association list with property names among the field-names of the declaration.

There is no built-in type test for records of type ACCESSFNS, HASHLINK or RECORD. Type tests can be defined for these kinds of records, or redefined for the other kinds, by including an expression of the form (TYPE? COM) in the record declaration (see page 8.14). Attempting to execute a TYPE? expression for a record that has no type test causes an error, TYPE? NOT IMPLEMENTED FOR THIS RECORD.

8.4 WITH

Often one wants to write a complex expression that manipulates several fields of a single record. The WITH construct can make it easier to write such expressions by allowing one to refer to the fields of a record as if they were variables within a lexical scope:

(with RECORD-NAME RECORD-INSTANCE FORM₁ ... FORMₙ)

RECORD-NAME is the name of a record, and RECORD-INSTANCE is an expression which evaluates to an instance of that record. The expressions FORM₁ ... FORMₙ are evaluated so that references to variables which are field-names of RECORD-NAME
are implemented via FETCH and SETQs of those variables are implemented via REPLACE.

For example, given

(RECORD RECN (FLD1 FLD2))
(SETQ INST (create RECN FLD1 ← 10 FLD2 ← 20))

Then the construct

(with RECN INST (SETQ FLD2 (PLUS FLD1 FLD2))

is equivalent to

(replace FLD2 of INST with (PLUS (fetch FLD1 of INST) (fetch FLD2 of INST))

Warning: WITH is implemented by doing simple substitutions in the body of the forms, without regard for how the record fields are used. This means, for example, if the record FOO is defined by (RECORD FOO (POINTER1 POINTER2)), then the form

(with FOO X (SELECTQ Y (POINTER1 POINTER1) NIL)

will be translated as

(SELECTQ Y ((CAR X) (CAR X)) NIL)

The user should be careful that record field names are not used except as variables in the WITH forms.

8.5 Record Declarations

A record is defined by evaluating a record declaration, which is an expression of the form:

(RECORD-TYPE RECORD-NAME RECORD-FIELDS RECORD-TAIL)

RECORD-TYPE specifies the "type" of data being described by the record declaration, and thereby implicitly specifies how the corresponding access/storage operations are performed. The different record types are described below.

RECORD-NAME is a litatom used to identify the record declaration for creating instances of the record via CREATE, testing via TYPE?, and dumping to files via the RECORDS file package command (page 17.38). DATATYPE and TYPERECOND declarations also use RECORD-NAME to identify the data structure (as described below).

RECORD-FIELDS describes the structure of the record. Its exact interpretation varies with RECORD-TYPE. For most record types it defines the names of the fields within the record that can be accessed with FETCH and REPLACE.
8.5.1 Record Types

Records can be used to describe a large variety of data objects, that are manipulated in different ways. The RECORD-TYPE field of the record declaration specifies how the data object is created, and how the various record fields are accessed. Depending on the record type, the record fields may be stored in a list, or in an array, or on the property list of a litatom. The following record types are defined:

**RECORD**

The RECORD record type is used to describe list structures. RECORD-FIELDS is interpreted as a list structure whose non-NIL literal atoms are taken as field-names to be associated with the corresponding elements and tails of a list structure. For example, with the record declaration (RECORD MSG (FROM TO TEXT)), (fetch FROM of X) translates as (CAR X).

NIL can be used as a place marker to fill an unnamed field, e.g., (A NIL B) describes a three element list, with B corresponding to the third element. A number may be used to indicate a sequence of NILs, e.g., (A 4 B) is interpreted as (A NIL NIL NIL NIL B).

**TYPERECORD**

The TYPERECORD record type is similar to RECORD, except that the record name is added to the front of the list structure to signify what "type" of record it is. This type field is used by the
record package in the translation of TYPE? expressions. CREATE will insert an extra field containing RECORD-NAME at the beginning of the structure, and the translation of the access and storage functions will take this extra field into account. For example, for (TYPERECORD MSG (FROM TO . TEXT)), (fetch FROM of X) translates as (CADR X), not (CAR X).

**ASSOCRECORD**

The ASSOCRECORD record type is used to describe list structures where the fields are stored in association list format:

\((\text{FIELDNAME}_1 . \text{VALUE}_1)\ (\text{FIELDNAME}_2 . \text{VALUE}_2)\ ...\)

**RECORD-FIELDS** is a list of literal atoms, interpreted as the permissible list of field names in the association list. Accessing is performed with ASSOC (or FASSOC, depending on current CLISP declarations, see page 21.12), storing with PUTASSOC.

**PROPRECORD**

The PROPRECORD record type is used to describe list structures where the fields are stored in property list format:

\((\text{FIELDNAME}_1 \text{VALUE}_1 \text{FIELDNAME}_2 \text{VALUE}_2 \ ...\)

**RECORD-FIELDS** is a list of literal atoms, interpreted as the permissible list of field names in the property list. Accessing is performed with LISTGET, storing with LISTPUT.

Both ASSOCRECORD and PROPRECORD are useful for defining data structures in which it is often the case that many of the fields are NIL. A CREATE expression for these record types only stores those fields which are non-NIL. Note, however, that with the record declaration (PROPRECORD FIE (H I J)) the expression (create FIE) would still construct (H NIL), since a later operation of (replace J of X with Y) could not possibly change the instance of the record if it were NIL.

**ARRAYRECORD**

The ARRAYRECORD record type is used to describe arrays. **RECORD-FIELDS** is interpreted as a list of field names that are associated with the corresponding elements of an array. NIL can be used as a place marker for an unnamed field (element). Positive integers can be used as abbreviation for the corresponding number of Nils. For example, (ARRAYRECORD (ORG DEST NIL ID 3 TEXT)) describes an eight element array, with ORG corresponding to the first element, ID to the fourth, and TEXT to the eighth.
Note that ARRAYRECORD only creates arrays of pointers. Other kinds of arrays must be implemented by the user with the ACCESSFNS record type (page 8.12).

**HASHLINK**

The HASHLINK record type can be used with any type of data object: it specifies that the value of a single field can be accessed by hashing the data object in a given hash array. Since the HASHLINK record type describes an accessing method, rather than a data structure, the CREATE expression is meaningless for HASHLINK records.

RECORD-FIELDS is either an atom FIELD-NAME, or a list (FIELD-NAME HARRAYNAME HARRAYSIZE). HARRAYNAME is a variable whose value is the hash array to be used; if not given, SYSHASHARRAY is used. If the value of the variable HARRAYNAME is not a hash array (at the time of the record declaration), it will be set to a new hash array with a size of HARRAYSIZE. HARRAYSIZE defaults to 100.

The HASHLINK record type is useful as a subdeclaration to other records to add additional fields to already existing data structures (see page 8.14). For example, suppose that FOO is a record declared with (RECORD FOO (A B C)). To add an additional field BAR, without modifying the already existing data structures, redefine FOO with:

(RECORD FOO (A B C) (HASHLINK FOO (BAR BARHARRAY)))

Now, (fetch BAR of X) will translate into (GETHASH X BARHARRAY), hashing off the existing list X.

**ATOMRECORD**

The ATOMRECORD record type is used to describe property lists of litatoms. RECORD-FIELDS is a list of property names. Accessing is performed with GETPROP, storing with PUTPROP. The CREATE expression is not initially defined for ATOMRECORD records.

**DATATYPE**

The DATATYPE record type is used to define a new user data type with type name RECORD-NAME (by calling DECLAREDATATYPE, page 8.21). Unlike other record types, the records of a DATATYPE declaration are represented with a completely new Interlisp type, and not in terms of other existing types.

RECORD-FIELDS is interpreted as a list of field specifications, where each specification is either a list (FIELDNAME FIELDTYPE), or an atom FIELDNAME. If FIELDTYPE is omitted, it defaults to POINTER. Possible values for FIELDTYPE are:

- **POINTER** Field contains a pointer to any arbitrary Interlisp object.
RECORD DECLARATIONS

INTEGER
FIXP  Field contains a signed integer. Note that an INTEGER field is not capable of holding everything that satisfies FIXP, such as bignums (page 7.1).

FLOATING
FLOATP  Field contains a floating point number.

SIGNEDWORD
FIELDWORD  Field contains a 16-bit signed integer.

FLAG  Field is a one bit field that "contains" T or NIL.

BITS N  Field contains an N-bit unsigned integer.

BYTE  Equivalent to BITS 8.

WORD  Equivalent to BITS 16.

XPOINTER  Field contains a pointer like POINTER, except that the field is not reference counted by the Interlisp-D garbage collector. XPOINTER fields are useful for implementing back-pointers in structures that would be circular and not otherwise collected by the reference-counting garbage collector.

Warning: XPOINTER fields should be used with great care. It is possible to damage the integrity of the storage allocation system by using pointers to objects that have been garbage collected. Code that uses XPOINTER fields should be sure that the objects pointed to have not been garbage collected. This can be done in two ways: The first is to maintain the object in a global structure, so that it is never garbage collected until explicitly deleted from the structure, at which point the program must invalidate all the XPOINTER fields of other objects pointing at it. The second is to declare the object as a DATATYPE beginning with a POINTER field that the program maintains as a pointer to an object of another type (e.g., the object containing the XPOINTER pointing back at it), and test that field for reasonableness whenever using the contents of the XPOINTER field.

For example, the declaration

(DATATYPE FOO
 ((FLG BITS 12)
  TEXT
  HEAD
  (DATE BITS 18)
  (PRIO FLOATP)
  (READ? FLAG)))

would define a data type FOO with two pointer fields, a floating point number, and fields for a 12 and 18 bit unsigned integers, and a flag (one bit). Fields are allocated in such a way as to optimize the storage used and not necessarily in the order specified. Generally, a DATATYPE record is much more storage...
compact than the corresponding RECORD structure would be; in addition, access is faster.

Since the user data type must be set up at run-time, the RECORDS file package command will dump a DECLAREDATATYPE expression as well as the DATATYPE declaration itself. If the record declaration is otherwise not needed at runtime, it can be kept out of the compiled file by using a (DECLARE: DONTCOPY -->) expression (see page 17.40), but it is still necessary to ensure that the datatype is properly initialized. For this, one can use the INITRECORDS file package command (page 17.38), which will dump only the DECLAREDATATYPE expression.

Note: When defining a new data type, it is sometimes useful to call the function DEFPRTN (page 25.16) to specify how instances of the new data type should be printed. This can be specified in the record declaration by including an INIT record specification (page 8.14), e.g. (DATATYPE QV.TYPE ... (INIT (DEFPRTN 'QV.TYPE (FUNCTION PRINT.QV.TYPE))).

Note: DATATYPE declarations cannot be used within local record declarations (page 21.13).

**BLOCKRECORD**

The BLOCKRECORD record type is used in low-level system programming to "overlay" an organized structure over an arbitrary piece of "unboxed" storage. RECORD-FIELDS is interpreted exactly as with a DATATYPE declaration, except that fields are not automatically rearranged to maximize storage efficiency. Like an ACCESSFNS record, a BLOCKRECORD does not have concrete instances; it merely provides a way of interpreting some existing block of storage. Thus, one cannot create an instance of a BLOCKRECORD (unless the declaration includes an explicit CREATE expression), nor is there a default type? expression for a BLOCKRECORD.

Warning: The programmer should exercise caution in using BLOCKRECORD declarations, as they enable one to write expressions that fetch and store arbitrary data in arbitrary locations, thereby evading the normal type system. Except in very specialized situations, a BLOCKRECORD should never contain POINTER or XPOINTER fields, nor be used to overlay an area of storage that contains pointers. Such use could compromise the garbage collector and storage allocation system. The programmer is responsible for ensuring that all FETCH and REPLACE expressions are performed only on suitable objects, as no type testing is performed.

A typical use for the BLOCKRECORD type in user code is to overlay a non-pointer portion of an existing DATATYPE. For this use, the LOCF macro is useful. (LOCF (fetch FIELD of DATUM))
can be used to refer to the storage that begins at the first word that contains FIELD of DATUM. For example, to define a new kind of Ethernet packet (page 31.26), one could overlay the "body" portion of the ETHERPACKET datatype declaration as follows:

ACCESSFNS MYPACKET
    {{MYBASE (LOCF (fetch (ETHERPACKET EPBODY) of DATUM)))}
    (BLOCKRECORD MYBASE
        {{MYTYPE WORD
            (MYLENGTH WORD)
            (MYSTATUS BYTE)
            (MYERRORCODE BYTE)
            (MYDATA INTEGER))
        (TYPE? (type? ETHERPACKET DATUM)))

With this declaration in effect, the expression (fetch MYLENGTH of PACKET) would retrieve the second 16-bit field beyond the offset inside PACKET where the EPBODY field starts. For more examples, see the EtherRecords library package.

ACCESSFNS

The ACCESSFNS record type is used to define data structures with user-defined access functions. For each field name, the user specifies how it is to be accessed and set. This allows the use of the record package with arbitrary data structures, with complex access methods.

RECORD-FIELDS is interpreted as a list of elements of the form (FIELD-NAME ACCESSDEF SETDEF). ACCESSDEF should be a function of one argument, the datum, and will be used for accessing the value of the field. SETDEF should be a function of two arguments, the datum and the new value, and will be used for storing a new value in a field. SETDEF may be omitted, in which case, no storing operations are allowed.

ACCESSDEF and/or SETDEF may also be a form written in terms of variables DATUM and (in SETDEF) NEWVALUE. For example, given the declaration

[ACCESSFNS FOO
    {{FIRSTCHAR (NTHCHAR DATUM 1)
            (RPLSTRING DATUM 1 NEWVALUE))
    (RESTCHARS (SUBSTRING DATUM 2)]

(replace (FOO FIRSTCHAR) of X with Y) would translate to (RPLSTRING X 1 Y). Since no SETDEF is given for the RESTCHARS field, attempting to perform (replace (FOO RESTCHARS) of X with Y) would generate an error, REPLACE UNDEFINED FOR FIELD. Note that ACCESSFNS do not have a CREATE definition. However, the user may supply one in the defaults or subdeclarations of the declaration, as described below.
Attempting to CREATE an ACCES SFNS record without specifying a create definition will cause an error CREATE NOT DEFINED FOR THIS RECORD.

ACCESSDEF and SETDEF can also be a property list which specify FAST, STANDARD and UNDOABLE versions of the ACCESSFNS forms, e.g.

\[\text{ACCESSFNS LITATOM} \]
\[\text{((DEF (STANDARD GETD FAST FGETD)} \]
\[\text{(STANDARD PUTD UNDOABLE /PUTD)} \]

means if FAST declaration is in effect, use FGETD for fetching, if UNDOABLE, use /PUTD for saving (see CLISP declarations, page 21.12).

Note: SETDEF forms should be written so that they return the new value, to be consistent with REPLACE operations for other record types. The REPLACE record operator does not enforce this, though.

The ACCESSFNS facility allows the use of data structures not specified by one of the built-in record types. For example, one possible representation of a data structure is to store the fields in parallel arrays, especially if the number of instances required is known, and they do not need to be garbage collected. Thus, to implement a data structure called LINK with two fields FROM and TO, one would have two arrays FROMARRAY and TOARRAY. The representation of an "instance" of the record would be an integer which is used to index into the arrays. This can be accomplished with the declaration:

\[\text{ACCESSFNS LINK} \]
\[\text{((FROM (ELT FROMARRAY DATUM)} \]
\[\text{(SETA FROMARRAY DATUM NEWVALUE))} \]
\[\text{(TO (ELT TOARRAY DATUM)} \]
\[\text{(SETA TOARRAY DATUM NEWVALUE))} \]
\[\text{(CREATE (PROGN (SETQ LINKCNT (ADD1 LINKCNT))}} \]
\[\text{(SETA FROMARRAY LINKCNT FROM)} \]
\[\text{(SETA TOARRAY LINKCNT TO))} \]
\[\text{(INIT (PROGN}} \]
\[\text{(SETQ FROMARRAY (ARRAY 100))} \]
\[\text{(SETQ TOARRAY (ARRAY 100))} \]
\[\text{(SETQ LINKCNT 0))} \]

To create a new LINK, a counter is incremented and the new elements stored. (Note: The CREATE form given the declaration probably should include a test for overflow.)
8.5.2 Optional Record Specifications

After the RECORD-FIELDS item in a record declaration expression there can be an arbitrary number of additional expressions in RECORD-TAIL. These expressions can be used to specify default values for record fields, special CREATE and TYPE? forms, and subdeclarations. The following expressions are permitted:

**FIELD-NAME ← FORM**

Allows the user to specify within the record declaration the default value to be stored in FIELD-NAME by a CREATE (if no value is given within the CREATE expression itself). Note that FORM is evaluated at CREATE time, not when the declaration is made.

**(CREATE FORM)**

Defines the manner in which CREATE of this record should be performed. This provides a way of specifying how ACCESSFNS should be created or overriding the usual definition of CREATE. If FORM contains the field-names of the declaration as variables, the forms given in the CREATE operation will be substituted in. If the word DATUM appears in the create form, the original CREATE definition is inserted. This effectively allows the user to "advise" the create.

Note: (CREATE FORM) may also be specified as "RECORD-NAME ← FORM".

**(INIT FORM)**

Specifies that FORM should be evaluated when the record is declared. FORM will also be dumped by the INITRECORDS file package command (page 17.38).

For example, see the example of an ACCESSFNS record declaration above. In this example, FROMARRAY and TOARRAY are initialized with an INIT form.

**(TYPE? FORM)**

Defines the manner in which TYPE? expressions are to be translated. FORM may either be an expression in terms of DATUM or a function of one argument.

**(SUBRECORD NAME . DEFAULTS)**

NAME must be a field that appears in the current declaration and the name of another record. This says that, for the purposes of translating CREATE expressions, substitute the top-level declaration of NAME for the SUBRECORD form, adding on any defaults specified.

For example: Given (RECORD B (E F G)), (RECORD A (B C D) (SUBRECORD B)) would be treated like (RECORD A (B C D) (RECORD B (E F G))) for the purposes of translating CREATE expressions.

**(a subdeclaration)**

If a record declaration expression occurs among the record specifications of another record declaration, it is known as a "subdeclaration." Subdeclarations are used to declare that fields of a record are to be interpreted as another type of record, or that the record data object is to be interpreted in more than one way.
The RECORD-NAME of a subdeclaration must be either the RECORD-NAME of its immediately superior declaration or one of the superior's field-names. Instead of identifying the declaration as with top level declarations, the record-name of a subdeclaration identifies the parent field or record that is being described by the subdeclaration. Subdeclarations can be nested to an arbitrary depth.

Giving a subdeclaration (RECORD NAME1 NAME2) is a simple way of defining a synonym for the field NAME1.

It is possible for a given field to have more than one subdeclaration. For example, in

(RECORD FOO (A B) (RECORD A (C D)) (RECORD A (Q R)))

(Q R) and (C D) are "overlayed," i.e. (fetch Q of X) and (fetch C of X) would be equivalent. In such cases, the first subdeclaration is the one used by CREATE.

(FIELD must be a field that appears in the current declaration. This defines SYN1 ... SYN_N as synonyms of FIELD. If there is only one synonym, this can be written as (SYNONYM FIELD SYN).

If (SYSTEM) is included in a record declaration, this indicates that the record is a "system" record rather than a "user" record. The only distinction between the two types of records is that "user" record declarations take precedence over "system" record declarations, in cases where an unqualified field name would be considered ambiguous. All of the records defined in the standard interlisp-D system are defined as system records.

8.6 Defining New Record Types

In addition to the built-in record types, users can declare their own record types by performing the following steps:

1) Add the new record-type to the value of CLISPRECORDTYPES;

2) Perform (MOVD 'RECORD RECORD-TYPE), i.e. give the record-type the same definition as that of the function RECORD;

3) Put the name of a function which will return the translation on the property list of RECORD-TYPE, as the value of the property USERRECORDTYPE. Whenever a record declaration of type RECORD-TYPE is encountered, this function will be passed the record declaration as its argument, and should return a new record declaration which the record package will then use in its place.
8.7 Record Manipulation Functions

(EDITREC NAME \textit{COM}_1 \ldots \textit{COM}_N) \quad \text{[NLambda NoSpread Function]}

EDITREC calls the editor on a copy of all declarations in which \textit{NAME} is the record name or a field name. On exit, it redeclares those that have changed and undeclares any that have been deleted. If \textit{NAME} is NIL, all declarations are edited.

\textit{COM}_1 \ldots \textit{COM}_N are (optional) edit commands.

When the user redeclares a global record, the translations of all expressions involving that record or any of its fields are automatically deleted from CLISPARRAY, and thus will be recomputed using the new information. If the user changes a local record declaration (page 21.13), or changes some other CLISP declaration (page 21.12), e.g., STANDARD to FAST, and wishes the new information to affect record expressions already translated, he must make sure the corresponding translations are removed, usually either by CLISPIFYing or using the DW edit macro.

(RECLOOK \textit{RECN}AME — — —) \quad \text{[Function]}

Returns the entire declaration for the record named \textit{RECN}AME; NIL if there is no record declaration with name \textit{RECN}AME. Note that the record package maintains internal state about current record declarations, so performing destructive operations (e.g. NCONC) on the value of RECLOOK may leave the record package in an inconsistent state. To change a record declaration, use EDITREC.

(FIELDLOOK \textit{FIELD}NAME) \quad \text{[Function]}

Returns the list of declarations in which \textit{FIELD}NAME is the name of a field.

(RECORDFIELDNAMES \textit{RECORD}NAME —) \quad \text{[Function]}

Returns the list of fields declared in record \textit{RECORD}NAME. \textit{RECORD}NAME may either be a name or an entire declaration.

(RECORDACCESS \textit{FIELD} \textit{DATUM} \textit{DEC} \textit{TYPE} \textit{NEWVALUE}) \quad \text{[Function]}

\textit{TYPE} is one of FETCH, REPLACE, FFETCH, FREPLACE, /REPLACE or their lowercase equivalents. \textit{TYPE} = NIL means FETCH. If \textit{TYPE} corresponds to a fetch operation, i.e. is FETCH, or FFETCH, RECORDACCESS performs (\textit{TYPE} \textit{FIELD} of \textit{DATUM}). If \textit{TYPE} corresponds to a replace, RECORDACCESS performs (\textit{TYPE} \textit{FIELD} of \textit{DATUM} with \textit{NEWVALUE}). \textit{DEC} is an optional declaration; if given, \textit{FIELD} is interpreted as a field name of that declaration.
Note that RECORDACCESS is relatively inefficient, although it is better than constructing the equivalent form and performing an EVAL.

(RECORDACCESSFORM FIELD DATUM TYPE NEWVALUE)  [Function]
Returns the form that would be compiled as a result of a record access. TYPE is one of FETCH, REPLACE, FFETCH, FREPLACE, /REPLACE or their lowercase equivalents. TYPE = NIL means FETCH.

8.8 Changetrans

A very common programming construction consists of assigning a new value to some datum that is a function of the current value of that datum. Some examples of such read-modify-write sequences include:

Incrementing a counter:

(SETQ X (PLUS X 1))

Pushing an item on the front of a list:

(SETQ X (CONS Y X))

Popping an item off a list:

(PROG1 (CAR X) (SETQ X (CDR X)))

It is easier to express such computations when the datum in question is a simple variable as above than when it is an element of some larger data structure. For example, if the datum to be modified was (CAR X), the above examples would be:

(CAR (RPLACA X (PLUS (CAR X) 1)))

(CAR (RPLACA X (CONS Y (CAR X))))

(PROG1 (CAAR X) (RPLACA X (CDAR X)))

and if the datum was an element in an array, (ELT A N), the examples would be:

(SETA A N (PLUS (ELT A N) 1)))

(SETA A N (CONS Y (ELT A N)))

(PROG1 (CAR (ELT A N)) (SETA A N (CDR (ELT A N))))

The difficulty in expressing (and reading) modification idioms is in part due to the well-known asymmetry of setting versus accessing operations on structures: RPLACA is used to set what CAR would return, SETA corresponds to ELT, and so on.

The "Changetrans" facility is designed to provide a more satisfactory notation in which to express certain common (but
user-extensible) structure modification operations. Changetran defines a set of CLISP words that encode the kind of modification that is to take place, e.g. pushing on a list, adding to a number, etc. More important, the expression that indicates the datum whose value is to be modified needs to be stated only once. Thus, the "change word" ADD is used to increase the value of a datum by the sum of a set of numbers. Its arguments are an expression denoting the datum, and a set of items to be added to its current value. The datum expression must be a variable or an accessing expression (involving FETCH, CAR, LAST, ELT, etc) that can be translated to the appropriate setting expression.

For example, (ADD (CADDR X) (FOO)) is equivalent to:

(CAR (RPLACA (CDDR X))
  (PLUS (FOO) (CADDR X)))

If the datum expression is a complicated form involving subsidiary function calls, such as (ELT (FOO X) (FIE Y)), Changetran goes to some lengths to make sure that those subsidiary functions are evaluated only once (it binds local variables to save the results), even though they logically appear in both the setting and accessing parts of the translation. Thus, in thinking about both efficiency and possible side effects, the user can rely on the fact that the forms will be evaluated only as often as they appear in the expression.

For ADD and all other changewords, the lower-case version (add, etc.) may also be specified. Like other CLISP words, change words are translated using all CLISP declarations in effect (see page 21.12).

The following is a list of those change words recognized by Changetran. Except for POP, the value of all built-in changeword forms is defined to be the new value of the datum.

(ADD DATUM ITEM1 ITEM2 ...) [Change Word]

Adds the specified items to the current value of the datum, stores the result back in the datum location. The translation will use IPLUS, PLUS, or FPLUS according to the CLISP declarations in effect (see page 21.12).

(PUSH DATUM ITEM1 ITEM2 ...) [Change Word]

CONSES the items onto the front of the current value of the datum, and stores the result back in the datum location. For example, (PUSH X A B) would translate as (SETQ X (CONS A (CONS B X))).

(PUSHNEW DATUM ITEM) [Change Word]

Like PUSH (with only one item) except that the item is not added if it is already FMEMB of the datum's value.
Note that, whereas (CAR (PUSH X 'FOO)) will always be FOO, (CAR (PUSHNEW X 'FOO)) might be something else if FOO already existed in the middle of the list.

(PUSHLIST DATUM ITEM1 ITEM2...)  [Change Word]

Similar to PUSH, except that the items are APPENDed in front of the current value of the datum. For example, (PUSHLIST X A B) would translate as (SETQ X (APPEND A B X)).

(POP DATUM)  [Change Word]

Returns CAR of the current value of the datum after storing its CDR into the datum. The current value is computed only once even though it is referenced twice. Note that this is the only built-in changeword for which the value of the form is not the new value of the datum.

(SWAP DATUM1 DATUM2)  [Change Word]

Sets DATUM1 to DATUM2 and vice versa.

(CHANGE DATUM FORM)  [Change Word]

This is the most flexible of all change words, since it enables the user to provide an arbitrary form describing what the new value should be, but it still highlights the fact that structure modification is to occur, and still enables the datum expression to appear only once. CHANGE sets DATUM to the value of FORM*, where FORM* is constructed from FORM by substituting the datum expression for every occurrence of the litatom DATUM. For example, (CHANGE (CAR X) (ITIMES DATUM 5)) translates as (CAR (RPLACA X (ITIMES (CAR X) 5))).

CHANGE is useful for expressing modifications that are not built-in and are not sufficiently common to justify defining a user-changeword. As for other changeword expressions, the user need not repeat the datum-expression and need not worry about multiple evaluation of the accessing form.

It is possible for the user to define new change words. To define a change word, say sub, that subtracts items from the current value of the datum, the user must put the property CLISPWORD, value (CHANGETRAN . sub) on both the upper and lower-case versions of sub:

(PUTPROP 'SUB 'CLISPWORD '(CHANGETRAN . sub))
(PUTPROP 'sub 'CLISPWORD '(CHANGETRAN . sub))

Then, the user must put (on the lower-case version of sub only) the property CHANGEWORD, with value FN. FN is a function that will be applied to a single argument, the whole sub form, and must return a form that Changetran can translate into an
appropriate expression. This form should be a list structure with the atom DATUM used whenever the user wants an accessing expression for the current value of the datum to appear. The form \((\text{DATUM} \leftarrow \text{FORM})\) (note that \(\text{DATUM} \leftarrow \) is a single atom) should occur once in the expression; this specifies that an appropriate storing expression into the datum should occur at that point. For example, sub could be defined with:

\[
(\text{PUTPROP 'sub 'CHANGEDATUM}
\)
\[
(\text{LAMBDA (FORM)}
\)
\[
(\text{LIST 'DATUM}
\)
\[
(\text{LIST 'IDIFFERENCE}
\)
\[
(\text{'DATUM}
\)
\[
(\text{CONS 'IPLUS (CDDR FORM)}}</})
\]

If the expression \((\text{sub (CAR X) A B})\) were encountered, the arguments to \(\text{SUB}\) would first be dwimified, and then the \(\text{CHANGEDATUM}\) function would be passed the list \((\text{sub (CAR X) A B})\), and return \((\text{DATUM} \leftarrow (\text{IDIFFERENCE DATUM (IPLUS A B)})\))

which Changetran would convert to \((\text{CAR (RPLACA X (IDIFFERENCE (CAR X) (IPLUS A B)})})\).

Note: The sub changeword as defined above will always use \(\text{IDIFFERENCE}\) and \(\text{IPLUS}\); add uses the correct addition operation depending on the current CLISP declarations (see page 21.12).

# 8.9 Built-In and User Data Types

Interlisp is a system for the manipulation of various kinds of data; it provides a large set of built-in data types, which may be used to represent a variety of abstract objects, and the user can also define additional "user data types" which can be manipulated exactly like built-in data types.

Each data type in Interlisp has an associated "type name," a litatom. Some of the type names of built-in data types are: LITATOM, LISTP, STRINGP, ARRAYP, STACKP, SMALLP, FIXP, and FLOATP. For user data types, the type name is specified when the data type is created.

\[
(\text{DATATYPES})
\]

[Function]

Returns a list of all type names currently defined.

\[
(\text{USERDATATYPES})
\]

[Function]

Returns list of names of currently declared user data types.

\[
(\text{TYPOENAME DATUM})
\]

[Function]

Returns the type name for the data type of DATUM.
(TYPENAMEP DATUM TYPE) [Function]
Returns T if DATUM is an object with type name equal to TYPE, otherwise NIL.

Note: TYPENAME and TYPENAMEP distinguish the logical data types ARRAYP, CCODEP and HARRAYP, even though they may be implemented as ARRAYPs in some Interlisp implementations.

In addition to built-in data-types such as atoms, lists, arrays, etc., Interlisp provides a way of defining completely new classes of objects, with a fixed number of fields determined by the definition of the data type. In order to define a new class of objects, the user must supply a name for the new data type and specifications for each of its fields. Each field may contain either a pointer (i.e., any arbitrary Interlisp datum), an integer, a floating point number, or an N-bit integer.

Note: The most convenient way to define new user data types is via DATATYPE record declarations (page 8.9) which call the following functions.

(DECLAREDATATYPE TYPENAME FIELDSPECS — —) [Function]
Defines a new user data type, with the name TYPENAME. FIELDSPECS is a list of "field specifications." Each field specification may be one of the following:

- **POINTER** Field may contain any Interlisp datum.
- **FIXP** Field contains an integer.
- **FLOATP** Field contains a floating point number.
- **(BITS N)** Field contains a non-negative integer less than \(2^N\).
- **BYTE** Equivalent to **(BITS 8)**.
- **WORD** Equivalent to **(BITS 16)**.
- **SIGNEDWORD** Field contains a 16 bit signed integer.

DECLAREDATATYPE returns a list of "field descriptors," one for each element of FIELDSPECS. A field descriptor contains information about where within the datum the field is actually stored.

If FIELDSPECS is NIL, TYPENAME is "undeclared." If TYPENAME is already declared as a data type, it is undeclared, and then re-declared with the new FIELDSPECS. An instance of a data type that has been undeclared has a type name of **DEALLOC**.

(FETCHFIELD DESCRIPTOR DATUM) [Function]
Returns the contents of the field described by DESCRIPTOR from DATUM. DESCRIPTOR must be a "field descriptor" as returned by DECLAREDATATYPE or GETDESCRIPTORS. If DATUM is not an
instance of the datatype of which \texttt{DESCRIPTOR} is a descriptor, causes error \texttt{DATUM OF INCORRECT TYPE}.

\begin{verbatim}
(REPLACEFIELD DESRIPTOR DATUM NEWVALUE) \hfill [Function]
\end{verbatim}

Store \texttt{NEWVALUE} into the field of \texttt{DATUM} described by \texttt{DESCRIPTOR}. \texttt{DESCRIPTOR} must be a field descriptor as returned by \texttt{DECLAREDATATYPE}. If \texttt{DATUM} is not an instance of the datatype of which \texttt{DESCRIPTOR} is a descriptor, causes error \texttt{DATUM OF INCORRECT TYPE}. Value is \texttt{NEWVALUE}.

\begin{verbatim}
(NCREATE TYPE OLDOBJ) \hfill [Function]
\end{verbatim}

Creates and returns a new instance of datatype \texttt{TYPE}.

If \texttt{OLDOBJ} is also a datum of datatype \texttt{TYPE}, the fields of the new object are initialized to the values of the corresponding fields in \texttt{OLDOBJ}.

\texttt{NCREATE} will not work for built-in datatypes, such as \texttt{ARRAYP}, \texttt{STRINGP}, etc. If \texttt{TYPE} is not the type name of a previously declared user data type, generates an error, \texttt{ILLEGAL DATA TYPE}.

\begin{verbatim}
(GETFIELDSPECS TYPENAME) \hfill [Function]
\end{verbatim}

Returns a list which is \texttt{EQUAL} to the \texttt{FIELDSPECS} argument given to \texttt{DECLAREDATATYPE} for \texttt{TYPENAME}; if \texttt{TYPENAME} is not a currently declared data-type, returns \texttt{NIL}.

\begin{verbatim}
(GETDESCRIPTORS TYPENAME) \hfill [Function]
\end{verbatim}

Returns a list of field descriptors, \texttt{EQUAL} to the value of \texttt{DECLAREDATATYPE} for \texttt{TYPENAME}. If \texttt{TYPENAME} is not an atom, \texttt{(TYPENAME TYPENAME)} is used.

Note that the user can define how user data types are to be printed via \texttt{DEFPRINT} (page 25.16), how they are to be evaluated by the interpreter via \texttt{DEFEVAL} (page 10.13), and how they are to be compiled by the compiler via \texttt{COMPILETYPELST} (page 18.11).
## 9. Conditionals and Iterative Statements

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.1</td>
<td>Data Type Predicates</td>
<td>9.1</td>
</tr>
<tr>
<td>9.2</td>
<td>Equality Predicates</td>
<td>9.2</td>
</tr>
<tr>
<td>9.3</td>
<td>Logical Predicates</td>
<td>9.3</td>
</tr>
<tr>
<td>9.4</td>
<td>The COND Conditional Function</td>
<td>9.4</td>
</tr>
<tr>
<td>9.5</td>
<td>The IF Statement</td>
<td>9.5</td>
</tr>
<tr>
<td>9.6</td>
<td>Selection Functions</td>
<td>9.6</td>
</tr>
<tr>
<td>9.7</td>
<td>PROG and Associated Control Functions</td>
<td>9.7</td>
</tr>
<tr>
<td>9.8</td>
<td>The Iterative Statement</td>
<td>9.9</td>
</tr>
<tr>
<td>9.8.1</td>
<td>l.s.types</td>
<td>9.10</td>
</tr>
<tr>
<td>9.8.2</td>
<td>Iteration Variable l.s.oprs</td>
<td>9.12</td>
</tr>
<tr>
<td>9.8.3</td>
<td>Condition l.s.oprs</td>
<td>9.15</td>
</tr>
<tr>
<td>9.8.4</td>
<td>Other l.s.oprs</td>
<td>9.16</td>
</tr>
<tr>
<td>9.8.5</td>
<td>Miscellaneous Hints on l.S.Oprs</td>
<td>9.17</td>
</tr>
<tr>
<td>9.8.6</td>
<td>Errors in Iterative Statements</td>
<td>9.19</td>
</tr>
<tr>
<td>9.8.7</td>
<td>Defining New Iterative Statement Operators</td>
<td>9.20</td>
</tr>
</tbody>
</table>
9. CONDITIONALS AND ITERATIVE STATEMENTS

In order to do any but the simplest computations, it is necessary to test values and execute expressions conditionally, and to execute a series of expressions. Interlisp supplies a large number of predicates, conditional functions, and control functions. Also, there is a complex "iterative statement" facility which allows the user to easily create complex loops and iterative constructs (page 9.9).

### 9.1 Data Type Predicates

Interlisp provides separate functions for testing whether objects are of certain commonly-used types:

- **(LITATOM X)** [Function]
  
  Returns T if X is a litatom (see page 2.1) NIL otherwise. Note that a number is not a litatom.

- **(SMALLP X)** [Function]
  
  Returns X if X is a small integer; NIL otherwise. (Note that the range of small integers is implementation-dependent. See page 7.1.)

- **(FIXP X)** [Function]
  
  Returns X if X is a small or large integer; NIL otherwise.

- **(FLOATP X)** [Function]
  
  Returns X if X is a floating point number; NIL otherwise.

- **(NUMBERP X)** [Function]
  
  Returns X if X is a number of any type (FIXP or FLOATP), NIL otherwise.

- **(ATOM X)** [Function]
  
  Returns T if X is an atom (i.e. a litatom or a number); NIL otherwise.
Warning: (ATOM X) is NIL if X is an array, string, etc. In many dialects of Lisp, the function ATOM is defined equivalent to the Interlisp function NLISTP.

(LISTP X)  [Function]
Returns X if X is a list cell, e.g., something created by CONS; NIL otherwise.

(NLISTP X)  [Function]
(NOT (LISTP X)). Returns T if X is not a list cell, NIL otherwise.

(STRINGP X)  [Function]
Returns X if X is a string, NIL otherwise.

(ARRAYP X)  [Function]
Returns X if X is an array, NIL otherwise.
Note: In some implementations of Interlisp (but not Interlisp-D), ARRAYP may also return X if it is of type CCODEP or HARRAYP.

(HARRAYP X)  [Function]
Returns X if it is a hash array object; otherwise NIL.
Note that HARRAYP returns NIL if X is a list whose CAR is an HARRAYP, even though this is accepted by the hash array functions.

Note: The empty list, () or NIL, is considered to be a litatom, rather than a list. Therefore, (LITATOM NIL) = (ATOM NIL) = T and (LISTP NIL) = NIL. Care should be taken when using these functions if the object may be the empty list NIL.

9.2  Equality Predicates
A common operation when dealing with data objects is to test whether two objects are equal. In some cases, such as when comparing two small integers, equality can be easily determined. However, sometimes there is more than one type of equality. For instance, given two lists, one can ask whether they are exactly the same object, or whether they are two distinct lists which contain the same elements. Confusion between these two types of equality is often the source of program errors. Interlisp supplies an extensive set of functions for testing equality:
(EQ X Y)  [Function]

Returns T if X and Y are identical pointers; NIL otherwise. EQ should not be used to compare two numbers, unless they are small integers; use EQP instead.

(NEQ X Y)  [Function]

(NOT (EQ X Y))

(NULL X)  [Function]

(NOT X)  [Function]

(EQ X NIL)

(EQP X Y)  [Function]

Returns T if X and Y are EQ, or if X and Y are numbers and are equal in value; NIL otherwise. For more discussion of EQP and other number functions, see page 7.1.

Note: EQP also can be used to compare stack pointers (page 11.4) and compiled code (page 10.10).

(EQUAL X Y)  [Function]

EQUAL returns T if X and Y are (1) EQ; or (2) EQU, i.e., numbers with equal value; or (3) STREQUAL, i.e., strings containing the same sequence of characters; or (4) lists and CAR of X is EQUAL to CAR of Y, and CDR of X is EQUAL to CDR of Y. EQUAL returns NIL otherwise. Note that EQUAL can be significantly slower than EQ.

A loose description of EQual might be to say that X and Y are EQUAL if they print out the same way.

(EQUALALL X Y)  [Function]

Like EQUAL, except it descends into the contents of arrays, hash arrays, user data types, etc. Two non-EQ arrays may be EQualALL if their respective components are EQualALL.

9.3 Logical Predicates

(AND X₁ X₂ ... Xₙ)  [NLambda NoSpread Function]

Takes an indefinite number of arguments (including zero), that are evaluated in order. If any argument evaluates to NIL, AND immediately returns NIL (without evaluating the remaining arguments). If all of the arguments evaluate to non-NIL, the value of the last argument is returned. (AND) = > T.
**LOGICAL PREDICATES**

**(OR X₁ X₂ ... Xₙ)**

Takes an indefinite number of arguments (including zero), that are evaluated in order. If any argument is non-NIL, the value of that argument is returned by **OR** (without evaluating the remaining arguments). If all of the arguments evaluate to NIL, NIL is returned. \((\text{OR}) = \text{NIL}\).

**AND** and **OR** can be used as simple logical connectives, but note that they may not evaluate all of their arguments. This makes a difference if the evaluation of some of the arguments causes side-effects. Another result of this implementation of **AND** and **OR** is that they can be used as simple conditional statements. For example: \((\text{AND (LISTP X)} \text{ (CDR X)})\) returns the value of \((\text{CDR X})\) if \(X\) is a list cell, otherwise it returns NIL without evaluating \((\text{CDR X})\). In general, this use of **AND** and **OR** should be avoided in favor of more explicit conditional statements in order to make programs more readable.

### 9.4 The COND Conditional Function

**(COND CLAUSE₁ CLAUSE₂ ... CLAUSEₖ)**

The conditional function of Interlisp, **COND**, takes an indefinite number of arguments, called clauses. Each **CLAUSEᵢ** is a list of the form \((Pᵢ \text{ Cᵢ₁} \ldots \text{ Cᵢₙ})\), where \(Pᵢ\) is the predicate, and \(Cᵢ₁ \ldots Cᵢₙ\) are the consequents. The operation of **COND** can be paraphrased as:

\[
\begin{align*}
\text{IF } P₁ \text{ THEN } & C₁₁ \ldots C₁ₙ \text{ ELSEIF } P₂ \text{ THEN } C₂₁ \ldots C₂ₙ \text{ ELSEIF } P₃ \ldots
\end{align*}
\]

The clauses are considered in sequence as follows: the predicate \(P₁\) of the clause \(\text{CLAUSEᵢ}\) is evaluated. If the value of \(P₁\) is "true" (non-NIL), the consequents \(Cᵢ₁ \ldots Cᵢₙ\) are evaluated in order, and the value of the **COND** is the value of \(Cᵢₙ\), the last expression in the clause. If \(P₁\) is "false" (EQ to NIL), then the remainder of **CLAUSEᵢ** is ignored, and the next clause, **CLAUSEᵢ₊₁**, is considered. If no \(Pᵢ\) is true for any clause, the value of the **COND** is NIL.

Note: If a clause has no consequents, and has the form \((Pᵢ)\), then if \(Pᵢ\) evaluates to non-NIL, it is returned as the value of the **COND**. It is only evaluated once.

Example:

\[
\leftarrow (\text{DEFINEQ (DOUBLE X)} \text{ (COND ((NUMBERP X) (PLUS X X))})
\]

**CONDITIONALS AND ITERATIVE STATEMENTS**
9.5 The IF Statement

The IF statement provides a way of specifying conditional expressions that is much easier and readable than using the COND function directly (page 9.4). CLISP translates expressions employing IF, THEN, ELSEIF, or ELSE (or their lowercase versions) into equivalent COND expressions. In general, statements of the form:

(if AAA then BBB elseif CCC then DDD else EEE)

are translated to:

(COND (AAA BBB)
       (CCC DDD)
       (T EEE))

The segment between IF or ELSEIF and the next THEN corresponds to the predicate of a COND clause, and the segment between THEN and the next ELSE or ELSEIF as the consequent(s). ELSE is the same as ELSEIF T THEN. These words are spelling corrected using the spelling list CLISPIFWORDSPLST. Lower case versions (if, then, elseif, else) may also be used.

If there is nothing following a THEN, or THEN is omitted entirely, then the resulting COND clause has a predicate but no consequent. For example, (if X then elseif ...) and (if X elseif ...)
both translate to (COND (X) ...), which means that if X is not NIL, it is returned as the value of the COND.

Note that only one expression is allowed as the predicate, but multiple expressions are allowed as the consequents after THEN or ELSE. Multiple consequent expressions are implicitly wrapped in a PROGN, and the value of the last one is returned as the value of the consequent. For example:

(if X then (PRINT "FOO") (PRINT "BAR") elseif Y then (PRINT "BAZ"))

CLISP considers IF, THEN, ELSE, and ELSEIF to have lower precedence than all infix and prefix operators, as well as Interlisp forms, so it is sometimes possible to omit parentheses around predicate or consequent forms. For example, (if FOO X Y then ...) is equivalent to (if (FOO X Y) then ...), and (if X then FOO X Y else ...) as equivalent to (if X then (FOO X Y) else ...). Essentially, CLISP determines whether the segment between THEN and the next ELSE or ELSEIF corresponds to one form or several and acts accordingly, occasionally interacting with the user to resolve ambiguous cases. Note that if FOO is bound as a variable, (if FOO then ...) is translated as (COND (FOO ...)), so if a call to the function FOO is desired, use (if (FOO) then ...).

9.6 Selection Functions

\[
\text{(SELECTQ } X \text{ CLAUSE}_1 \text{ CLAUSE}_2 \ldots \text{ CLAUSE}_k \text{ DEFAULT}) \quad \text{[N} \text{Lambda NoSpread Function]} 
\]

Selects a form or sequence of forms based on the value of \(X\). Each clause \(\text{CLAUSE}_j\) is a list of the form \((S_j \text{ C}_1 \ldots \text{ C}_N)\) where \(S_j\) is the selection key. The operation of SELECTQ can be paraphrased as:

\[
\text{IF } X = S_1 \text{ THEN C}_1 \ldots \text{ C}_N \text{ ELSEIF } X = S_2 \text{ THEN } \ldots \text{ ELSE DEFAULT.}
\]

If \(S_j\) is an atom, the value of \(X\) is tested to see if it is EQ to \(S_j\) (which is not evaluated). If so, the expressions \(\text{C}_1 \ldots \text{ C}_N\) are evaluated in sequence, and the value of the SELECTQ is the value of the last expression evaluated, i.e., \(\text{C}_N\).

If \(S_j\) is a list, the value of \(X\) is compared with each element (not evaluated) of \(S_j\), and if \(X\) is EQ to any one of them, then \(\text{C}_1 \ldots \text{ C}_N\) are evaluated as above.

If \(\text{CLAUSE}_j\) is not selected in one of the two ways described, \(\text{CLAUSE}_{j+1}\) is tested, etc., until all the clauses have been tested. If none is selected, DEFAULT is evaluated, and its value is returned as the value of the SELECTQ. DEFAULT must be present.
An example of the form of a SELECTQ is:

\[ \text{SELECTQ MONTH} \]
\[ \text{(FEBRUARY (if (LEAPYEARP) then 29 else 28))} \]
\[ \text{((APRIL JUNE SEPTEMBER NOVEMBER) 30)} \]
\[ 31 \]

If the value of MONTH is the litatom FEBRUARY, the SELECTQ returns 28 or 29 (depending on (LEAPYEARP)); otherwise if MONTH is APRIL, JUNE, SEPTEMBER, or NOVEMBER, the SELECTQ returns 30; otherwise it returns 31.

SELECTQ compiles open, and is therefore very fast; however, it will not work if the value of X is a list, a large integer, or floating point number, since SELECTQ uses EQ for all comparisons.

Note: SELCHARQ (page 2.15) is a version of SELECTQ that recognizes CHARCODE litatoms.

\[ \text{(SELECTC} X \text{ CLAUSE}_1 \text{ CLAUSE}_2 \ldots \text{ CLAUSE}_K \text{ DEFAULT)} \]

"SELECTQ-on-Constant." Similar to SELECTQ except that the selection keys are evaluated, and the result used as a SELECTQ-style selection key.

SELECTC is compiled as a SELECTQ, with the selection keys evaluated at compile-time. Therefore, the selection keys act like compile-time constants (see page 18.7). For example:

\[ \text{[SELECTC NUM} \]
\[ \{( \text{for X from 1 to 9 collect (TIMES X X)} \text{ "SQUARE" )} \]
\[ \text{"HIP"} \]
\[ \text{]} \]

compiles as:

\[ \text{[SELECTQ NUM} \]
\[ \{( 1 4 9 16 25 36 49 64 81) \text{ "SQUARE" )} \]
\[ \text{"HIP"} \]
\[ \text{]} \]

9.7 PROG and Associated Control Functions

\[ \text{(PROG1} X_1 X_2 \ldots X_N) \]

Evaluates its arguments in order, and returns the value of its first argument \( X_1 \). For example, (PROG1 \( X \) (SETQ \( X \) \( Y \))) sets \( X \) to \( Y \), and returns \( X \)'s original value.

\[ \text{(PROG2} X_1 X_2 \ldots X_N) \]

Similar to PROG1. Evaluates its arguments in order, and returns the value of its second argument \( X_2 \).
(PROGN \(X_1\) \(X_2\) ... \(X_N\))

[Function]

PROGN evaluates each of its arguments in order, and returns the value of its last argument. PROGN is used to specify more than one computation where the syntax allows only one, e.g., 

\((\text{SELECTQ} \ldots \ (\text{PROGN} \ldots))\) allows evaluation of several expressions as the default condition for a SELECTQ.

(PROG \(V\) \(E_1\) \(E_2\) ... \(E_N\))

This function allows the user to write an ALGOL-like program containing Interlisp expressions (forms) to be executed. The first argument, \(V\) \(VARLST\), is a list of local variables (must be NIL if no variables are used). Each atom in \(V\) \(VARLST\) is treated as the name of a local variable and bound to NIL. \(VARLST\) can also contain lists of the form \((\text{LITATOM} \ \text{FORM})\). In this case, \(LITATOM\) is the name of the variable and is bound to the value of \(FORM\). The evaluation takes place before any of the bindings are performed, e.g., 

\((\text{PROG} \ (\text{X Y} \ (\text{Y X}) ...)\) will bind local variable X to the value of Y (evaluated outside the PROG) and local variable Y to the value of X (outside the PROG). An attempt to use anything other than a litatom as a PROG variable will cause an error, ARG NOT LITATOM. An attempt to use NIL or T as a PROG variable will cause an error, ATTEMPT TO BIND NIL OR T.

The rest of the PROG is a sequence of non-atomic statements (forms) and litatoms (labels). The forms are evaluated sequentially; the labels serve only as markers. The two special functions \textsc{GO} and \textsc{RETURN} alter this flow of control as described below. The value of the PROG is usually specified by the function \textsc{RETURN}. If no \textsc{RETURN} is executed before the PROG "falls off the end," the value of the PROG is NIL.

(GO \(U\))

[Function]

\textsc{GO} is used to cause a transfer in a PROG. \((\text{GO} \ L)\) will cause the PROG to evaluate forms starting at the label \(L\) (GO does not evaluate its argument). A \textsc{GO} can be used at any level in a PROG. If the label is not found, \textsc{GO} will search higher progs \textit{within the same function}, e.g., 

\(\text{PROG} \ldots \ A \ldots \ (\text{PROG} \ldots \ (\text{GO} \ A))\). If the label is not found in the function in which the PROG appears, an error is generated, UNDEFINED OR ILLEGAL GO.

(RETURN \(X\))

A \textsc{RETURN} is the normal exit for a PROG. Its argument is evaluated and is immediately returned the value of the PROG in which it appears.

Note: If a \textsc{GO} or \textsc{RETURN} is executed in an interpreted function which is not a PROG, the \textsc{GO} or \textsc{RETURN} will be executed in the last interpreted PROG entered if any, otherwise cause an error.
GO or RETURN inside of a compiled function that is not a PROG is not allowed, and will cause an error at compile time.

As a corollary, GO or RETURN in a functional argument, e.g., to SORT, will not work compiled. Also, since NLSETQ’s and ERSETQ’s compile as separate functions, a GO or RETURN cannot be used inside of a compiled NLSETQ or ERSETQ if the corresponding PROG is outside, i.e., above, the NLSETQ or ERSETQ.

\[
\text{(LET VARLIST } E_1 E_2 \ldots E_N)\]

[Macro]

LET is essentially a PROG that can’t contain GO’s or RETURN’s, and whose last form is the returned value.

\[
\text{(LET* VARLIST } E_1 E_2 \ldots E_N)\]

[Macro]

\[
\text{(PROG* VARLIST } E_1 E_2 \ldots E_N)\]

[Macro]

(Let* and PROG* differ from LET and PROG only in that the binding of the bound variables is done "sequentially." Thus

\[
\text{(LET* ((A (LIST 5))}
\text{ (B (LIST A A)))}
\text{ (EQ A (CADR B)))}
\]

would evaluate to T; whereas the same form with LET might even find A an unbound variable when evaluating (LIST A A).

9.8 The Iterative Statement

The iterative statement (i.s.) in its various forms permits the user to specify complicated iterative statements in a straightforward and visible manner. Rather than the user having to perform the mental transformations to an equivalent Interlisp form using PROG, MAPC, MAPCAR, etc., the system does it for him. The goal was to provide a robust and tolerant facility which could "make sense" out of a wide class of iterative statements. Accordingly, the user should not feel obliged to read and understand in detail the description of each operator given below in order to use iterative statements.

An iterative statement is a form consisting of a number of special words (known as i.s. operators or i.s.oprs), followed by operands. Many i.s.oprs (FOR, DO, WHILE, etc.) are similar to iterative statements in other programming languages; other i.s.oprs (COLLECT, JOIN, IN, etc.) specify useful operations in a Lisp environment. Lower case versions of i.s.oprs (do, collect, etc.)
The following i.s.oprs are examples of a certain kind of iterative statement operator called an i.s.type. The i.s.type specifies what is to be done at each iteration. Its operand is called the "body" of the iterative statement. Each iterative statement must have one and only one i.s.type.

**DO FORM** [i.s. Operator]

Specifies what is to be done at each iteration. DO with no other operator specifies an infinite loop. If some explicit or implicit terminating condition is specified, the value of the i.s. is NIL. Translates to MAPC or MAP whenever possible.

**COLLECT FORM** [i.s. Operator]

Specifies that the value of FORM at each iteration is to be collected in a list, which is returned as the value of the i.s. when it
terminates. Translates to MAPCAR, MAPLIST or SUBSET whenever possible.

When COLLECT translates to a PROG (e.g., if UNTIL, WHILE, etc. appear in the i.s.), the translation employs an open TCONC using two pointers similar to that used by the compiler for compiling MAPCAR. To disable this translation, perform (CLDISABLE 'FCOLLECT) (see page 21.26).

**JOIN FORM**  
Similar to COLLECT, except that the values of FORM at each iteration are NCONCed. Translates to MAPCONC or MAPCON whenever possible. /NCONC, /MAPCONC, and /MAPCON are used when the CLISP declaration UNDOABLE is in effect.

**SUM FORM**  
Specifies that the values of FORM at each iteration be added together and returned as the value of the i.s., e.g., (for I from 1 to 5 sum (TIMES I I)) returns 1 + 4 + 9 + 16 + 25 = 55. IPLUS, FPPLUS, or PLUS will be used in the translation depending on the CLISP declarations in effect.

**COUNT FORM**  
Counts the number of times that FORM is true, and returns that count as its value.

**ALWAYS FORM**  
Returns T if the value of FORM is non-NIL for all iterations. (Note: returns NIL as soon as the value of FORM is NIL).

**NEVER FORM**  
Similar to ALWAYS, except returns T if the value of FORM is never true. (Note: returns NIL as soon as the value of FORM is non-NIL).

The following i.s.types explicitly refer to the iteration variable (i.v.) of the iterative statement, which is a variable set at each iteration. This is explained below under FOR.

**THEREIS FORM**  
Returns the first value of the i.v. for which FORM is non-NIL, e.g., (for X in Y thereis (NUMBERP X)) returns the first number in Y. (Note: returns the value of the i.v. as soon as the value of FORM is non-NIL).
9.8.2 Iteration Variable I.s.oprs

FOR VAR

Specifies the iteration variable (i.v.) which is used in conjunction with IN, ON, FROM, TO, and BY. The variable is rebound within the i.s., so the value of the variable outside the i.s. is not effected. Example:

\[
\begin{align*}
\leftarrow (\text{SETQ } X \ 55) \\
55 \\
\leftarrow (\text{for X from 1 to 5 collect (TIMES X X)}) \\
(1 \ 4 \ 9 \ 16 \ 25) \\
\leftarrow X \\
55
\end{align*}
\]

FOR VARS

VARS a list of variables, e.g., (for (X Y Z) ...). The first variable is the i.v., the rest are dummy variables. See BIND below.

FOR OLD VAR

Similar to FOR, except that VAR is not rebound within the i.s., so the value of the i.v. outside of the i.s. is changed. Example:

\[
\begin{align*}
\leftarrow (\text{SETQ } X \ 55) \\
55 \\
\leftarrow (\text{for old X from 1 to 5 collect (TIMES X X)}) \\
(1 \ 4 \ 9 \ 16 \ 25) \\
\leftarrow X \\
6
\end{align*}
\]

BIND VAR

BIND VARS

Used to specify dummy variables, which are bound locally within the i.s.

Note: FOR, FOR OLD, and BIND variables can be initialized by using the form VAR=FORM:
FOR OLD (X←FORM) BIND (Y←FORM) ...

IN FORM

Specifies that the i.s. is to iterate down a list with the i.v. being reset to the corresponding element at each iteration. For example, (for X in Y do ...) corresponds to (MAPC Y (FUNCTION (LAMBDA (X) ...))). If no i.v. has been specified, a dummy is supplied, e.g., (in Y collect CADR) is equivalent to (MAPCAR Y (FUNCTION CADR)).

ON FORM

Same as IN except that the i.v. is reset to the corresponding tail at each iteration. Thus IN corresponds to MAPC, MAPCAR, and MAPCONC, while ON corresponds to MAP, MAPLIST, and MAPCON.

Note: for both IN and ON, FORM is evaluated before the main part of the i.s. is entered, i.e. outside of the scope of any of the bound variables of the i.s. For example, (for X bind (Y←'(1 2 3)) in Y ...) will map down the list which is the value of Y evaluated outside of the i.s., not (1 2 3).

IN OLD VAR

Specifies that the i.s. is to iterate down VAR, with VAR itself being reset to the corresponding tail at each iteration, e.g., after (for X in old L do ... until ...) finishes, L will be some tail of its original value.

IN OLD (VAR←FORM)

Same as IN OLD VAR, except VAR is first set to value of FORM.

ON OLD VAR

Same as IN OLD VAR except the i.v. is reset to the current value of VAR at each iteration, instead of to (CAR VAR).

ON OLD (VAR←FORM)

Same as ON OLD VAR, except VAR is first set to value of FORM.

INSIDE FORM

Similar to IN, except treats first non-list, non-NIL tail as the last element of the iteration, e.g., INSIDE '(A B C D E) iterates five times with the i.v. set to E on the last iteration. INSIDE 'A is equivalent to INSIDE '(A), which will iterate once.
THE ITERATIVE STATEMENT

FROM FORM

[1.5. Operator]

Used to specify an initial value for a numerical i.v. The i.v. is automatically incremented by 1 after each iteration (unless BY is specified). If no i.v. has been specified, a dummy i.v. is supplied and initialized, e.g., (from 2 to 5 collect SQRT) returns (1.414 1.732 2.0 2.236).

TO FORM

[1.5. Operator]

Used to specify the final value for a numerical i.v. If FROM is not specified, the i.v. is initialized to 1. If no i.v. has been specified, a dummy i.v. is supplied and initialized. If BY is not specified, the i.v. is automatically incremented by 1 after each iteration. When the i.v. is definitely being incremented, i.e., either BY is not specified, or its operand is a positive number, the i.s. terminates when the i.v. exceeds the value of FORM. Similarly, when the i.v. is definitely being decremented the i.s. terminates when the i.v. becomes less than the value of FORM (see description of BY).

Note: FORM is evaluated only once, when the i.s. is first entered, and its value bound to a temporary variable against which the i.v. is checked each iteration. If the user wishes to specify an i.s. in which the value of the boundary condition is recomputed each iteration, he should use WHILE or UNTIL instead of TO.

Note: When both the operands to TO and FROM are numbers, and TO's operand is less than FROM's operand, the i.v. is decremented by 1 after each iteration. In this case, the i.s. terminates when the i.v. becomes less than the value of FORM. For example, (from 10 to 1 do PRINT) prints the numbers from 10 down to 1.

BY FORM (with IN/ON)

[1.5. Operator]

If IN or ON have been specified, the value of FORM determines the tail for the next iteration, which in turn determines the value for the i.v. as described earlier, i.e., the new i.v. is CAR of the tail for IN, the tail itself for ON. In conjunction with IN, the user can refer to the current tail within FORM by using the i.v. or the operand for IN/ON, e.g., (for Z in L by (CDR Z) ...) or (for Z in L by (CDR L) ...). At translation time, the name of the internal variable which holds the value of the current tail is substituted for the i.v. throughout FORM. For example, (for X in Y by (CDR (MEMB 'FOO (CDR X) ...))) collect X) specifies that after each iteration, CDR of the current tail is to be searched for the atom FOO, and (CDR of) this latter tail to be used for the next iteration.

BY FORM (without IN/ON)

[1.5. Operator]

If IN or ON have not been used, BY specifies how the i.v. itself is reset at each iteration. If FROM or TO have been specified, the
i.v. is known to be numerical, so the new i.v. is computed by adding the value of FORM (which is reevaluated each iteration) to the current value of the i.v., e.g., (for N from 1 to 10 by 2 collect N) makes a list of the first five odd numbers.

If FORM is a positive number (FORM itself, not its value, which in general CLISP would have no way of knowing in advance), the i.s. terminates when the value of the i.v. exceeds the value of TO’s operand. If FORM is a negative number, the i.s. terminates when the value of the i.v. becomes less than TO’s operand, e.g., (for I from N to M by -2 until (LESSP I M) ...). Otherwise, the terminating condition for each iteration depends on the value of FORM for that iteration: if FORM<0, the test is whether the i.v. is less than TO’s operand, if FORM>0 the test is whether the i.v. exceeds TO’s operand, otherwise if FORM=0, the i.s. terminates unconditionally.

If FROM or TO have not been specified and FORM is not a number, the i.v. is simply reset to the value of FORM after each iteration, e.g., (for I from N by M ...) is equivalent to (for I~N by (PLUS I M) ...).

AS VAR

Used to specify an iterative statement involving more than one iterative variable, e.g., (for X in Y as U in V do ...) corresponds to MAP2C (page 10.16). The i.s. terminates when any of the terminating conditions are met, e.g., (for X in Y as I from 1 to 10 collect X) makes a list of the first ten elements of Y, or however many elements there are on Y if less than 10.

The operand to AS, VAR, specifies the new i.v. For the remainder of the i.s., or until another AS is encountered, all operators refer to the new i.v. For example, (for I from 1 to N1 as J from 1 to N2 by 2 as K from N3 to 1 by -1 ...) terminates when I exceeds N1, or J exceeds N2, or K becomes less than 1. After each iteration, I is incremented by 1, J by 2, and K by -1.

OUTOF FORM

For use with generators (page 11.16). On each iteration, the i.v. is set to successive values returned by the generator. The i.s. terminates when the generator runs out.

9.8.3 Condition i.s.oprs

WHEN FORM

Provides a way of excepting certain iterations. For example, (for X in Y collect X when (NUMBERP X)) collects only the elements of Y that are numbers.
THE ITERATIVE STATEMENT

9.8.4 Other l.s.ops

FIRST FORM

FORM is evaluated once before the first iteration, e.g., (for X Y Z in L first (FOO Y Z) ...), and FOO could be used to initialize Y and Z.

FINALLY FORM

FORM is evaluated after the i.s. terminates. For example, (for X in L bind Y=0 do (if (ATOM X) then (SETQ Y (PLUS Y 1))) finally (RETURN Y)) will return the number of atoms in L.

EACHTIME FORM

FORM is evaluated at the beginning of each iteration before, and regardless of, any testing. For example, consider,

(for I from 1 to N
do (... (FOO I) ...)
unless (... (FOO I) ...)
until (... (FOO I) ...)
The user might want to set a temporary variable to the value of
(FOO I) in order to avoid computing it three times each iteration.
However, without knowing the translation, he would not know
whether to put the assignment in the operand to DO, UNLESS, or
UNTIL, i.e., which one would be executed first. He can avoid this
problem by simply writing EACHTIME (SETQ J (FOO I)).

DECLARE: DECL

[1.S. Operator]
Inserts the form (DECLARE DECL) immediately following the
PROG variable list in the translation, or, in the case that the
translation is a mapping function rather than a PROG,
immediately following the argument list of the lambda
expression in the translation. This can be used to declare
variables bound in the iterative statement to be compiled as
local or special variables (see page 18.5). For example (for X in Y
declare: (LOCALVARS X) ...). Several DECLARE:s can appear in
the same i.s.; the declarations are inserted in the order they
appear.

DECLARE DECL

[1.S. Operator]
Same as DECLARE:

Note that since DECLARE is also the name of a function, DECLARE
cannot be used as an i.s. operator when it appears as CAR of a
form, i.e. as the first i.s. operator in an iterative statement.
However, declare (lower-case version) can be the first i.s.
operator.

ORIGINAL I.S.OPR OPERAND

[1.S. Operator]
I.S.OPR will be translated using its original, built-in
interpretation, independent of any user defined i.s. operators.
See page 9.20.

There are also a number of i.s.oprs that make it easier to create
iterative statements that use the clock, looping for a given
period of time. See timers, page 12.16.

9.8.5 Miscellaneous Hints on I.S.Oprs

- Lowercase versions of all i.s. operators are equivalent to the
  uppercase, e.g., (for X in Y ...) is equivalent to (FOR X IN Y ...).
- Each i.s. operator is of lower precedence than all Interlisp forms,
  so parentheses around the operands can be omitted, and will be
  supplied where necessary, e.g., BIND (X Y Z) can be written BIND
X Y Z, OLD (X←FORM) as OLD X←FORM, WHEN (NUMBERP X) as WHEN NUMBERP X, etc.

- RETURN or GO may be used in any operand. (In this case, the translation of the iterative statement will always be in the form of a PROG, never a mapping function.) RETURN means return from the i.s. (with the indicated value), not from the function in which the i.s. appears. GO refers to a label elsewhere in the function in which the i.s. appears, except for the labels $SLP, $ITERATE, and $OUT which are reserved, as described below.

- In the case of FIRST, FINALLY, EACHTIME, DECLARE: or one of the i.s. types, e.g., DO, COLLECT, SUM, etc., the operand can consist of more than one form, e.g., COLLECT (PRINT (CAR X)) (CDR X), in which case a PROGN is supplied.

- Each operand can be the name of a function, in which case it is applied to the (last) i.v., e.g., (for X in Y do PRINT when NUMBERP) is the same as (for X in Y do (PRINT X) when (NUMBERP X)). Note that the i.v. need not be explicitly specified, e.g., (in Y do PRINT when NUMBERP) will work.

For i.s. types, e.g., DO, COLLECT, JOIN, the function is always applied to the first i.v. in the i.s., whether explicitly named or not. For example, (in Y as I from 1 to 10 do PRINT) prints elements on Y, not integers between 1 and 10.

Note that this feature does not make much sense for FOR, OLD, BIND, IN, or ON, since they "operate" before the loop starts, when the i.v. may not even be bound.

In the case of BY in conjunction with IN, the function is applied to the current tail e.g., (for X in Y by CDDR ...) is the same as (for X in Y by (CDDR X) ...).

- While the exact form of the translation of an iterative statement depends on which operators are present, a PROG will always be used whenever the i.s. specifies dummy variables, i.e., if a BIND operator appears, or there is more than one variable specified by a FOR operator, or a GO, RETURN, or a reference to the variable $VAL appears in any of the operands. When a PROG is used, the form of the translation is:

(PROG VARIABLES
  {initialize}
$SLP {eachtime}
  {test}
  {body}
$ITERATE
  {aftertest}
  {update}
(GO $SLP)
$OUT {finalize}
(RETURN $VAL))
where \{test\} corresponds to that portion of the loop that tests for termination and also for those iterations for which \{body\} is not going to be executed, (as indicated by a WHEN or UNLESS); \{body\} corresponds to the operand of the i.s.type, e.g., DO, COLLECT, etc.; \{aftertest\} corresponds to those tests for termination specified by REPEATWHILE or REPEATUNTIL; and \{update\} corresponds to that part that resets the tail, increments the counter, etc. in preparation for the next iteration. \{initialize\}, \{finalize\}, and \{eachtime\} correspond to the operands of FIRST, FINALLY, and EACHTIME, if any.

Note that since \{body\} always appears at the top level of the PROG, the user can insert labels in \{body\}, and GO to them from within \{body\} or from other i.s. operands, e.g., (for X in Y first (GO A) do (FOO) A (FIE)). However, since \{body\} is dwimified as a list of forms, the label(s) should be added to the dummy variables for the iterative statement in order to prevent their being dwimified and possibly "corrected", e.g., (for X in Y bind A first (GO A) do (FOO) A (FIE)). The user can also GO to $$LIP, $$ITERATE, or $$OUT, or explicitly set $$VAL.

### 9.8.6 Errors in Iterative Statements

An error will be generated and an appropriate diagnostic printed if any of the following conditions hold:

1. Operator with null operand, i.e., two adjacent operators, as in (for X in Y until do ...)
2. Operand consisting of more than one form (except as operand to FIRST, FINALLY, or one of the i.s. types), e.g., (for X in Y (PRINT X) collect ...).
3. IN, ON, FROM, TO, or BY appear twice in same i.s.
4. Both IN and ON used on same i.v.
5. FROM or TO used with IN or ON on same i.v.
6. More than one i.s. type, e.g., a DO and a SUM.

In 3, 4, or 5, an error is not generated if an intervening AS occurs. If an error occurs, the i.s. is left unchanged.

If no DO, COLLECT, JOIN or any of the other i.s. types are specified, CLISP will first attempt to find an operand consisting of more than one form, e.g., (for X in Y (PRINT X) when ATOM X ...), and in this case will insert a DO after the first form. (In this case, condition 2 is not considered to be met, and an error is not generated.) If CLISP cannot find such an operand, and no WHILE or UNTIL appears in the i.s., a warning message is printed: NO DO, COLLECT, OR JOIN: followed by the i.s.
Similarly, if no terminating condition is detected, i.e., no IN, ON, WHILE, UNTIL, TO, or a RETURN or GO, a warning message is printed: POSSIBLE NON-TERMINATING ITERATIVE STATEMENT: followed by the iterative statement. However, since the user may be planning to terminate the i.s. via an error, control-E, or a RETFROM from a lower function, the i.s. is still translated. Note: The error message is not printed if the value of CLISPI.S.GAG is T (initially NIL).

9.8.7 Defining New Iterative Statement Operators

The following function is available for defining new or redefining existing iterative statement operators:

\[
\text{(I.S.0PR NAME FORM OTHERS EVALFLG)}
\]  

[Function]

NAME is the name of the new i.s.opr. If FORM is a list, NAME will be a new i.s.type (see page 9.10, and FORM its body.

OTHERS is an (optional) list of additional i.s. operators and operands which will be added to the i.s. at the place where NAME appears. If FORM is NIL, NAME is a new i.s.opr defined entirely by OTHERS.

In both FORM and OTHERS, the atom \$\$VAL can be used to reference the value to be returned by the i.s., I.V. to reference the current i.v., and BODY to reference NAME's operand. In other words, the current i.v. will be substituted for all instances of I.V. and NAME's operand will be substituted for all instances of BODY throughout FORM and OTHERS.

If EVALFLG is T, FORM and OTHERS are evaluated at translation time, and their values used as described above. A dummy variable for use in translation that does not clash with a dummy variable already used by some other i.s. operators can be obtained by calling (GETDUMMYVAR). (GETDUMMYVAR T) will return a dummy variable and also insure that it is bound as a PROG variable in the translation.

If NAME was previously an i.s.opr and is being redefined, the message (NAME REDEFINED) will be printed (unless DFNSFLG = T), and all expressions using the i.s.opr NAME that have been translated will have their translations discarded.

The following are some examples of how I.S.OPR could be called to define some existing i.s.oprs, and create some new ones:

\[
\text{(I.S.OPR 'COLLECT '(%SETQ \$\$VAL (NCONC1 \$\$VAL BODY)))}
\]

\[
\text{SUM}
\]
(I.S.OPR 'SUM
  '(($SVAL←$SVAL + BODY)
    '(FIRST $SVAL←0))

Note: $SVAL + BODY is used instead of (IPLUS $SVAL BODY) so that the choice of function used in the translation, i.e., IPLUS, FPLUS, or PLUS, will be determined by the declarations then in effect.

NEVER

(I.S.OPR 'NEVER
  '(if BODY then $SVAL←NIL (GO $SOUT)))

Note: (if BODY then (RETURN NIL)) would exit from the i.s. immediately and therefore not execute the operations specified via a FINALLY (if any).

THEREIS

(I.S.OPR 'THEREIS
  '(if BODY then $SVAL←I.V. (GO $SOUT)))

RCOLLECT To define RCOLLECT, a version of COLLECT which uses CONS instead of NCONC1 and then reverses the list of values:

(I.S.OPR 'RCOLLECT
  '($SVAL←(CONS BODY $SVAL))
    '(FINALLY (RETURN (DREVERSE $SVAL))))

TCOLLECT To define TCOLLECT, a version of COLLECT which uses TCONC:

(I.S.OPR 'TCOLLECT
  '((TCONC $SVAL BODY))
    '(FIRST $SVAL←(CONS FINALLY (RETURN (CAR $SVAL))))]

PRODUCT

(I.S.OPR 'PRODUCT
  '($SVAL←$SVAL*BODY)
    '(FIRST $SVAL←1))

UPTO To define UPTO, a version of TO whose operand is evaluated only once:

(I.S.OPR 'UPTO
  NIL
    '(BIND $SFOO←BODY TO $SFOO))

TO To redefine TO so that instead of recomputing FORM each iteration, a variable is bound to the value of FORM, and then that variable is used:

(I.S.OPR 'TO
  NIL
    '(BIND $SEND FIRST $SEND←BODY ORIGINAL TO $SEND))

Note the use of ORIGINAL to redefine TO in terms of its original definition. ORIGINAL is intended for use in redefining built-in operators, since their definitions are not accessible, and hence
not directly modifiable. Thus if the operator had been defined by the user via I.S.OPR, ORIGINAL would not obtain its original definition. In this case, one presumably would simply modify the i.s.opr definition.

I.S.OPR can also be used to define synonyms for already defined i.s. operators by calling I.S.OPR with FORM an atom, e.g., (I.S.OPR 'WHERE 'WHEN) makes WHERE be the same as WHEN. Similarly, following (I.S.OPR 'ISTHERE 'THEREIS), one can write (ISTHERE ATOM IN Y), and following (I.S.OPR 'FIND 'FOR) and (I.S.OPR 'SUCHTHAT 'THEREIS), one can write (find X in Y suchthat X member Z). In the current system, WHERE is synonymous with WHEN, SUCHTHAT and ISTHERE with THEREIS, FIND with FOR, and THRU with TO.

If FORM is the atom MODIFIER, then NAME is defined as an i.s.opr which can immediately follow another i.s. operator (i.e., an error will not be generated, as described previously). NAME will not terminate the scope of the previous operator, and will be stripped off when DWIMIFY is called on its operand. OLD is an example of a MODIFIER type of operator. The MODIFIER feature allows the user to define i.s. operators similar to OLD, for use in conjunction with some other user defined i.s.opr which will produce the appropriate translation.

The file package command I.S.OPRS (page 17.39) will dump the definition of i.s.ops. (I.S.OPRS PRODUCT UPTO) as a file package command will print suitable expressions so that these iterative statement operators will be (re)defined when the file is loaded.
# 10. Function Definition, Manipulation, and Evaluation

## 10.1. Function Types

<table>
<thead>
<tr>
<th>Subsection</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.1.1. Lambda-Spread Functions</td>
<td>10.3</td>
</tr>
<tr>
<td>10.1.2. Nlambda-Spread Functions</td>
<td>10.4</td>
</tr>
<tr>
<td>10.1.3. Lambda-Nospread Functions</td>
<td>10.5</td>
</tr>
<tr>
<td>10.1.4. Nlambda-Nospread Functions</td>
<td>10.6</td>
</tr>
<tr>
<td>10.1.5. Compiled Functions</td>
<td>10.6</td>
</tr>
<tr>
<td>10.1.6. Function Type Functions</td>
<td>10.6</td>
</tr>
</tbody>
</table>

## 10.2. Defining Functions | 10.9 |

## 10.3. Function Evaluation | 10.11 |

## 10.4. Iterating and Mapping Functions | 10.14 |

## 10.5. Functional Arguments | 10.18 |

## 10.6. Macros | 10.21 |

### 10.6.1. DEFMACRO | 10.24 |

### 10.6.2. Interpreting Macros | 10.28 |
10. FUNCTION DEFINITION, MANIPULATION, AND EVALUATION

The Interlisp programming system is designed to help the user define and debug functions. Developing an applications program in Interlisp involves defining a number of functions in terms of the system primitives and other user-defined functions. Once defined, the user's functions may be referenced exactly like Interlisp primitive functions, so the programming process can be viewed as extending the Interlisp language to include the required functionality.

Functions are defined with a list expressions known as an "expr definition." An expr definition specifies if the function has a fixed or variable number of arguments, whether these arguments are evaluated or not, the function argument names, and a series of forms which define the behavior of the function. For example:

(LAMBDA (X Y) (PRINT X) (PRINT Y))

A function defined with this expr definition would have two evaluated arguments, X and Y, and it would execute (PRINT X) and (PRINT Y) when evaluated. Other types of expr definitions are described below.

A function is defined by putting an expr definition in the function definition cell of a litatom. There are a number of functions for accessing and setting function definition cells, but one usually defines a function with DEFINEQ (page 10.9). For example:

← (DEFINEQ (FOO (LAMBDA (X Y) (PRINT X) (PRINT Y))))
(FOO)

The expression above will define the function FOO to have the expr definition (LAMBDA (X Y) (PRINT X) (PRINT Y)). After being defined, this function may be evaluated just like any system function:

← (FOO 3 (IPLUS 3 4))
3
7
7
←

All function definition cells do not contain expr definitions. The compiler (page 18.1) translates expr definitions into compiled code objects, which execute much faster. Interlisp provides a
number of "function type functions" which determine how a given function is defined, the number and names of function arguments, etc. See page 10.7.

Usually, functions are evaluated automatically when they appear within another function or when typed into Interlisp. However, sometimes it is useful to invoke the Interlisp interpreter explicitly to apply a given "functional argument" to some data. There are a number of functions which will apply a given function repeatedly. For example, MAPCAR will apply a function (or an expr definition) to all of the elements of a list, and return the values returned by the function:

\[ \leftarrow \text{MAPCAR } '(1 2 3 4 5) \text{ (LAMBDA (X) (TIMES X X))} \]
\[ (1 4 9 16 25) \]

When using functional arguments, there are a number of problems which can arise, related with accessing free variables from within a function argument. Many times these problems can be solved using the function FUNCTION to create a FUNARG object (see page 10.18).

The macro facility provides another way of specifying the behavior of a function (see page 10.21). Macros are very useful when developing code which should run very quickly, which should be compiled differently than it is interpreted, or which should run differently in different implementations of Interlisp.

### 10.1 Function Types

Interlisp functions are defined using list expressions called "expr definitions." An expr definition is a list of the form \((\text{LAMBDA-WORD } \text{ARG-LIST } \text{FORM}_1 \ldots \text{FORM}_N)\). \text{LAMBDA-WORD} determines whether the arguments to this function will be evaluated or not, \text{ARG-LIST} determines the number and names of arguments, and \text{FORM}_1 \ldots \text{FORM}_N are a series of forms to be evaluated after the arguments are bound to the local variables in \text{ARG-LIST}.

If \text{LAMBDA-WORD} is the litatom \text{LAMBDA}, then the arguments to the function are evaluated. If \text{LAMBDA-WORD} is the litatom \text{NLAMBDA}, then the arguments to the function are not evaluated. Functions which evaluate or don't evaluate their arguments are therefore known as "lambda" or "nlambda" functions, respectively.

If \text{ARG-LIST} is \text{NIL} or a list of litatoms, this indicates a function with a fixed number of arguments. Each litatom is the name of an argument for the function defined by this expression. The process of binding these litatoms to the individual arguments is
10.1.1 Lambda-Spread Functions

Lambda-spread functions take a fixed number of evaluated arguments. This is the most common function type. A lambda-spread expr definition has the form:

\[(\text{LAMBDA } (\text{ARG}_1 \ldots \text{ARG}_M) \text{FORM}_1 \ldots \text{FORM}_N)\]

The argument list \((\text{ARG}_1 \ldots \text{ARG}_M)\) is a list of litatoms that gives the number and names of the formal arguments to the function. If the argument list is () or NIL, this indicates that the function takes no arguments. When a lambda-spread function is applied to some arguments, the arguments are evaluated, and bound to the local variables \(\text{ARG}_1 \ldots \text{ARG}_M\). Then, \(\text{FORM}_1 \ldots \text{FORM}_N\) are evaluated in order, and the value of the function is the value of \(\text{FORM}_N\).

\[
\leftarrow (\text{DEFINEQ} (\text{FOO} (\text{LAMBDA} (X Y) (\text{LIST} X Y))))
\]

\[
(\text{FOO})
\]

\[
\leftarrow (\text{FOO} 99 (\text{PLUS} 3 4))
\]

\[
(99 7)
\]
In the above example, the function FOO defined by (LAMBDA (X Y) (LIST X Y)) is applied to the arguments 99 and (PLUS 3 4), these arguments are evaluated (giving 99 and 7), the local variable X is bound to 99 and Y to 7, (LIST X Y) is evaluated, returning (99 7), and this is returned as the value of the function.

A standard feature of the Interlisp system is that no error occurs if a spread function is called with too many or too few arguments. If a function is called with too many arguments, the extra arguments are evaluated but ignored. If a function is called with too few arguments, the unsupplied ones will be delivered as NIL. In fact, a spread function cannot distinguish between being given NIL as an argument, and not being given that argument, e.g., (FOO) and (FOO NIL) are exactly the same for spread functions. If it is necessary to distinguish between these two cases, use an nlambda function and explicitly evaluate the arguments with the EVAL function (page 10.12).

10.1.2 Nlambda-Spread Functions

Nlambda-spread functions take a fixed number of unevaluated arguments. An nlambda-spread expr definition has the form:

(NLAMBDA (ARG_1 ... ARG_M) FORM_1 ... FORM_N)

Nlambda-spread functions are evaluated similarly to lambda-spread functions, except that the arguments are not evaluated before being bound to the variables ARG_1 ... ARG_M.

→ DEFINEQ (FOO (NLAMBDA (X Y) (LIST X Y)) )
(FOO)
→ (FOO 99 (PLUS 3 4))
(99 (PLUS 3 4))

In the above example, the function FOO defined by (NLAMBDA (X Y) (LIST X Y)) is applied to the arguments 99 and (PLUS 3 4), these arguments are bound unevaluated to X and Y, (LIST X Y) is evaluated, returning (99 (PLUS 3 4)), and this is returned as the value of the function.

Note: Functions can be defined so that all of their arguments are evaluated (lambda functions) or none are evaluated (nlambda functions). If it is desirable to write a function which only evaluates some of its arguments (e.g. SETQ), the function should be defined as an nlambda, with some arguments explicitly evaluated using the function EVAL (page 10.12). If this is done, the user should put the litatom EVAL on the property list of the function under the property INFO. This informs various system packages such as DWIM, CLISP, and Masterscope that this function in fact does evaluate its arguments, even though it is an nlambda.
Warning: A frequent problem that occurs when evaluating arguments to nlambda functions with EVAL (page 10.12) is that the form being evaluated may reference variables that are not accessible within the nlambda function. This is usually not a problem when interpreting code, but when the code is compiled, the values of "local" variables may not be accessible on the stack (see page 18.5). The system nlambda functions that evaluate their arguments (such as SETQ) are expanded in-line by the compiler, so this is not a problem. Using the macro facility (page 10.21) is recommended in cases where it is necessary to evaluate some arguments to an nlambda function.

10.1.3 Lambda-Nospread Functions

Lambda-nospread functions take a variable number of evaluated arguments. A lambda-nospread expr definition has the form:

\( \text{LAMBDA } \text{VAR FORM}_1 \ldots \text{FORM}_N \)

\( \text{VAR} \) may be any litatom, except NIL and T. When a lambda-nospread function is applied to some arguments, each of these arguments is evaluated and the values stored on the stack. \( \text{VAR} \) is then bound to the number of arguments which have been evaluated. For example, if \( \text{FOO} \) is defined by \((\text{LAMBDA } X \ldots)\), when \((\text{FOO} \ A \ B \ C)\) is evaluated, \( A, B, \) and \( C \) are evaluated and \( X \) is bound to 3. \( \text{VAR} \) should never be reset.

The following functions are used for accessing the arguments of lambda-nospread functions:

\( \text{ARG VAR} \ M \) \quad [\text{NLambda Function}]

Returns the \( M \)th argument for the lambda-nospread function whose argument list is \( \text{VAR} \). \( \text{VAR} \) is the name of the atomic argument list to a lambda-nospread function, and is not evaluated; \( M \) is the number of the desired argument, and is evaluated. The value of \( \text{ARG} \) is undefined for \( M \) less than or equal to 0 or greater than the value of \( \text{VAR} \).

\( \text{SETARG VAR} \ M \ X \) \quad [\text{NLambda Function}]

Sets the \( M \)th argument for the lambda-nospread function whose argument list is \( \text{VAR} \) to \( X \). \( \text{VAR} \) is not evaluated; \( M \) and \( X \) are evaluated. \( M \) should be between 1 and the value of \( \text{VAR} \).

In the example below, the function \( \text{FOO} \) is defined to collect and return a list of all of the evaluated arguments it is given (the value of the for statement).

\( \text{DEFINEQ (FOO} \)
\( \text{(LAMBDA } X \)
\( \text{(for ARGNUM from 1 to } X \text{ collect (ARG X ARGNUM)})] \)
10.1.4 Nlambda-Nospread Functions

Nlambda-nospread functions take a variable number of unevaluated arguments. An nlambda-nospread expr definition has the form:

\[(\text{Nlambda}\ VALUE\ FORM_1\ \ldots\ FORM_N)\]

\(\text{VAR}\) may be any litatom, except \text{T} and \text{NIL}. Though similar in form to lambda-nospread expr definitions, an nlambda-nospread is evaluated quite differently. When an nlambda-nospread function is applied to some arguments, \(\text{VAR}\) is simply bound to a list of the unevaluated arguments. The user may pick apart this list, and evaluate different arguments.

In the example below, \text{FOO} is defined to return the reverse of the list of arguments it is given (unevaluated):

\[
\begin{align*}
\text{FOO} & \leftarrow \text{DEFINEQ} (\text{FOO} (\text{Nlambda} \text{ X} (\text{REVERSE} \text{ X}))) \\
\text{FOO} & \leftarrow (\text{FOO} 99 (\text{PLUS} 3 4)) \\
\text{PLUS} & \leftarrow (99 7) \\
\text{PLUS} & \leftarrow (\text{FOO} 99 (\text{PLUS} 3 4) (\text{TIMES} 3 4)) \\
\text{TIMES} & \leftarrow (99 7 12)
\end{align*}
\]

Note: The warning about evaluating arguments to nlambda functions (page 10.5) also applies to nlambda-nospread function.

10.1.5 Compiled Functions

Functions defined by expr definitions can be compiled by the Interlisp compiler (page 18.1). The compiler produces compiled code objects (of data type \text{CCODEP}) which execute more quickly than the corresponding expr definition code. Functions defined by compiled code objects may have the same four types as expr definitions (lambda/nolambda, spread/nospread). Functions created by the compiler are referred to as compiled functions.

10.1.6 Function Type Functions

There are a variety of functions used for examining the type, argument list, etc. of functions. These functions may be given either a litatom, in which case they obtain the function
definition from the litatom's definition cell, or a function definition itself.

(FNTYP FN) [Function]

Returns NIL if FN is not a function definition or the name of a defined function. Otherwise FNTYP returns one of the following litatoms, depending on the type of function definition:

- EXPR: Lambda-spread expr definition.
- CEXPR: Lambda-spread compiled definition.
- FEXPR: Lambda-spread compiled definition.
- CFEXPR: Lambda-spread compiled definition.
- EXPR*: Lambda-nospread expr definition.
- CEXPR*: Lambda-nospread compiled definition.
- FEXPR*: Lambda-nospread compiled definition.
- CFEXPR*: Lambda-nospread compiled definition.
- FUNARG: FNTYP returns the litatom FUNARG if FN is a FUNARG expression. See page 10.18.

EXPR, FEXPR, EXPR*, and FEXPR* indicate that FN is defined by an expr definition. CEXPR, CFEXPR, CEXPR*, and CFEXPR* indicate that FN is defined by a compiled definition, as indicated by the prefix C. The suffix * indicates that FN has an indefinite number of arguments, i.e., is a nospread function. The prefix F indicates unevaluated arguments. Thus, for example, a CFEXPR* is a compiled nospread-nlambda function.

(EXPRP FN) [Function]

Returns T if (FNTYP FN) is either EXPR, FEXPR, EXPR*, or FEXPR*; NIL otherwise. However, (EXPRP FN) is also true if FN is (has) a list definition, even if it does not begin with LAMBDA or NLAMBDA. In other words, EXPRP is not quite as selective as FNTYP.

(CCODEP FN) [Function]

Returns T if (FNTYP FN) is either CEXPR, CFEXPR, CEXPR*, or CFEXPR*; NIL otherwise.

(ARGTYPE FN) [Function]

FN is the name of a function or its definition. ARGTYPE returns 0, 1, 2, or 3, or NIL if FN is not a function. The interpretation of this value is:

0 Lambda-spread function (EXPR, CEXPR)
1 Nlambda-spread function (FEPR, CFEXPR)
2 Lambda-nospread function (EXPR*, CEXPR*)
### FUNCTION TYPES

3. **Nlambda-nospread function (FEXPR*, CFEXPR*)**
   - i.e., `ARGLTYPE` corresponds to the rows of `FNTYP`'s.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>(NARGS FN)</strong></td>
<td>Returns the number of arguments of <code>FN</code>, or <code>NIL</code> if <code>FN</code> is not a function. If <code>FN</code> is a nospread function, the value of <code>NARGS</code> is 1.</td>
</tr>
<tr>
<td><strong>(ARGLIST FN)</strong></td>
<td>Returns the “argument list” for <code>FN</code>. Note that the “argument list” is a litatom for nospread functions. Since <code>NIL</code> is a possible value for <code>ARGLIST</code>, an error is generated, <code>ARGS NOT AVAILABLE</code>, if <code>FN</code> is not a function. If <code>FN</code> is a compiled function, the argument list is constructed, i.e., each call to <code>ARGLIST</code> requires making a new list. For functions defined by expr definitions, lists beginning with <code>LAMBDA</code> or <code>NLAMBDA</code>, the argument list is simply <code>CADR</code> of <code>GETD</code>. If <code>FN</code> has an expr definition, and <code>CAR</code> of the definition is not <code>LAMBDA</code> or <code>NLAMBDA</code>, <code>ARGLIST</code> will check to see if <code>CAR</code> of the definition is a member of <code>LAMBDASPLST</code> (page 20.14). If it is, <code>ARGLIST</code> presumes this is a function object the user is defining via <code>DWIMUSERFORMS</code> (page 20.11), and simply returns <code>CADR</code> of the definition as its argument list. Otherwise <code>ARGLIST</code> generates an error as described above.</td>
</tr>
<tr>
<td><strong>(SMARTARGLIST FN EXPLAINFLG TAIL)</strong></td>
<td>A &quot;smart&quot; version of <code>ARGLIST</code> that tries various strategies to get the arglist of <code>FN</code>. First, <code>SMARTARGLIST</code> checks the property list of <code>FN</code> under the property <code>ARGNAMES</code>. For spread functions, the argument list itself is stored. For nospread functions, the form is <code>(NIL ARGLIST₁ . ARGLIST₂)</code>, where <code>ARGLIST₁</code> is the value <code>SMARTARGLIST</code> should return when <code>EXPLAINFLG = T</code>, and <code>ARGLIST₂</code> the value when <code>EXPLAINFLG = NIL</code>. For example, <code>(GETPROP 'DEFINEQ 'ARGNAMES) = (NIL (X₁ Xᵵ ... Xₙ) . X)</code>. This allows the user to specify special argument lists. Second, if <code>FN</code> is not defined as a function, <code>SMARTARGLIST</code> attempts spelling correction on <code>FN</code> by calling <code>FNCHECK</code> (page 20.23), passing <code>TAIL</code> to be used for the call to <code>FIXSPELL</code>. If unsuccessful, an error will be generated, <code>FN NOT A FUNCTION</code>. Third, if <code>FN</code> is known to the file package (page 17.1) but not loaded in, <code>SMARTARGLIST</code> will obtain the arglist information from the file. Otherwise, <code>SMARTARGLIST</code> simply returns <code>(ARGLIST FN)</code>. <code>SMARTARGLIST</code> is used by <code>BREAK</code> (page 15.5) and <code>ADVISE</code> (page 15.11) with <code>EXPLAINFLG = NIL</code> for constructing equivalent expr...</td>
</tr>
</tbody>
</table>
10.2 Defining Functions

Function definitions are stored in a "function definition cell" associated with each litatom. This cell is directly accessible via the two functions PUTD and GETD (page 10.11), but it is usually easier to define functions with DEFINEQ:

\[
(\text{DEFINEQ } X_1 X_2 \ldots X_N)
\]

[NLambda NoSpread Function]

\text{DEFINEQ} is the function normally used for defining functions. It takes an indefinite number of arguments which are not evaluated. Each \(X_i\) must be a list defining one function, of the form \((\text{NAME} \ \text{DEFINITION})\). For example:

\[
(\text{DEFINEQ (DOUBLE (LAMBDA (X) (IPLUS X X))})
\]

The above expression will define the function DOUBLE with the expr definition \((\text{LAMBDA (X) (IPLUS X X)})\). \(X_i\) may also have the form \((\text{NAME ARGS} \ . \ \text{DEF-BODY})\), in which case an appropriate lambda expr definition will be constructed. Therefore, the above expression is exactly the same as:

\[
(\text{DEFINEQ (DOUBLE (X) (IPLUS X X))})
\]

Note that this alternate form can only be used for Lambda functions. The first form must be used to define an nlambda function.

\text{DEFINEQ} returns a list of the names of the functions defined.

\[
(\text{DEFINE X \rightarrow})
\]

Lambda-spread version of \text{DEFINEQ}. Each element of the list \(X\) is itself a list either of the form \((\text{NAME} \ \text{DEFINITION})\) or \((\text{NAME ARGS} \ . \ \text{DEF-BODY})\). \text{DEFINE} will generate an error, \text{INCORRECT DEFINING FORM}, on encountering an atom where a defining list is expected.

Note: \text{DEFINE} and \text{DEFINEQ} will operate correctly if the function is already defined and \text{BROKEN}, \text{ADVISED}, or \text{BROKEN-IN}.

For expressions involving type-in only, if the time stamp facility is enabled (page 16.76), both \text{DEFINE} and \text{DEFINEQ} will stamp the definition with the user's initials and date.
**UNSAFE.TO.MODIFY.FNS**

Value is a list of functions that should not be redefined, because doing so may cause unusual bugs (or crash the system!). If the user tries to modify a function on this list (using DEFINEQ, TRACE, etc), the system will print "Warning: XXX may be safe to modify -- continue?" If the user types "Yes", the function is modified, otherwise an error occurs. This provides a measure of safety for novices who may accidently redefine important system functions. Users can add their own functions onto this list.

Note: By convention, all functions starting with the character backslash ("\") are system internal functions, which should never be redefined or modified by the user. Backslash functions are not on UNSAFE.TO.MODIFY.FNS, so trying to redefine them will not cause a warning.

**DFNFLG**

DFNFLG is a global variable that affects the operation of DEFINEQ and DEFINE. If DFNFLG = NIL, an attempt to redefine a function FN will cause DEFINE to print the message (FN REDEFINED) and to save the old definition of FN using SAVEDEF (page 17.27) before redefining it (except if the old and new definitions are EQUAL, in which case the effect is simply a no-op). If DFNFLG = T, the function is simply redefined. If DFNFLG = PROP or ALLPROP, the new definition is stored on the property list under the property EXPR. ALLPROP also affects the operation of RPAQQ and RPAQ (page 17.54). DFNFLG is initially NIL.

DFNFLG is reset by LOAD (page 17.6) to enable various ways of handling the defining of functions and setting of variables when loading a file. For most applications, the user will not reset DFNFLG directly.

Note: The compiler does NOT respect the value of DFNFLG when it redefines functions to their compiled definitions (see page 18.1). Therefore, if you set DFNFLG to PROP to completely avoid inadvertently redefining something in your running system, you must use compile mode F, not ST.

Note: The functions SAVEDEF and UNSAVEDEF (page 17.27) can be useful for "saving" and restoring function definitions from property lists.

**GETD FN**

Returns the function definition of FN. Returns NIL if FN is not a litatom, or has no definition.

GETD of a compiled function constructs a pointer to the definition, with the result that two successive calls do not
necessarily produce EQ results. EQP or EQUAL must be used to compare compiled definitions.

**PUTD FN DEF —)**  
**[Function]**  
Puts DEF into FN's function cell, and returns DEF. Generates an error, ARG NOT LITATOM, if FN is not a litatom. Generates an error, ILLEGAL ARG, if DEF is a string, number, or a litatom other than NIL.

**MOVDF FROM TO COPYFLG —)**  
**[Function]**  
Moves the definition of FROM to TO, i.e., redefines TO. If COPYFLG = T, a COPY of the definition of FROM is used. COPYFLG = T is only meaningful for expr definitions, although MOVDF works for compiled functions as well. MOVDF returns TO.

COPYDEF (page 17.27) is a higher-level function that only moves expr definitions, but works also for variables, records, etc.

**MOVDF? FROM TO COPYFLG —)**  
**[Function]**  
if TO is not defined, same as (MOVDF FROM TO COPYFLG). Otherwise, does nothing and returns NIL.

### 10.3 Function Evaluation

Usually, function application is done automatically by the Interlisp interpreter. If a form is typed into Interlisp whose CAR is a function, this function is applied to the arguments in the CDR of the form. These arguments are evaluated or not, and bound to the function parameters, as determined by the type of the function, and the body of the function is evaluated. This sequence is repeated as each form in the body of the function is evaluated.

There are some situations where it is necessary to explicitly call the evaluator, and Interlisp supplies a number of functions that will do this. These functions take "functional arguments", which may either be litatoms with function definitions, or expr definition forms such as (LAMBDA (X) ...), or FUNARG expressions (see page 10.18).

**APPLY FN ARGLIST —)**  
**[Function]**  
Applies the function FN to the arguments in the list ARGLIST, and returns its value. APPLY is a lambda function, so its arguments are evaluated, but the individual elements of ARGLIST are not evaluated. Therefore, lambda and nlambda functions are treated the same by APPLY—lambda functions take their...
arguments from ARGLIST without evaluating them. For example:

\[-\text{APPLV}'\text{APPEND}'((\text{PLUS} \ 1 \ 2 \ 3) \ (4 \ 5 \ 6)))\]
\[\text{(PLUS} \ 1 \ 2 \ 3 \ 4 \ 5 \ 6)\]

Note that FN may explicitly evaluate one or more of its arguments itself. For example, the system function SETQ is an nlambda function that explicitly evaluates its second argument. Therefore, (APPLY 'SETQ '(FOO (ADD1 3))) will set FOO to 4, instead of setting it to the expression (ADD1 3).

APPLY can be used for manipulating expr definitions, for example:

\[-\text{APPLV}'\text{LAMBDA}(X \ Y) (\text{TIMES} \ X \ Y)'(3 \ 4))\]
\[12\]

\[(\text{APPLV* FN ARG1 ARG2 ... ARGN})\]

[NoSpread Function]

Nospread version of APPLY. Applies the function FN to the arguments ARG1 ARG2 ... ARGN. For example,

\[-\text{APPLV* 'APPEND}'((\text{PLUS} \ 1 \ 2 \ 3) \ '(4 \ 5 \ 6))\]
\[\text{(PLUS} \ 1 \ 2 \ 3 \ 4 \ 5 \ 6)\]

\[(\text{EVAL X —})\]

[Function]

EVAL evaluates the expression X and returns this value, i.e., EVAL provides a way of calling the Interlisp interpreter. Note that EVAL is itself a lambda function, so its argument is first evaluated, e.g.,

\[-\text{SETQ FOO}'(\text{ADD1} \ 3))\]
\[\text{(ADD1} \ 3)\]
\[-\text{EVAL FOO}\]
\[4\]
\[-\text{EVAL 'FOO}\]
\[\text{(ADD1} \ 3)\]

\[(\text{QUOTE X})\]

[NLlambda NoSpread Function]

QUOTE prevents its arguments from being evaluated. Its value is X itself, e.g., (QUOTE FOO) is FOO.

Interlisp functions can either evaluate or not evaluate their arguments. QUOTE can be used in those cases where it is desirable to specify arguments unevaluated.

Note: The character single-quote (') is defined with a read macro so it returns the next expression, wrapped in a call to QUOTE (page 25.42). For example, 'FOO reads as (QUOTE FOO). This is the form used for examples in this manual.

Since giving QUOTE more than one argument is almost always a parentheses error, and one that would otherwise go undetected,
QUOTEMay 1981

Function Evaluation

QUOTE itself generates an error in this case, PARENTHESIS ERROR.

(KWOTE X) [Function]
Value is an expression which when evaluated yields X. If X is NIL or a number, this is X itself. Otherwise, (LIST (QUOTE QUOTE) X). For example,

(KWOTE 5) = > 5
(KWOTE (CONS 'A 'B)) = > (QUOTE (A . B))

(NLAMBDA.ARGS X) [Function]
This function interprets its argument as a list of unevaluated Nlambda arguments. If any of the elements in this list are of the form (QUOTE ...), the enclosing QUOTE is stripped off. Actually, NLAMBDA.ARGS stops processing the list after the first non-quoted argument. Therefore, whereas (NLAMBDA.ARGS '((QUOTE FOO) BAR)) - > (FOO BAR), (NLAMBDA.ARGS '(FOO (QUOTE BAR))) - > (FOO (QUOTE BAR)).

NLAMBDA.ARGS is called by a number of nlambda functions in the system, to interpret their arguments. For instance, the function BREAK calls NLAMBDA.ARGS so that (BREAK 'FOO) will break the function FOO, rather than the function QUOTE.

(EVALA X A) [Function]
Simulates association list variable lookup. X is a form, A is a list of the form:

((NAME_1 . VAL_1) (NAME_2 . VAL_2) ... (NAME_N . VAL_N))

The variable names and values in A are "spread" on the stack, and then X is evaluated. Therefore, any variables appearing free in X, that also appears as CAR of an element of A will be given the value in the CDR of that element.

(DEFEVAL TYPE FN) [Function]
Specifies how a datum of a particular type is to be evaluated. Intended primarily for user defined data types, but works for all data types except lists, literal atoms, and numbers. TYPE is a type name. FN is a function object, i.e. name of a function or a lambda expression. Whenever the interpreter encounters a datum of the indicated type, FN is applied to the datum and its value returned as the result of the evaluation. DEFEVAL returns the previous evaling function for this type. If FN = NIL, DEFEVAL returns the current evaling function without changing it. If FN = T, the evaling function is set back to the system default (which for all data types except lists is to return the datum itself).
Note: COMPILETYPELST (page 18.11) permits the user to specify how a datum of a particular type is to be compiled.

(EVALHOOK FORM EVALHOOKFN) [Function]

EVALHOOK evaluates the expression FORM, and returns its value. While evaluating FORM, the function EVAL behaves in a special way. Whenever a list other than FORM itself is to be evaluated, whether implicitly or via an explicit call to EVAL, EVALHOOKFN is invoked (it should be a function), with the form to be evaluated as its argument. EVALHOOKFN is then responsible for evaluating the form; whatever is returned is assumed to be the result of evaluating the form. During the execution of EVALHOOKFN, this special evaluation is turned off. (Note that EVALHOOK does not effect the evaluations of variables, only of lists).

Here is an example of a simple tracing routine that uses the EVALHOOK feature:

\begin{verbatim}
<- DEFINEQ (PRINTHOOK (FORM)
  (printout T "eval: " FORM T)
  (EVALHOOK FORM (FUNCTION PRINTHOOK)
(PRINTHOOK))
\end{verbatim}

Using PRINTHOOK, one might see the following interaction:

\begin{verbatim}
<- (EVALHOOK '(LIST (CONS 1 2) (CONS 3 4)) 'PRINTHOOK)
eval: (CONS 1 2)
eval: (CONS 3 4)
((1 . 2) (3 . 4))
\end{verbatim}

10.4 Iterating and Mapping Functions

The functions below are used to evaluate a form or apply a function repeatedly. RPT, RPTQ, and FRPTQ evaluate an expression a specified number of times. MAP, MAPCAR, MAPLIST, etc. apply a given function repeatedly to different elements of a list, possibly constructing another list.

These functions allow efficient iterative computations, but they are difficult to use. For programming iterative computations, it is usually better to use the CLISP Iterative Statement facility (page 9.9), which provides a more general and complete facility for expressing iterative statements. Whenever possible, CLISP translates iterative statements into expressions using the functions below, so there is no efficiency loss.
(RPT N FORM) [Function]
Evaluates the expression FORM, N times. Returns the value of the last evaluation. If N less than or equal to 0, FORM is not evaluated, and RPT returns NIL.
Before each evaluation, the local variable RPTN is bound to the number of evaluations yet to take place. This variable can be referenced within FORM. For example, (RPT 10 '(PRINT RPTN)) will print the numbers 10, 9, ..., 1, and return 1.

(RPTQ N FORM1 FORM2 ... FORMN) [NLambda NoSpread Function]
Nlambda-nospread version of RPT: N is evaluated, FORMi are not. Returns the value of the last evaluation of FORMN.

(FRPTQ N FORM1 FORM2 ... FORMN) [NLambda NoSpread Function]
Faster version of RPTQ. Does not bind RPTN.

(MAP MAPX MAPFN1 MAPFN2) [Function]
If MAPFN2 is NIL, MAP applies the function MAPFN1 to successive tails of the list MAPX. That is, first it computes (MAPFN1 MAPX), and then (MAPFN1 (CDR MAPX)), etc., until MAPX becomes a non-list. If MAPFN2 is provided, (MAPFN2 MAPX) is used instead of (CDR MAPX) for the next call for MAPFN1, e.g., if MAPFN2 were CDDR, alternate elements of the list would be skipped. MAP returns NIL.

(MAPC MAPX MAPFN1 MAPFN2) [Function]
Identical to MAP, except that (MAPFN1 (CAR MAPX)) is computed at each iteration instead of (MAPFN1 MAPX), i.e., MAPC works on elements, MAP on tails. MAPC returns NIL.

(MAPLIST MAPX MAPFN1 MAPFN2) [Function]
Successively computes the same values that MAP would compute, and returns a list consisting of those values.

(MAPCAR MAPX MAPFN1 MAPFN2) [Function]
Computes the same values that MAPC would compute, and returns a list consisting of those values, e.g., (MAPCAR X 'FNTYP) is a list of FNTYPs for each element on X.

(MAPCON MAPX MAPFN1 MAPFN2) [Function]
Computes the same values as MAP and MAPLIST but NCONCs these values to form a list which it returns.
(MAPCONC MAPX MAPFN1 MAPFN2) [Function]
Computes the same values as MAPC and MAPCAR, but NCONCs the values to form a list which it returns.

Note that MAPCAR creates a new list which is a mapping of the old list in that each element of the new list is the result of applying a function to the corresponding element on the original list. MAPCONC is used when there are a variable number of elements (including none) to be inserted at each iteration. Examples:

(MAPCONC '(A B C NIL D NIL)
       '(LAMBDA (Y) (if (NULL Y) then NIL else (LIST Y))))
=> (A B C D)

This MAPCONC returns a list consisting of MAPX with all NILs removed.

(MAPCONC '((A B) (C (D E F)) (G) H I)
       '(LAMBDA (Y) (if (LISP Y) then Y else NIL)))
=> (A B D E F G)

This MAPCONC returns a linear list consisting of all the lists on MAPX.

Since MAPCONC uses NCONC to string the corresponding lists together, in this example the original list will be altered to be ((A B D E F G) C (D E F G) (G) H I). If this is an undesirable side effect, the functional argument to MAPCONC should return instead a top level copy of the lists, i.e. (LAMBDA (Y) (if (LISTP Y) then (APPEND Y) else NIL)).

(MAP2C MAPX MAPY MAPFN1 MAPFN2) [Function]
Identical to MAPC except MAPFN1 is a function of two arguments, and (MAPFN1 (CAR MAPX) (CAR MAPY)) is computed at each iteration. Terminates when either MAPX or MAPY is a non-list.

MAPFN2 is still a function of one argument, and is applied twice on each iteration; (MAPFN2 MAPX) gives the new MAPX, (MAPFN2 MAPY) the new MAPY. CDR is used if MAPFN2 is not supplied, i.e., is NIL.

(MAP2CAR MAPX MAPY MAPFN1 MAPFN2) [Function]
Identical to MAPCAR except MAPFN1 is a function of two arguments and (MAPFN1 (CAR MAPX) (CAR MAPY)) is used to assemble the new list. Terminates when either MAPX or MAPY is a non-list.
ITERATING AND MAPPING FUNCTIONS

(SUBSET MAPX MAPFN1 MAPFN2) [Function]
Applies MAPFN1 to elements of MAPX and returns a list of those elements for which this application is non-NIL, e.g.,

(SUBSET '(A B 3 C 4) 'NUMBERP) = (3 4).

MAPFN2 plays the same role as with MAP, MAPC, et al.

(EVERY EVERYX EVERYFN1 EVERYFN2) [Function]
Returns T if the result of applying EVERYFN1 to each element in EVERYX is true, otherwise NIL. For example, (EVERY '(X Y Z) 'ATOM) = > T.

EVERY operates by evaluating (EVERYFN1 (CAR EVERYX) EVERYX). The second argument is passed to EVERYFN1 so that it can look at the next element on EVERYX if necessary. If EVERYFN1 yields NIL, EVERY immediately returns NIL. Otherwise, EVERY computes (EVERYFN2 EVERYX), or (CDR EVERYX) if EVERYFN2 = NIL, and uses this as the "new" EVERYX, and the process continues. For example, (EVERY X 'ATOM 'CDDR) is true if every other element of X is atomic.

(SOME SOMEX SOMEFN1 SOMEFN2) [Function]
Returns the tail of SOMEX beginning with the first element that satisfies SOMEFN1, i.e., for which SOMEFN1 applied to that element is true. Value is NIL if no such element exists. (SOME X '(LAMBDA (Z) (EQUAL Z Y))) is equivalent to (MEMBER Y X).

SOME operates analogously to EVERY. At each stage, (SOMEFN1 (CAR SOMEX) SOMEX) is computed, and if this is not NIL, SOMEX is returned as the value of SOME. Otherwise, (SOMEFN2 SOMEX) is computed, or (CDR SOMEX) if SOMEFN2 = NIL, and used for the next SOMEX.

(NOTANY SOMEX SOMEFN1 SOMEFN2) [Function]
(NOT (SOME SOMEX SOMEFN1 SOMEFN2))

(NOEVERY EVERYX EVERYFN1 EVERYFN2) [Function]
(NOT (EVERY EVERYX EVERYFN1 EVERYFN2))

(MAPPRINT LST FILE LEFT RIGHT SEP PFN LISPXPRINTFLG) [Function]
A general printing function. For each element of the list LST, applies PFN to the element, and FILE. If PFN is NIL, PRINT1 is used. Between each application, MAPPRINT performs PRINT1 of SEP (or " " if SEP = NIL). If LEFT is given, it is printed (using PRINT1) initially; if RIGHT is given it is printed (using PRINT1) at the end.

For example, (MAPPRINT X NIL '%( '%)) is equivalent to PRINT1 for lists. To print a list with commas between each element and a final "." one could use (MAPPRINT X T NIL '%. '%).
If \( \text{LISPXPRINTFLG} = \text{T} \), \( \text{LISPXPRIN1} \) (page 13.25) is used instead of \( \text{PRIN1} \).

10.5 Functional Arguments

The functions that call the Interlisp-D evaluator take "functional arguments", which may either be litatoms with function definitions, or expr definition forms such as \( \text{(LAMBDA (X) ...)} \), or \( \text{FUNARG} \) expressions (below).

The following functions are useful when one wants to supply a functional argument which will always return NIL, T, or 0. Note that the arguments \( X_1 \ldots X_N \) to these functions are evaluated, though they are not used.

\[
\begin{align*}
\text{(NIL } X_1 \ldots X_N) & \quad \text{[NoSpread Function]} \\
\text{Returns NIL.} \\
\text{(TRUE } X_1 \ldots X_N) & \quad \text{[NoSpread Function]} \\
\text{Returns T.} \\
\text{(ZERO } X_1 \ldots X_N) & \quad \text{[NoSpread Function]} \\
\text{Returns 0.}
\end{align*}
\]

When using expr definitions as functional arguments, they should be enclosed within the function \( \text{FUNCTION} \) rather than \( \text{QUOTE} \), so that they will be compiled as separate functions. \( \text{FUNCTION} \) can also be used to create \( \text{FUNARG} \) expressions, which can be used to solve some problems with referencing free variables, or to create functional arguments which carry "state" along with them.

\[
\text{(FUNCTION } \text{FN ENV}) \quad \text{[NLambda Function]}
\]

If \( \text{ENV} = \text{NIL} \), \( \text{FUNCTION} \) is the same as \( \text{QUOTE} \), except that it is treated differently when compiled. Consider the function definition:

\[
\text{(DEFINEQ (FOO (LST))}
\quad \text{(FIE LST (FUNCTION (LAMBDA (Z) (ITIMES Z Z))))}
\]

\( \text{FOO} \) calls the function \( \text{FIE} \) with the value of \( \text{LST} \) and the expr definition \( \text{(LAMBDA (Z) (LIST (CAR Z))} \).

If \( \text{FOO} \) is run interpreted, it doesn't make any difference whether \( \text{FUNCTION} \) or \( \text{QUOTE} \) is used. However, when \( \text{FOO} \) is compiled, if \( \text{FUNCTION} \) is used the compiler will define and compile the expr
FUNCTIONAL ARGUMENTS

definition as an auxiliary function (See page 18.10). The compiled expr definition will run considerably faster, which can make a big difference if it is applied repeatedly.

Note: Compiling FUNCTION will not create an auxiliary function if it is a functional argument to a function that compiles open, such as most of the mapping functions (MAPCAR, MAPLIST, etc.).

If ENV is not NIL, it can be a list of variables that are (presumably) used freely by FN. In this case, the value of FUNCTION is an expression of the form (FUNARG FN POS), where POS is a stack pointer to a frame that contains the variable bindings for those variables on ENV. ENV can also be a stack pointer itself, in which case the value of FUNCTION is (FUNARG FN ENV). Finally, ENV can be an atom, in which case it is evaluated, and the value interpreted as described above.

As explained above, one of the possible values that FUNCTION can return is the form (FUNARG FN POS), where FN is a function and POS is a stack pointer. FUNARG is not a function itself. Like LAMBDA and NLAMBDA, it has meaning and is specially recognized by Interlisp only in the context of applying a function to arguments. In other words, the expression (FUNARG FN POS) is used exactly like a function. When a FUNARG expression is applied or is CAR of a form being EVAL'ed, the APPLY or EVAL takes place in the access environment specified by ENV (see page 11.1). Consider the following example:

\[
\begin{align*}
&\leftarrow (\text{DEFINEQ} (\text{DO.TWICE} (\text{FN} \text{VAL})) \\
&\quad (\text{APPLY*} \text{FN} (\text{APPLY*} \text{FN} \text{VAL}))) \\
&\begin{align*}
&\text{(DO.TWICE)} \\
&\quad \leftarrow (\text{DO.TWICE} [\text{FUNCTION} (\text{LAMBDA} (X) (\text{IPLUS} X \text{X})]) \\
&\quad \quad 5) \\
&\quad 20 \\
&\quad \leftarrow (\text{SETQ} \text{VAL} 1) \\
&\quad 1 \\
&\quad \leftarrow (\text{DO.TWICE} [\text{FUNCTION} (\text{LAMBDA} (X) (\text{IPLUS} X \text{VAL})]) \\
&\quad \quad 5) \\
&\quad 15 \\
&\quad \leftarrow (\text{DO.TWICE} [\text{FUNCTION} (\text{LAMBDA} (X) (\text{IPLUS} X \text{VAL})) (\text{VAL})] \\
&\quad \quad 5) \\
&\quad 7
\end{align*}
\end{align*}
\]

DO.TWICE is defined to apply a function FN to a value VAL, and apply FN again to the value returned; in other words it calculates (FN (FN VAL)). Given the expr definition (LAMBDA (X) (IPLUS X X)), which doubles a given value, it correctly calculates (FN (FN 5)) = (FN 10) = 20. However, when given (LAMBDA (X) (IPLUS X VAL)), which should add the value of the global variable VAL to the argument X, it does something unexpected, returning 15, rather than 5 + 1 + 1 = 7. The problem is that when the expr
FUNCTIONAL ARGUMENTS

definition is evaluated, it is evaluated in the context of 
DO.TWICE, where VAL is bound to the second argument of 
DO.TWICE, namely 5. In this case, one solution is to use the ENV 
argument to FUNCTION to construct a FUNARG expression which 
contains the value of VAL at the time that the FUNCTION is 
executed. Now, when (LAMBDA (X) (IPLUS X VAL)) is evaluated, 
it is evaluated in an environment where the global value of VAL 
is accessible. Admittedly, this is a somewhat contrived example 
(it would be easy enough to change the argument names to 
DO.TWICE so there would be no conflict), but this situation arises 
ocasionally with large systems of programs that construct 
functions, and pass them around.

Note: System functions with functional arguments (APPLY, 
MAPCAR, etc.) are compiled so that their arguments are local, 
and not accessible (see page 18.5). This reduces problems with 
conflicts with free variables used in functional arguments.

FUNARG expressions can be used for more than just 
circumventing the clashing of variables. For example, a FUNARG 
expression can be returned as the value of a computation, and 
then used "higher up". Furthermore, if the function in a 
FUNARG expression sets any of the variables contained in the 
frame, only the frame would be changed. For example, consider 
the following function:

<- (DEFINEQ (MAKECOUNTER (CNT)) 
  (FUNCTION [LAMBDA NIL 
    (PROG1 CNT (SETQ CNT (ADD1 CNT) 
      (CNT)))))

The function MAKECOUNTER returns a FUNARG that increments 
and returns the previous value of the counter CNT. However, this 
是 done within the environment of the call to MAKECOUNTER 
where FUNCTION was executed, which the FUNARG expression 
"carries around" with it, even after MAKECOUNTER has finished 
executing. Note that each call to MAKECOUNTER creates a 
FUNARG expression with a new, independent environment, so 
that multiple counters can be generated and used:

<- (SETQ C1 (MAKECOUNTER 1)) 
(FUNARG (LAMBDA NIL (PROG1 CNT (SETQ CNT (ADD1 CNT)))))
#1,13724/*FUNARG) 
<- (APPLY C1) 
1 
<- (APPLY C1) 
2 
<- (SETQ C2 (MAKECOUNTER 17)) 
(FUNARG (LAMBDA NIL (PROG1 CNT (SETQ CNT (ADD1 CNT)))))
#1,13736/*FUNARG) 
<- (APPLY C2) 
17
10.6 Macros

Macros provide an alternative way of specifying the action of a function. Whereas function definitions are evaluated with a "function call", which involves binding variables and other housekeeping tasks, macros are evaluated by translating one Interlisp form into another, which is then evaluated.

A litatom may have both a function definition and a macro definition. When a form is evaluated by the interpreter, if the CAR has a function definition, it is used (with a function call), otherwise if it has a macro definition, then that is used. However, when a form is compiled, the CAR is checked for a macro definition first, and only if there isn't one is the function definition compiled. This allows functions that behave differently when compiled and interpreted. For example, it is possible to define a function that, when interpreted, has a function definition that is slow and has a lot of error checks, for use when debugging a system. This function could also have a macro definition that defines a fast version of the function, which is used when the debugged system is compiled.

Macro definitions are represented by lists that are stored on the property list of a litatom. Macros are often used for functions that should be compiled differently in different Interlisp implementations, and the exact property name a macro definition is stored under determines whether it should be used in a particular implementation. The global variable MACROPROPS contains a list of all possible macro property names which should be saved by the MACROS file package command. Typical macro property names are DMACRO for Interlisp-D, 10MACRO for Interlisp-10, VAXMACRO for Interlisp-VAX, JMACRO for Interlisp-Jerico, and MACRO for...
"implementation independent" macros. The global variable \texttt{COMPILERMACROPROPS} is a list of macro property names. Interlisp determines whether a litatom has a macro definition by checking these property names, in order, and using the first non-\texttt{NIL} property value as the macro definition. In Interlisp-D this list contains \texttt{DMACRO} and \texttt{MACRO} in that order so that \texttt{DMACROS} will override the implementation-independent \texttt{MACRO} properties. In general, use a \texttt{DMACRO} property for macros that are to be used only in Interlisp-D, use \texttt{10MACRO} for macros that are to be used only in Interlisp-10, and use \texttt{MACRO} for macros that are to affect both systems.

Macro definitions can take the following forms:

- \texttt{(LAMBDA ...)}
- \texttt{(NLAMBDA ...)}

A function can be made to compile open by giving it a macro definition of the form \texttt{(LAMBDA ...)} or \texttt{(NLAMBDA ...)}, e.g.,
\[
\texttt{(LAMBDA (X) (COND ((GREATERP X 0) X) (T (MINUS X))) for ABS.}
\]
The effect is as if the macro definition were written in place of the function wherever it appears in a function being compiled, i.e., it compiles as a lambda or nlambda expression. This saves the time necessary to call the function at the price of more compiled code generated in-line.

- \texttt{(NIL EXPRESSION)}
- \texttt{(LIST EXPRESSION)}

"Substitution" macro. Each argument in the form being evaluated or compiled is substituted for the corresponding atom in \texttt{LIST}, and the result of the substitution is used instead of the form. For example, if the macro definition of \texttt{ADD1} is \texttt{((X) (IPLUS X 1))}, then, \texttt{(ADD1 (CAR Y))} is compiled as \texttt{(IPLUS (CAR Y) 1)}.

Note that \texttt{ABS} could be defined by the substitution macro \texttt{((X) (COND ((GREATERP X 0) X) (T (MINUS X)))}. In this case, however, \texttt{(ABS (FOO X))} would compile as

\[
\texttt{(COND ((GREATERP (FOO X) 0)}
\begin{align*}
\texttt{(FOO X)}
\texttt{(T (MINUS (FOO X)))}
\end{align*}
\]

and \texttt{(FOO X)} would be evaluated two times. (Code to evaluate \texttt{(FOO X)} would be generated three times.)

This is a cross between substitution and \texttt{LAMBDA} macros. When the compiler processes an \texttt{OPENLAMBDA}, it attempts to substitute the actual arguments for the formals wherever this preserves the frequency and order of evaluation that would have resulted from a \texttt{LAMBDA} expression, and produces a \texttt{LAMBDA} binding only for those that require it.

Note: \texttt{OPENLAMBDA} assumes that it can substitute literally the actual arguments for the formal arguments in the body of the macro if the actual is side-effect free or a constant. Thus, you should be careful to use names in \texttt{ARGS} which don't occur in

\texttt{FUNCTION DEFINITION, MANIPULATION, AND EVALUATION}
BODY (except as variable references). For example, if FOO has a macro definition of

(OPENLAMBDA (ENV) (FETCH (MY-RECORD-TYPE ENV) OF BAR))

then (FOO NIL) will expand to

(FETCH (MY-RECORD-TYPE NIL) OF BAR)

T When a macro definition is the atom T, it means that the compiler should ignore the macro, and compile the function definition; this is a simple way of turning off other macros. For example, the user may have a function that runs in both Interlisp-D and Interlisp-10, but has a macro definition that should only be used when compiling in Interlisp-10. If the MACRO property has the macro specification, a DMACRO of T will cause it to be ignored by the Interlisp-D compiler. Note that this DMACRO would not be necessary if the macro were specified by a 10MACRO instead of a MACRO.

(= . OTHER-FUNCTION) A simple way to tell the compiler to compile one function exactly as it would compile another. For example, when compiling in Interlisp-D, FRPLACAS are treated as RPLACAS. This is achieved by having FRPLACA have a DMACRO of (= . RPLACA).

(LITATOM EXPRESSION) If a macro definition begins with a litatom other than those given above, this allows computation of the Interlisp expression to be evaluated or compiled in place of the form. LITATOM is bound to the CDR of the calling form, EXPRESSION is evaluated, and the result of this evaluation is evaluated or compiled in place of the form. For example, LIST could be compiled using the computed macro:

[X (LIST 'CONS
    (CAR X)
    (AND (CDR X)
    (CONS 'LIST
    (CDR X))

This would cause (LIST X Y Z) to compile as (CONS X (CONS Y (CONS Z NIL))). Note the recursion in the macro expansion.

If the result of the evaluation is the litatom IGNOREMACRO, the macro is ignored and the compilation of the expression proceeds as if there were no macro definition. If the litatom in question is normally treated specially by the compiler (CAR, CDR, COND, AND, etc.), and also has a macro, if the macro expansion returns IGNOREMACRO, the litatom will still be treated specially.

In Interlisp-10, if the result of the evaluation is the atom INSTRUCTIONS, no code will be generated by the compiler. It is then assumed the evaluation was done for effect and the necessary code, if any, has been added. This is a way of giving direct instructions to the compiler if you understand it.
Note: It is often useful, when constructing complex macro expressions, to use the BQUOTE facility (see page 25.42).

The following function is quite useful for debugging macro definitions:

\[
\text{(EXPANDMACRO EXP QUIETFLG ---) [Function]}
\]

Takes a form whose CAR has a macro definition and expands the form as it would be compiled. The result is prettyprinted, unless QUIETFLG = T, in which case the result is simply returned.

10.6.1 DEFMACRO

Macros defined with the function DEFMACRO are much like "computed" macros (page 10.23), in that they are defined with a form that is evaluated, and the result of the evaluation is used (evaluated or compiled) in place of the macro call. However, DEFMACRO macros support complex argument lists with optional arguments, default values, and keyword arguments. In addition, argument list destructuring is supported.

\[
\text{(DEFMACRO NAME ARGS FORM) [NLambda NoSpread Function]}
\]

Defines NAME as a macro with the arguments ARGS and the definition form FORM (NAME, ARGS, and FORM are unevaluated). If an expression starting with NAME is evaluated or compiled, arguments are bound according to ARGS, FORM is evaluated, and the value of FORM is evaluated or compiled instead. The interpretation of ARGS is described below.

Note: Unlike the function DEFMACRO in Common Lisp, this function currently does not remove any function definition for NAME.

ARGS is a list that defines how the argument list passed to the macro NAME is interpreted. Specifically, ARGS defines a set of variables that are set to various arguments in the macro call (unevaluated), that FORM can reference to construct the macro form.

In the simplest case, ARGS is a simple list of variable names that are set to the corresponding elements of the macro call (unevaluated). For example, given:

\[
\text{(DEFMACRO FOO (A B) (LIST 'PLUS A B))}
\]

The macro call (FOO X (BAR Y Z)) will expand to (PLUS X (BAR Y Z) (BAR Y Z)).

The list ARGS can include any of a number of special "&-keywords" (beginning with the character "&") that are used
to set variables to particular items from the macro call form, as follows:

&OPTIONAL

Used to define optional arguments, possibly with default values. Each element on ARGS after &OPTIONAL until the next &-keyword or the end of the list defines an optional argument, which can either be a litatom or a list, interpreted as follows:

VAR

If an optional argument is specified as a litatom, that variable is set to the corresponding element of the macro call (unevaluated).

(VAR DEFAULT)

If an optional argument is specified as a two element list, VAR is the variable to be set, and DEFAULT is a form that is evaluated and used as the default if there is no corresponding element in the macro call.

(VAR DEFAULT VARSETP)

If an optional argument is specified as a three element list, VAR and DEFAULT are the variable to be set and the default form, and VARSETP is a variable that is set to T if the optional argument is given in the macro call, NIL otherwise. This can be used to determine whether the argument was not given, or whether it was specified with the default value.

For example, after

(DEFMACRO FOO (&OPTIONAL A (B 5) (C 6 CSET)) FORM)

expanding the macro call (FOO) would cause FORM to be evaluated with A set to NIL, B set to 5, C set to 6, and CSET set to NIL. (FOO 4 5 6) would be the same, except that A would be set to 4 and CSET would be set to T.

&REST

&BODY

Used to get a list of all additional arguments from the macro call. Either &REST or &BODY should be followed by a single litatom, which is set to a list of all arguments to the macro after the position of the &-keyword. For example, given

(DEFMACRO FOO (A B &REST C) FORM)

expanding the macro call (FOO 1 2 3 4 5) would cause FORM to be evaluated with A set to 1, B set to 2, and C set to (3 4 5).

Note: If the macro calling form contains keyword arguments (see &KEY below) these are included in the &REST list.

&KEY

Used to define keyword arguments, that are specified in the macro call by including a "keyword" (a litatom starting with the character ":") followed by a value.

Each element on ARGS after &KEY until the next &-keyword or the end of the list defines a keyword argument, which can either be a litatom or a list, interpreted as follows:
VAR
(VAR)
((KEYWORD VAR))

If a keyword argument is specified by a single litatom VAR, or a one-element list containing VAR, it is set to the value of a keyword argument, where the keyword used is created by adding the character ":" to the front of VAR. If a keyword argument is specified by a single-element list containing a two-element list, KEYWORD is interpreted as the keyword (which should start with the letter ":"), and VAR is the variable to set.

(VAR DEFAULT)
((KEYWORD VAR) DEFAULT)
(VAR DEFAULT VARSETP)
((KEYWORD VAR) DEFAULT VARSETP)

If a keyword argument is specified by a two or three-element list, the first element of the list specifies the keyword and variable to set as above. Similar to &OPTIONAL (above), the second element DEFAULT is a form that is evaluated and used as the default if there is no corresponding element in the macro call, and the third element VARSETP is a variable that is set to T if the optional argument is given in the macro call, NIL otherwise.

For example, the form

(DEFMACRO FOO (&KEY A (B 5 BSET) (:BAR C) 6 CSET) FORM)

Defines a macro with keys :A, :B (defaulting to 5), and :BAR. Expanding the macro call (FOO :BAR 2 :A 1) would cause FORM to be evaluated with A set to 1, B set to 5, BSET set to NIL, C set to 2, and CSET set to T.

&ALLOW-OTHER-KEYS

It is an error for any keywords to be supplied in a macro call that are not defined as keywords in the macro argument list, unless either the &-keyword &ALLOW-OTHER-KEYS appears in ARGS, or the keyword :ALLOW-OTHER-KEYS (with a non-NIL value) appears in the macro call.

&AUX

Used to bind and initialize auxiliary variables, using a syntax similar to PROG (page 9.8). Any elements after &AUX should be either litatoms or lists, interpreted as follows:

VAR

Single litatoms are interpreted as auxiliary variables that are initially bound to NIL.

(VAR EXP)

If an auxiliary variable is specified as a two element list, VAR is a variable initially bound to the result of evaluating the form EXP.

For example, given
(DEFMACRO FOO (A B &AUX C (D 5)) FORM)
C will be bound to NIL and D to 5 when FORM is evaluated.

&WHOLE
Used to get the whole macro calling form. Should be the first element of ARGS, and should be followed by a single litatom, which is set to the entire macro calling form. Other &-keywords or arguments can follow. For example, given

(DEFMACRO FOO (&WHOLE X A B) FORM)
Expanding the macro call (FOO 1 2) would cause FORM to be evaluated with X set to (FOO 1 2), A set to 1, and B set to 2.

DEFMACRO macros also support argument list "destructuring," a facility for accessing the structure of individual arguments to a macro. Any place in an argument list where a litatom is expected, an argument list (in the form described above) can appear instead. Such an embedded argument list is used to match the corresponding parts of that particular argument, which should be a list structure in the same form. In the simplest case, where the embedded argument list does not include &-keywords, this provides a simple way of picking apart list structures passed as arguments to a macro. For example, given

(DEFMACRO FOO (A (B (C . 0)) E) FORM)
Expanding the macro call (FOO 1 (2 (3 4 5)) 6) would cause FORM to be evaluated with A set to 1, B set to 2, C set to 3, 0 set to (4 5), and E set to 6. Note that the embedded argument list (B (C . D)) has an embedded argument list (C . D). Also notice that if an argument list ends in a dotted pair, that the final litatom matches the rest of the arguments in the macro call.

An embedded argument list can also include &-keywords, for interpreting parts of embedded list structures as if they appeared in a top-level macro call. For example, given

(DEFMACRO FOO (A (B (C . D)) E) FORM)
Expanding the macro call (FOO 1 (2 (3 4 5)) 6) would cause FORM to be evaluated with A set to 1, B set to 2, C set to 3, D set to (4 5), and E set to 6. Note that the embedded argument list (B (C . D)) has an embedded argument list (C . D). Also notice that if an argument list ends in a dotted pair, that the final litatom matches the rest of the arguments in the macro call.

Warning: Embedded argument lists can only appear in positions in an argument list where a list is otherwise not accepted. In the above example, it would not be possible to specify an embedded argument list after the &OPTIONAL keyword, because it would be interpreted as an optional argument specification (with variable name, default value, set variable). However, it would be possible to specify an embedded argument list as the first element of an optional argument specification list, as so:

(DEFMACRO FOO (A (B &OPTIONAL ((X Y Z) '(1 (2 3)))) D) FORM)
In this case, X, Y, and Z default to 1, 2, and 3, respectively. Note that the "default" value has to be an appropriate list structure. Also, in this case either the whole structure (X (Y Z)) can be
10.6.2 Interpreting Macros

When the interpreter encounters a form CAR of which is an undefined function, it tries interpreting it as a macro. If CAR of the form has a macro definition, the macro is expanded, and the result of this expansion is evaluated in place of the original form. CLISPTRAN (page 21.25) is used to save the result of this expansion so that the expansion only has to be done once. On subsequent occasions, the translation (expansion) is retrieved from CLISPARRAY the same as for other CLISP constructs.

Note: Because of the way that the evaluator processes macros, if you have a macro on FOO, then typing (FOO 'A 'B) will work, but FOO(A B) will not work.

Sometimes, macros contain calls to functions that assume that the macro is being compiled. The variable SHOULDCOMPILEMACROATOMS is a list of functions that should be compiled to work correctly (initially (OPCODES) in Interlisp-D, (ASSEMBLE LOC) in Interlisp-10). UNSAFEMACROATOMS is a list of functions which effect the operation of the compiler, so such macro forms shouldn't even be expanded except by the compiler (initially NIL in Interlisp-D, (C2EXP STORIN CEXP COMP) in Interlisp-10). If the interpreter encounters a macro containing calls to functions on these two lists, instead of the macro being expanded, a dummy function is created with the form as its definition, and the dummy function is then compiled. A form consisting of a call to this dummy function with no arguments is then evaluated in place of the original form, and CLISPTRAN is used to save the translation as described above. There are some situations for which this procedure is not amenable, e.g. a GO inside the form which is being compiled will cause the compiler to give an UNDEFINED TAG error message because it is not compiling the entire function, just a part of it.
# Table of Contents

11. Variable Bindings and the Interlisp Stack

11.1. The Spaghetti Stack

11.2. Stack Functions

11.2.1. Searching the Stack

11.2.2. Variable Bindings in Stack Frames

11.2.3. Evaluating Expressions in Stack Frames

11.2.4. Altering Flow of Control

11.2.5. Releasing and Reusing Stack Pointers

11.2.6. Backtrace Functions

11.2.7. Other Stack Functions

11.3. The Stack and the Interpreter

11.4. Generators

11.5. Coroutines

11.6. Possibilities Lists
[This page intentionally left blank]
A number of schemes have been used in different implementations of Lisp for storing the values of variables. These include:

1. Storing values on an association list paired with the variable names.
2. Storing values on the property list of the atom which is the name of the variable.
3. Storing values in a special value cell associated with the atom name, putting old values on the function call stack, and restoring these values when exiting from a function.
4. Storing values on the function call stack.

Interlisp-10 uses the third scheme, so called "shallow binding". When a function is entered, the value of each variable bound by the function (function argument) is stored in a value cell associated with that variable name. The value that was in the value cell is stored in a block of storage called the basic frame for this function call. In addition, on exit from the function each variable must be individually unbound; that is, the old value saved in the basic frame must be restored to the value cell. Thus there is a higher cost for binding and unbinding a variable than in the fourth scheme, "deep binding". However, to find the current value of any variable, it is only necessary to access the variable's value cell, thus making variable reference considerably cheaper under shallow binding than under deep binding, especially for free variables. However, the shallow binding scheme used does require an additional overhead in switching contexts when doing "spaghetti stack" operations.

Interlisp-D uses the fourth scheme, "deep binding." Every time a function is entered, a basic frame containing the new variables is put on top of the stack. Therefore, any variable reference requires searching the stack for the first instance of that variable, which makes free variable use somewhat more expensive than in a shallow binding scheme. On the other hand, spaghetti stack operations are considerably faster. Some other tricks involving copying freely-referenced variables to higher frames on the stack are also used to speed up the search.

The basic frames are allocated on a stack; for most user purposes, these frames should be thought of as containing the variable
names associated with the function call, and the current values for that frame. The descriptions of the stack functions in below are presented from this viewpoint. Both interpreted and compiled functions store both the names and values of variables so that interpreted and compiled functions are compatible and can be freely intermixed, i.e., free variables can be used with no SPECVAR declarations necessary. However, it is possible to suppress storing of names in compiled functions, either for efficiency or to avoid a clash, via a LOCALVAR declaration (see page 18.5). The names are also very useful in debugging, for they make possible a complete symbolic backtrace in case of error.

In addition to the binding information, additional information is associated with each function call: access information indicating the path to search the basic frames for variable bindings, control information, and temporary results are also stored on the stack in a block called the frame extension. The interpreter also stores information about partially evaluated expressions as described on page 11.14.

11.1 The Spaghetti Stack

The Bobrow/Wegbreit paper, "A Model and Stack Implementation for Multiple Environments" (Communications of the ACM, Vol. 16, 10, October 1973.), describes an access and control mechanism more general than a simple linear stack. The access and control mechanism used by Interlisp is a slightly modified version of the one proposed by Bobrow and Wegbreit. This mechanism is called the "spaghetti stack."

The spaghetti system presents the access and control stack as a data structure composed of "frames." The functions described below operate on this structure. These primitives allow user functions to manipulate the stack in a machine independent way. Backtracking, coroutines, and more sophisticated control schemes can be easily implemented with these primitives.

The evaluation of a function requires the allocation of storage to hold the values of its local variables during the computation. In addition to variable bindings, an activation of a function requires a return link (indicating where control is to go after the completion of the computation) and room for temporaries needed during the computation. In the spaghetti system, one "stack" is used for storing all this information, but it is best to view this stack as a tree of linked objects called frame extensions (or simply frames).
A frame extension is a variable sized block of storage containing a frame name, a pointer to some variable bindings (the BLINK), and two pointers to other frame extensions (the ALINK and CLINK). In addition to these components, a frame extension contains other information (such as temporaries and reference counts) that does not interest us here.

The block of storage holding the variable bindings is called a basic frame. A basic frame is essentially an array of pairs, each of which contains a variable name and its value. The reason frame extensions point to basic frames (rather than just having them "built in") is so that two frame extensions can share a common basic frame. This allows two processes to communicate via shared variable bindings.

The chain of frame extensions which can be reached via the successive ALINKs from a given frame is called the "access chain" of the frame. The first frame in the access chain is the starting frame. The chain through successive CLINKs is called the "control chain".

A frame extension completely specifies the variable bindings and control information necessary for the evaluation of a function. Whenever a function (or in fact, any form which generally binds local variables) is evaluated, it is associated with some frame extension.

In the beginning there is precisely one frame extension in existence. This is the frame in which the top-level call to the interpreter is being run. This frame is called the "top-level" frame.

Since precisely one function is being executed at any instant, exactly one frame is distinguished as having the "control bubble" in it. This frame is called the active frame. Initially, the top-level frame is the active frame. If the computation in the active frame invokes another function, a new basic frame and frame extension are built. The frame name of this basic frame will be the name of the function being called. The ALINK, BLINK, and CLINK of the new frame all depend on precisely how the function is invoked. The new function is then run in this new frame by passing control to that frame, i.e., it is made the active frame.

Once the active computation has been completed, control normally returns to the frame pointed to by the CLINK of the active frame. That is, the frame in the CLINK becomes the active frame.

In most cases, the storage associated with the basic frame and frame extension just abandoned can be reclaimed. However, it is possible to obtain a pointer to a frame extension and to "hold on" to this frame even after it has been exited. This pointer can
be used later to run another computation in that environment, or even "continue" the exited computation.

A separate data type, called a stack pointer, is used for this purpose. A stack pointer is just a cell that literally points to a frame extension. Stack pointers print as `#ADRIFRAMENAME`, e.g., `#1,13636/COND`. Stack pointers are returned by many of the stack manipulating functions described below. Except for certain abbreviations (such as "the frame with such-and-such a name"), stack pointers are the only way the user can reference a frame extension. As long as the user has a stack pointer which references a frame extension, that frame extension (and all those that can be reached from it) will not be garbage collected.

Note that two stack pointers referencing the same frame extension are not necessarily EQ, i.e., `(EQ (STKPOS 'FOO) (STKPOS 'FOO)) = NIL`. However, EQP can be used to test if two different stack pointers reference the same frame extension (page 9.3).

It is possible to evaluate a form with respect to an access chain other than the current one by using a stack pointer to refer to the head of the access chain desired. Note, however, that this can be very expensive when using a shallow binding scheme such as that in Interlisp-10. When evaluating the form, since all references to variables under the shallow binding scheme go through the variable's value cell, the values in the value cells must be adjusted to reflect the values appropriate to the desired access chain. This is done by changing all the bindings on the current access chain (all the name-value pairs) so that they contain the value current at the time of the call. Then along the new access path, all bindings are made to contain the previous value of the variable, and the current value is placed in the value cell. For that part of the access path which is shared by the old and new chain, no work has to be done. The context switching time, i.e. the overhead in switching from the current, active, access chain to another one, is directly proportional to the size of the two branches that are not shared between the access contexts. This cost should be remembered in using generators and coroutines (page 11.16).

11.2 Stack Functions

In the descriptions of the stack functions below, when we refer to an argument as a stack descriptor, we mean that it is one of the following:
A stack pointer

A stack pointer is an object that points to a frame on the stack. Stack pointers are returned by many of the stack manipulating functions described below.

NIL

Specifies the active frame; that is, the frame of the stack function itself.

T

Specifies the top-level frame.

A litatom

Specifies the first frame (along the control chain from the active frame) that has the frame name LITATOM. Equivalent to (STKPOS LITATOM -1).

A list of litatoms

Specifies the first frame (along the control chain from the active frame) whose frame name is included in the list.

A number N

Specifies the Nth frame back from the active frame. If N is negative, the control chain is followed, otherwise the access chain is followed. Equivalent to (STKNTH N)

In the stack functions described below, the following errors can occur: The error ILLEGAL STACK ARG occurs when a stack descriptor is expected and the supplied argument is either not a legal stack descriptor (i.e., not a stack pointer, litatom, or number), or is a litatom or number for which there is no corresponding stack frame, e.g., (STKNTH -1 'FOO) where there is no frame named FOO in the active control chain or (STKNTH -10 'EVALQT). The error STACK POINTER HAS BEEN RELEASED occurs whenever a released stack pointer is supplied as a stack descriptor argument for any purpose other than as a stack pointer to re-use.

Note: The creation of a single stack pointer can result in the retention of a large amount of stack space. Therefore, one should try to release stack pointers when they are no longer needed (see page 11.9).

11.2.1 Searching the Stack

(STKPOS FRAMENAME N POS OLDPPOS)

[Function]

Returns a stack pointer to the Nth frame with frame name FRAMENAME. The search begins with (and includes) the frame specified by the stack descriptor POS. The search proceeds along the control chain from POS if N is negative, or along the access chain if N is positive. If N is NIL, -1 is used. Returns a stack pointer to the frame if such a frame exists, otherwise returns NIL. If OLDPPOS is supplied and is a stack pointer, it is reused. If OLDPPOS is supplied and is a stack pointer and STKPOS returns NIL, OLDPPOS is released. If OLDPPOS is not a stack pointer it is ignored.

Note: (STKPOS 'STKPOS) causes an error, ILLEGAL STACK ARG; it is not permissible to create a stack pointer to the active frame.
(STKNTH N POS OLDPOS)  [Function]

Returns a stack pointer to the Nth frame back from the frame specified by the stack descriptor POS. If N is negative, the control chain from POS is followed. If N is positive the access chain is followed. If N equals 0, STKNTH returns a stack pointer to POS (this provides a way to copy a stack pointer). Returns NIL if there are fewer than N frames in the appropriate chain. If OLDPOS is supplied and is a stack pointer, it is reused. If OLDPOS is not a stack pointer it is ignored.

Note: (STKNTH 0) causes an error, ILLEGAL STACK ARG; it is not possible to create a stack pointer to the active frame.

(STKNAME POS)  [Function]

Returns the frame name of the frame specified by the stack descriptor POS.

(SETSTKNAME POS NAME)  [Function]

Changes the frame name of the frame specified by POS to be NAME. Returns NAME.

(STKNTHNAME N POS)  [Function]

Returns the frame name of the Nth frame back from POS. Equivalent to (STKNAME (STKNTH N POS)) but avoids creation of a stack pointer.

In summary, STKPOS converts function names to stack pointers, STKNTH converts numbers to stack pointers, STKNAME converts stack pointers to function names, and STKNTHNAME converts numbers to function names.

11.2.2 Variable Bindings in Stack Frames

The following functions are used for accessing and changing bindings. Some of functions take an argument, N, which specifies a particular binding in the basic frame. If N is a literal atom, it is assumed to be the name of a variable bound in the basic frame. If N is a number, it is assumed to reference the Nth binding in the basic frame. The first binding is 1. If the basic frame contains no binding with the given name or if the number is too large or too small, the error ILLEGAL ARG occurs.

(STKSCAN VAR IPOS OPOS)  [Function]

Searches beginning at IPOS for a frame in which a variable named VAR is bound. The search follows the access chain. Returns a stack pointer to the frame if found, otherwise returns NIL. If OPOS is a stack pointer it is reused, otherwise it is ignored.
(FRAME SCAN ATOM POS)  [Function]
Returns the relative position of the binding of ATOM in the basic frame of POS. Returns NIL if ATOM is not found.

(STKARG N POS —)  [Function]
Returns the value of the binding specified by N in the basic frame of the frame specified by the stack descriptor POS. N can be a literal atom or number.

(STKARGNAME N POS)  [Function]
Returns the name of the binding specified by N, in the basic frame of the frame specified by the stack descriptor POS. N can be a literal atom or number.

(SETSTKARG N POS VAL)  [Function]
Sets the value of the binding specified by N in the basic frame of the frame specified by the stack descriptor POS. N can be a literal atom or a number. Returns VAL.

(SETSTKARGNAME N POS NAME)  [Function]
Sets the variable name to NAME of the binding specified by N in the basic frame of the frame specified by the stack descriptor POS. N can be a literal atom or a number. Returns NAME.

(STKNARGS POS —)  [Function]
Returns the number of arguments bound in the basic frame of the frame specified by the stack descriptor POS.

(VARIABLES POS)  [Function]
Returns a list of the variables bound at POS.

(STKARGS POS —)  [Function]
Returns a list of the values of the variables bound at POS.

11.2.3 Evaluating Expressions in Stack Frames
The following functions are used to evaluate an expression in a different environment:

(ENVEVAL FORM APOS CPOS AFLG CFLG)  [Function]
Evaluates FORM in the environment specified by APOS and CPOS. That is, a new active frame is created with the frame specified by the stack descriptor APOS as its ALINK, and the frame specified by the stack descriptor CPOS as its CLINK. Then FORM is evaluated. If AFLG is not NIL, and APOS is a stack pointer, then
APOS will be released. Similarly, if CFLG is not NIL, and CPOS is a stack pointer, then CPOS will be released.

**(ENVAPPLY FN ARG5 APOS CPOS AFLG CFLG)**

APPLYs FN to ARG5 in the environment specified by APOS and CPOS. AFLG and CFLG have the same interpretation as with ENVEVAL.

**(EVALV VAR POS RELFLG)**

Evaluates VAR, where VAR is assumed to be a litatom, in the access environment specified by the stack descriptor POS. If VAR is unbound, EVALV returns NOBIND and does not generate an error. If RELFLG is non-NIL and POS is a stack pointer, it will be released after the variable is looked up. While EVALV could be defined as (ENVEVAL VAR POS NIL RELFLG) it is in fact somewhat faster.

**(STKEVAL POS FORM FLG —)**

Evaluates FORM in the access environment of the frame specified by the stack descriptor POS. If FLG is not NIL and POS is a stack pointer, releases POS. The definition of STKEVAL is (ENVEVAL FORM POS NIL FLG).

**(STKAPPLY POS FN ARG5 FLG)**

Similar to STKEVAL but applies FN to ARG5.

### 11.2.4 Altering Flow of Control

The following functions are used to alter the normal flow of control, possibly jumping to a different frame on the stack. RETEVAL and RETAPPLY allow evaluating an expression in the specified environment first.

**(RETFROM POS VAL FLG)**

Return from the frame specified by the stack descriptor POS, with the value VAL. If FLG is not NIL, and POS is a stack pointer, then POS is released. An attempt to RETFROM the top level (e.g., (RETFROM T)) causes an error, ILLEGAL STACK ARG. RETFROM can be written in terms of ENVEVAL as follows:

(RETFROM
 (LAMBDA (POS VAL FLG)
  (ENVEVAL (LIST 'QUOTE VAL)
   NIL
    (if (STKNTH -1 POS (if FLG then POS))
     else (ERRORX (LIST 19 POS))))
NIL
T))

(RETTO POS VAL FLG)  [Function]
Like RETFROM, except returns to the frame specified by POS.

(RETEVAL POS FORM FLG —)  [Function]
Evaluates FORM in the access environment of the frame specified by the stack descriptor POS, and then returns from POS with that value. If FLG is not NIL and POS is a stack pointer, then POS is released. The definition of RETEVAL is equivalent to (ENVEVAL FORM POS (STKNTH -1 POS) FLG T), except that RETEVAL does not create a stack pointer.

(RETAPPLY POS FN ARGS FLG)  [Function]
Similar to RETEVAL except applies FN to ARGS.

11.2.5 Releasing and Reusing Stack Pointers

The following functions and variables are used for manipulating stack pointers:

(STACKP X)  [Function]
Returns X if X is a stack pointer, otherwise returns NIL.

(RELSTK POS)  [Function]
Release the stack pointer POS (see below). If POS is not a stack pointer, does nothing. Returns POS.

(RELSTKP X)  [Function]
Returns T if X is a released stack pointer, NIL otherwise.

(CLEARSTK FLG)  [Function]
If FLG is NIL, releases all active stack pointers, and returns NIL. If FLG is T, returns a list of all the active (unreleased) stack pointers.

CLEARSTKLST  [Variable]
A variable used by the top-level executive. Every time the top-level executive is re-entered (e.g., following errors, or control-D), CLEARSTKLST is checked. If its value is T, all active stack pointers are released using CLEARSTK. If its value is a list, then all stack pointers on that list are released. If its value is NIL, nothing is released. CLEARSTKLST is initially T.
A variable used by the top-level executive. If CLEARSTKLST is T (see above) all active stack pointers except those on NOCLEARSTKLST are released. NOCLEARSTKLST is initially NIL.

Note: If one wishes to use multiple environments that survive through control-D, either CLEARSTKLST should be set to NIL, or else those stack pointers to be retained should be explicitly added to NOCLEARSTKLST.

The creation of a single stack pointer can result in the retention of a large amount of stack space. Furthermore, this space will not be freed until the next garbage collection, even if the stack pointer is no longer being used, unless the stack pointer is explicitly released or reused. If there is sufficient amount of stack space tied up in this fashion, a STACK OVERFLOW condition can occur, even in the simplest of computations. For this reason, the user should consider releasing a stack pointer when the environment referenced by the stack pointer is no longer needed.

The effects of releasing a stack pointer are:

1. The link between the stack pointer and the stack is broken by setting the contents of the stack pointer to the "released mark" (currently unboxed 0). A released stack pointer prints as #ADRI#0.

2. If this stack pointer was the last remaining reference to a frame extension; that is, if no other stack pointer references the frame extension and the extension is not contained in the active control or access chain, then the extension may be reclaimed, and is reclaimed immediately. The process repeats for the access and control chains of the reclaimed extension so that all stack space that was reachable only from the released stack pointer is reclaimed.

A stack pointer may be released using the function RELSTK, but there are some cases for which RELSTK is not sufficient. For example, if a function contains a call to RETFROM in which a stack pointer was used to specify where to return to, it would not be possible to simultaneously release the stack pointer. (A RELSTK appearing in the function following the call to RETFROM would not be executed!) To permit release of a stack pointer in this situation, the stack functions that relinquish control have optional flag arguments to denote whether or not a stack pointer is to be released (AFLG and CFLG). Note that in this case releasing the stack pointer will not cause the stack space to be reclaimed immediately because the frame referenced by the stack pointer will have become part of the active environment.

Another way of avoiding creating new stack pointers is to reuse stack pointers that are no longer needed. The stack functions
that create stack pointers (STKPOS, STKNTH, and STKSCAN) have an optional argument which is a stack pointer to reuse. When a stack pointer is reused, two things happen. First the stack pointer is released (see above). Then the pointer to the new frame extension is deposited in the stack pointer. The old stack pointer (with its new contents) is the value of the function. Note that the reused stack pointer will be released even if the function does not find the specified frame.

Note that even if stack pointers are explicitly being released, creation of many stack pointers can cause a garbage collection of stack pointer space. Thus, if the user’s application requires creating many stack pointers, he definitely should take advantage of reusing stack pointers.

11.2.6 Backtrace Functions

The following functions perform a "backtrace," printing information about every frame on the stack. Arguments allow only backtracing a selected range of the stack, skipping selected frames, and printing different amounts of information about each frame.

(BACKTRACE IPOS EPOS FLAGS FILE PRINTFN)  [Function]
Performs a backtrace beginning at the frame specified by the stack descriptor IPOS, and ending with the frame specified by the stack descriptor EPOS. FLAGS is a number in which the options of the BACKTRACE are encoded. If a bit is set, the corresponding information is included in the backtrace.

bit 0 - print arguments of non-SUBRs.
bit 1 - print temporaries of the interpreter.
bit 2 - print SUBR arguments and local variables.
bit 3 - omit printing of UNTRACE: and function names.
bit 4 - follow access chain instead of control chain.
bit 5 - print temporaries, i.e. the blips (see page 11.14).

For example: If FLAGS = 47Q, everything is printed. If FLAGS = 21Q, follows the access chain, prints arguments.

FILE is the file that the backtrace is printed to. FILE must be open. PRINTFN is used when printing the values of variables, temporaries, blips, etc. PRINTFN = NIL defaults to PRINT.

(BAKTRACE IPOS EPOS SKIPFNS FLAGS FILE)  [Function]
Prints a backtrace from IPOS to EPOS onto FILE. FLAGS specifies the options of the backtrace, e.g., do/don’t print arguments,
do/don't print temporaries of the interpreter, etc., and is the same as for BACKTRACE.

SKIPFNS is a list of functions. As BAKTRACE scans down the stack, the stack name of each frame is passed to each function in SKIPFNS, and if any of them return non-NIL, POS is skipped (including all variables).

BAKTRACE collapses the sequence of several function calls corresponding to a call to a system package into a single "function" using BAKTRACELST as described below. For example, any call to the editor is printed as **EDITOR**, a break is printed as **BREAK**, etc.

BAKTRACE is used by the BT, BTV, BTV+, BTV*, and BTV! break commands, with FLAGS = 0, 1, 5, 7, and 47 respectively.

Note: BAKTRACE calls BACKTRACE with a PRINTFN of SHOWPRINT (page 25.10), so that if SYSPRETTYFLG = T, the values will be prettyprinted.

**BAKTRACELST**

Used for telling BAKTRACE (therefore, the BT, BTV, etc. commands) to abbreviate various sequences of function calls on the stack by a single key, e.g. **BREAK**, **EDITOR**, etc.

The operation of BAKTRACE and format of BAKTRACELST is described so that the user can add his own entries to BAKTRACELST. Each entry on BAKTRACELST is a list of the form (FRAMENAME KEY . PATTERN) or (FRAMENAME (KEY1 . PATTERN1) ... (KEYN . PATTERNN)), where a pattern is a list of elements that are either atoms, which match a single frame, or lists, which are interpreted as a list of alternative patterns, e.g. (PROGN **BREAK** EVAL (ERRORSET BREAK1A BREAK1) (BREAK1))

BAKTRACE operates by scanning up the stack and, at each point, comparing the current frame name, with the frame names on BAKTRACELST, i.e. it does an ASSOC. If the frame name does appear, BAKTRACE attempts to match the stack as of that point with (one of) the patterns. If the match is successful, BAKTRACE prints the corresponding key, and continues with where the match left off. If the frame name does not appear, or the match fails, BAKTRACE simply prints the frame name and continues with the next higher frame (unless the SKIPFNS applied to the frame name are non-NIL as described above).

Matching is performed by comparing atoms in the pattern with the current frame name, and matching lists as patterns, i.e. sequences of function calls, always working up the stack. For example, either of the sequence of function calls "... BREAK1 BREAK1A ERRORSET EVAL PROGN ..." or "... BREAK1 EVAL
11.2.7 Other Stack Functions

**PROGN ...** would match with the sample entry given above, causing **BREAK** to be printed.

Special features:

- The litatom & can be used to match any frame.
- The pattern "." can be used to match nothing. - is useful for specifying an optional match, e.g. the example above could also have been written as (PROGN **BREAK** EVAL ((ERRORSET BREAK1) -) BREAK1).
- It is not necessary to provide in the pattern for matching dummy frames, i.e. frames for which DUMMYFRAMEP (see page 11.13) is true, e.g. in Interlisp-10, *PROG*LAM, *ENV*, NOLINKDEF1, etc. When working on a match, the matcher automatically skips over these frames when they do not match.
- If a match succeeds and the KEY is NIL, nothing is printed. For example, (*PROG*LAM NIL EVALA *ENV). This sequence will occur following an error which then causes a break if some of the function’s arguments are LOCALVARS.

11.2.7 Other Stack Functions

(DUMMYFRAMEP POS) [Function]

Returns T if the user never wrote a call to the function at POS, e.g. in Interlisp-10, DUMMYFRAMEP is T for *PROG*LAM, *ENV*, and FOOBLOCK frames (see block compiler, page 18.17).

REALFRAMEP and REALSTKNTH can be used to write functions which manipulate the stack and work on either interpreted or compiled code:

(REALFRAMEP POS INTERPFLG) [Function]

Returns POS if POS is a "real" frame, i.e. if POS is not a dummy frame and POS is a frame that does not disappear when compiled (such as COND); otherwise NIL. If INTERPFLG = T, returns POS if POS is not a dummy frame. For example, if (STKNAME POS) = COND, (REALFRAMEP POS) is NIL, but (REALFRAMEP POS T) is POS.

(REALSTKNTH N POS INTERPFLG OLDPOS) [Function]

Returns a stack pointer to the Nth (or -Nth) frames for which (REALFRAMEP POS INTERPFLG) is POS.

(MAPDL MAPDLFN MAPDLPOS) [Function]

Starts at MAPDLPOS and applies the function MAPDLFN to two arguments (the frame name and a stack pointer to the frame),
STACK FUNCTIONS

for each frame until the top of the stack is reached. Returns NIL.
For example,

```
(MAPDL (FUNCTION (LAMBDA (X POS)
                (if (IGREATERP (STKNARGS POS) 2)
                    then (PRINT X))]

will print all functions of more than two arguments.

(SEARCHPDL SRCHFN SRCHPOS)

Similar to MAPDL, except searches the stack starting at position
SRCHPOS until it finds a frame for which SRCHFN, a function of
two arguments applied to the name of the frame and the frame
itself, is not NIL. Returns (NAME . FRAME) if such a frame is
found, otherwise NIL.

11.3 The Stack and the Interpreter

In addition to the names and values of arguments for functions,
information regarding partially-evaluated expressions is kept on
the push-down list. For example, consider the following
definition of the function FACT (intentionally faulty):

```
(FACT
  (LAMBDA (N)
    (COND
      ((ZEROP N)
        L)
      (T (ITIMES N (FACT (SUB1 N))))
```

In evaluating the form (FACT 1), as soon as FACT is entered, the
interpreter begins evaluating the implicit PROGN following the
LAMBDA. The first function entered in this process is COND.
COND begins to process its list of clauses. After calling ZEROP
and getting a NIL value, COND proceeds to the next clause and
evaluates T. Since T is true, the evaluation of the implicit PROGN
that is the consequent of the T clause is begun. This requires
calling the function ITIMES. However before ITIMES can be
called, its arguments must be evaluated. The first argument is
evaluated by retrieving the current binding of N from its value
cell; the second involves a recursive call to FACT, and another
implicit PROGN, etc.

Note that at each stage of this process, some portion of an
expression has been evaluated, and another is awaiting
evaluation. The output below (from Interlisp-10) illustrates this
by showing the state of the push-down list at the point in the
computation of (FACT 1) when the unbound atom L is reached.

←FACT(1)
u.b.a. L (in FACT) in ((ZEROP N) L)
(L broken)
:BTV!

*TAIL* (L)

*ARG1 (((ZEROP N) L) (T (ITIMES N (FACT (SUB1 N)))))
COND

*FORM* (COND ((ZEROP N) L) (T (ITIMES N (FACT (SUB1 N)))))
*TAIL* (((ZEROP N) L) (T (ITIMES N (FACT (SUB1 N)))))

N 0
FACT

*FORM* (FACT (SUB1 N))
*FN* ITIMES
*TAIL* ((FACT (SUB1 N)))
*ARGVAl* 1
*FORM* (ITIMES N (FACT (SUB1 N)))
*TAIL* ((ITIMES N (FACT (SUB1 N))))

*ARG1 (((ZEROP N) L) (T (ITIMES N (FACT (SUB1 N)))))
COND

*FORM* (COND ((ZEROP N) L) (T (ITIMES N (FACT (SUB1 N)))))
*TAIL* (((ZEROP N) L) (T (ITIMES N (FACT (SUB1 N)))))

N 1
FACT

**TOP**

Internal calls to EVAL, e.g., from COND and the interpreter, are marked on the push-down list by a special mark or blip which the backtrace prints as *FORM*. The genealogy of *FORM*'s is thus a history of the computation. Other temporary information stored on the stack by the interpreter includes the tail of a partially evaluated implicit PROGN (e.g., a cond clause or lambda expression) and the tail of a partially evaluated form (i.e., those arguments not yet evaluated), both indicated on the backtrace by *TAIL*, the values of arguments that have already been evaluated, indicated by *ARGVAL*, and the names of functions waiting to be called, indicated by *FN*. *ARG1, ..., ARGn* are used by the backtrace to indicate the (unnamed) arguments to SUBRs.

Note that a function is not actually entered and does not appear on the stack, until its arguments have been evaluated (except for nlambda functions, of course). Also note that the *ARG1,
*FORM*, *TAIL*, etc. "bindings" comprise the actual working storage. In other words, in the above example, if a (lower) function changed the value of the *ARG1* binding, the COND would continue interpreting the new binding as a list of COND clauses. Similarly, if the *ARGVAL* binding were changed, the new value would be given to ITIMES as its first argument after its second argument had been evaluated, and ITIMES was actually called.

Note that *FORM*, *TAIL*, *ARGVAL*, etc., do not actually appear as variables on the stack, i.e., evaluating *FORM* or calling STKSCAN to search for it will not work. However, the functions BLIPVAL, SETBLIPVAL, and BLIPSCAN described below are available for accessing these internal blips. These functions currently know about four different types of blips:

*FN*  The name of a function about to be called.
*ARGVAL*  An argument for a function about to be called.
*FORM*  A form in the process of evaluation.
*TAIL*  The tail of a COND clause, implicit PROGN, PROG, etc.

```
(BLIPVAL BLIPTYP IPOS FLG)  [Function]
Returns the value of the specified blip of type BLIPTYP. If FLG is a number N, finds the Nth blip of the desired type, searching the control chain beginning at the frame specified by the stack descriptor IPOS. If FLG is NIL, 1 is used. If FLG is T, returns the number of blips of the specified type at IPOS.

(SETBLIPVAL BLIPTYP IPOS N VAL)  [Function]
Sets the value of the specified blip of type BLIPTYP. Searches for the Nth blip of the desired type, beginning with the frame specified by the stack descriptor IPOS, and following the control chain.

(BLIPSCAN BLIPTYP IPOS)  [Function]
Returns a stack pointer to the frame in which a blip of type BLIPTYP is located. Search begins at the frame specified by the stack descriptor IPOS and follows the control chain.
```

### 11.4 Generators

A generator is like a subroutine except that it retains information about previous times it has been called. Some of this state may be data (for example, the seed in a random number generator), and some may be in program state (as in a recursive generator.
which finds all the atoms in a list structure). For example, if
LISTGEN is defined by:

(DEFINEQ (LISTGEN L)
  (if L then (PRODUCE (CAR L))
    (LISTGEN (CDR L))))

we can use the function GENERATOR (described below) to create
a generator that uses LISTGEN to produce the elements of a list
one at a time, e.g.,

(SEIQ QGR (GENERATOR (LISTGEN '(A B C))))

creates a generator, which can be called by

(GENERATE GR)

to produce as values on successive calls, A, B, C. When GENERATE
(not GENERATOR) is called the first time, it simply starts
evaluating (LISTGEN '(A B C)). PRODUCE gets called from
LISTGEN, and pops back up to GENERATE with the indicated
value after saving the state. When GENERATE gets called again,
it continues from where the last PRODUCE left off. This process
continues until finally LISTGEN completes and returns a value (it
doesn't matter what it is). GENERATE then returns GR itself as its
value, so that the program that called GENERATE can tell that it
is finished, i.e., there are no more values to be generated.

(GENERATOR FORM COMVAR)

[NLambda Function]

An nlambda function that creates a generator which uses FORM
to compute values. GENERATOR returns a generator handle
which is represented by a dotted pair of stack pointers.

COMVAR is optional. If its value (EVAL of) is a generator handle,
the list structure and stack pointers will be reused. Otherwise, a
new generator handle will be constructed.

GENERATOR compiles open.

(PRODUCE VAL)

[Function]

Used from within a generator to return VAL as the value of the
corresponding call to GENERATE.

(GENERATE HANDLE VAL)

[Function]

Restarts the generator represented by HANDLE. VAL is returned
as the value of the PRODUCE which last suspended the operation
of the generator. When the generator runs out of values,
GENERATE returns HANDLE itself.

Examples:
The following function will go down recursively through a list structure and produce the atoms in the list structure one at a time.

```lisp
(DISTINCT (LEAVESG (L))
 (if (ATOM L)
   then (PRODUCE L)
 else (LEAVESG (CAR L))
   (if (CDR L)
     then (LEAVESG (CDR L))
)
```

The following function prints each of these atoms as it appears. It illustrates how a loop can be set up to use a generator.

```lisp
(DISTINCT (PLEAVESG1 (L))
 (PROG (X LHANDLE)
   (SETQ LHANDLE (GENERATOR (LEAVESG (L)))))
 (LP (SETQ X (GENERATE LHANDLE))
   (if (EQ X LHANDLE)
     then (RETURN NIL))
   (PRINT X)
 (GO LP))
```

Note that the loop terminates when the value of the generator is `EQ` to the dotted pair which is the value produced by the call to `GENERATOR`. A CLISP iterative operator, `OUTOF`, is provided which makes it much easier to write the loop in `PLEAVESG1`. `OUTOF` (or `outof`) can precede a form which is to be used as a generator. On each iteration, the iteration variable will be set to successive values returned by the generator; the loop will be terminated automatically when the generator runs out. Therefore, the following is equivalent to the above program `PLEAVESG1`:

```lisp
(DISTINCT (PLEAVESG2 (L))
 (for X outof (LEAVESG (L)) do (PRINT X)))
```

Here is another example; the following form will print the first N atoms.

```lisp
(for X outof (MAPATOMS (FUNCTION PRODUCE))
  as I from 1 to N do (PRINT X))
```

### 11.5 Coroutines

This package provides facilities for the creation and use of fully general coroutine structures. It uses a stack pointer to preserve the state of a coroutine, and allows arbitrary switching between $N$ different coroutines, rather than just a call to a generator and return. This package is slightly more efficient than the generator.
package described above, and allows more flexibility on specification of what to do when a coroutine terminates.

(COROUTINE CALLPTR COROUTPTR COROUTFORM ENDFORM)  [N lambda Function]
This nlambda function is used to create a coroutine and initialize the linkage. CALLPTR and COROUTPTR are the names of two variables, which will be set to appropriate stack pointers. If the values of CALLPTR or COROUTPTR are already stack pointers, the stack pointers will be reused. COROUTFORM is the form which is evaluated to start the coroutine; ENDFORM is a form to be evaluated if COROUTFORM actually returns when it runs out of values.

COROUTINE compiles open.

(RESUME FROMPTR TOPTR VAL)  [Function]
Used to transfer control from one coroutine to another. FROMPTR should be the stack pointer for the current coroutine, which will be smashed to preserve the current state. TOPTR should be the stack pointer which has preserved the state of the coroutine to be transferred to, and VAL is the value that is to be returned to the latter coroutine as the value of the RESUME which suspended the operation of that coroutine.

For example, the following is the way one might write the LEAVES program using the coroutine package:

(DEFINEQ (LEAVESC (L COROUTPTR CALLPTR))
  (if (ATOM L)
      then (RESUME COROUTPTR CALLPTR L)
    else (LEAVESC (CAR L) COROUTPTR CALLPTR)
      (if (CDR L) then (LEAVESC (CDR L) COROUTPTR CALLPTR))))]

A function PLEAVESC which uses LEAVESC can be defined as follows:

(DEFINEQ (PLEAVESC (L)
  (bind PLHANDLE LHANDLE
    first (COROUTINE PLHANDLE LHANDLE
      (LEAVESC LHANDLE PLHANDLE)
    )
  (RETFROM 'PLEAVESC)
  do (PRINT (RESUME PLHANDLE LHANDLE))))]

By RESUMEing LEAVESC repeatedly, this function will print all the leaves of list L and then return out of PLEAVESC via the RETFROM. The RETFROM is necessary to break out of the non-terminating do-loop. This was done to illustrate the additional flexibility allowed through the use of ENDFORM.

We use two coroutines working on two trees in the example EQLEAVES, defined below. EQLEAVES tests to see whether two
trees have the same leaf set in the same order, e.g., (EQLEAVES '(A B C) '(A B (C))) is true.

(DEFINEQ (EQLEAVES L1 L2)
  (bind LHANDLE1 LHANDLE2 PE EL1 EL2
    first (COROUTINE PE LHANDLE1 (LEAVESC L1 LHANDLE1 PE) 'NO-MORE)
    (COROUTINE PE LHANDLE2 (LEAVESC L2 LHANDLE2 PE) 'NO-MORE)
    do (SETQ EL1 (RESUME PE LHANDLE1))
    (SETQ EL2 (RESUME PE LHANDLE2))
    (if (NEQ EL1 EL2)
      then (RETURN NIL))
    repeatuntil (EQ EL1 'NO-MORE)
    finally (RETURN T)))

11.6 Possibilities Lists

A possibilities list is the interface between a generator and a consumer. The possibilities list is initialized by a call to POSSIBILITIES, and elements are obtained from it by using TRYNEXT. By using the spaghetti stack to maintain separate environments, this package allows a regime in which a generator can put a few items in a possibilities list, suspend itself until they have been consumed, and be subsequently aroused and generate some more.

(POSSIBILITIES FORM) [NLambda Function]

This nlambda function is used for the initial creation of a possibilities list. FORM will be evaluated to create the list. It should use the functions NOTE and AU-REVOIR described below to generate possibilities. Normally, one would set some variable to the possibilities list which is returned, so it can be used later, e.g.:

(SETQ PLIST (POSSIBILITIES (GENERFN V1 V2))).

POSSIBILITIES compiles open.

(NOTE VAL LSTFLG) [Function]

Used within a generator to put items on the possibilities list being generated. If LSTFLG is equal to NIL, VAL is treated as a single item. If LSTFLG is non-NIL, then the list VAL is NCONCeD on the end of the possibilities list. Note that it is perfectly reasonable to create a possibilities list using a second generator, and NOTE that list as possibilities for the current generator with
LSTFLG equal to T. The lower generator will be resumed at the appropriate point.

(AU-REVOIR VAL)  [NoSpread Function]
Puts VAL on the possibilities list if it is given, and then suspends the generator and returns to the consumer in such a fashion that control will return to the generator at the AU-REVOIR if the consumer exhausts the possibilities list.

Note: NIL is not put on the possibilities list unless it is explicitly given as an argument to AU-REVOIR, i.e., (AU-REVOIR) and (AU-REVOIR NIL) are not the same. AU-REVOIR and ADIEU are lambda nospreads to enable them to distinguish these two cases.

(ADIEU VAL)  [NoSpread Function]
Like AU-REVOIR except releases the generator instead of suspending it.

(TRYNEXT PLST ENDFORM VAL)  [N Lambda Function]
This nlambda function allows a consumer to use a possibilities list. It removes the first item from the possibilities list named by PLST (i.e. PLST must be an atom whose value is a possibilities list), and returns that item, provided it is not a generator handle. If a generator handle is encountered, the generator is reawakened. When it returns a possibilities list, this list is added to the front of the current list. When a call to TRYNEXT causes a generator to be awakened, VAL is returned as the value of the AU-REVOIR which put that generator to sleep. If PLST is empty, it evaluates ENDFORM in the caller's environment.

TRYNEXT compiles open.

(CLEANPOSSLST PLST)  [Function]
This function is provided to release any stack pointers which may be left in the PLST which was not used to exhaustion.

For example, FIB is a generator for fibonacci numbers. It starts out by NOTEing its two arguments, then suspends itself. Thereafter, on being re-awakened, it will NOTE two more terms in the series and suspends again. PRINTFIB uses FIB to print the first N fibonacci numbers.

(DEFINEQ (FIB (F1 F2)
  (do (NOTE F1)
     (NOTE F2)
     (SETQ F1 (IPLUS F1 F2))
     (SETQ F2 (IPLUS F1 F2))
     (AU-REVOIR))

VARIABLE BINDINGS AND THE INTERLISP STACK 11.21
Note that this AU-REVOIR just suspends the generator and adds nothing to the possibilities list except the generator.

(DEFINEQ (PRINTFIB (N))
  (PROG ((FL (POSSIBILITIES (FIB 0 1))))
    (RPTQ N (PRINT (TRYNEXT FL)))
    (CLEANPOSLST FL))

Note that FIB itself will never terminate.
# 12. Miscellaneous

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.1. Greeting and Initialization Files</td>
<td>12.1</td>
</tr>
<tr>
<td>12.2. Idle Mode</td>
<td>12.4</td>
</tr>
<tr>
<td>12.3. Saving Virtual Memory State</td>
<td>12.6</td>
</tr>
<tr>
<td>12.4. System Version Information</td>
<td>12.11</td>
</tr>
<tr>
<td>12.5. Date and Time Functions</td>
<td>12.13</td>
</tr>
<tr>
<td>12.6. Timers and Duration Functions</td>
<td>12.16</td>
</tr>
<tr>
<td>12.7. Resources</td>
<td>12.19</td>
</tr>
<tr>
<td>12.7.1. A Simple Example</td>
<td>12.20</td>
</tr>
<tr>
<td>12.7.2. Trade-offs in More Complicated Cases</td>
<td>12.22</td>
</tr>
<tr>
<td>12.7.3. Macros for Accessing Resources</td>
<td>12.23</td>
</tr>
<tr>
<td>12.7.4. Saving Resources in a File</td>
<td>12.23</td>
</tr>
<tr>
<td>12.8.1. Pattern Elements</td>
<td>12.25</td>
</tr>
<tr>
<td>12.8.2. Element Patterns</td>
<td>12.25</td>
</tr>
<tr>
<td>12.8.3. Segment Patterns</td>
<td>12.27</td>
</tr>
<tr>
<td>12.8.4. Assignments</td>
<td>12.28</td>
</tr>
<tr>
<td>12.8.5. Place-Markers</td>
<td>12.29</td>
</tr>
<tr>
<td>12.8.6. Replacements</td>
<td>12.29</td>
</tr>
<tr>
<td>12.8.7. Reconstruction</td>
<td>12.30</td>
</tr>
<tr>
<td>12.8.8. Examples</td>
<td>12.31</td>
</tr>
</tbody>
</table>
[This page intentionally left blank]
12. MISCELLANEOUS

12.1 Greeting and Initialization Files

Many of the features of Interlisp are controlled by variables that the user can adjust to his or her own tastes. In addition, the user can modify the action of system functions in ways not specifically provided for by using ADVISE (page 15.11). In order to encourage customizing the Interlisp environment, Interlisp includes a facility for automatically loading initialization files (or "init files") when an Interlisp system is first started. Each user can have a separate "user init file" that customizes the Interlisp environment to his/her tastes. In addition, there can be a "site init file" that applies to all users at a given physical site, setting system variables that are the same for all users such as the name of the nearest printer, etc.

The process of loading init files, also known as "greeting"", occurs when an Interlisp system created by MAKESYS (page 12.9) is started for the first time. The user can also explicitly invoke the greeting operation at any time via the function GREET (below). The process of greeting includes the following steps:

1. Any previous greeting operation is undone. The side effects of the greeting operation are stored on a global variable as well as on the history list, thus enabling the previous greeting to be undone even if it has dropped off of the bottom of the history list.

2. All of the items on the list PREGREETFORMS are evaluated:

3. The site init file is loaded. GREET looks for a file by the name (DSK)INIT.LISP. If this is found, it is loaded. If it is not found, the system prints "Please enter name of system init file (e.g. (server)<directory>INIT.extension):" and waits for the user to type a file name, followed by a carriage return. If the user just types a carriage return without typing a file name, no site init file is loaded. Note: The site init file is loaded with LDFLG set to SYSLOAD, so that no file package information is saved, and nothing is printed out.

4. The user init file is loaded. The user init file is found by using the variable USERGREETFILES (described below), which is normally set in the site init file. The user init file is loaded with normal file
package settings, but under errorset protection and with PRETTYHEADER set to NIL to suppress the "FILE CREATED" message.

(5) All of the items on the list POSTGREETFORMS are evaluated.

(6) A greeting is printed such as "Hello, XXX.", where XXX is the value of the variable FIRSTNAME (if non-NIL). The variable GREETDATES (below) can be set to modify this greeting for particular dates.

**GREET NAME —**

*Function*

Performs the greeting for the user whose username is NAME (if NAME = NIL, uses the login name). When Interlisp first starts up, it performs (GREET).

**GREETFILENAME USER**

*Function*

If USER is T, GREETFILENAME returns the file name of the site init file, asking the user if it doesn't exist. Otherwise, USER is interpreted to be a user's system name, and GREETFILENAME returns the file name for the user init file (if it exists).

**USERGREETFILES**

*Variable*

USERGREETFILES specifies a series of file names to try as the user init file. The value of USERGREETFILES is a list, where each element is a list of litatoms. For each item in USERGREETFILES, the user name is substituted for the litatom USER and the value of COMPILE.EXT (page 18.13) is substituted for the litatom COM, and the litatoms are packed into a single file name. The first such file that is found is the user init file.

For example, suppose that the value of USERGREETFILES was

```
(([ERIS]< USER >LISP>INIT.COM)
 ([ERIS]< USER >LISP>INIT)
 ([ERIS]< USER >INIT.COM)
 ([ERIS]< USER >INIT))
```

If the user name was JONES, and the value of COMPILE.EXT was DCOM, then this would search for the files {ERIS}<JONES>LISP>INIT.DCOM, {ERIS}<JONES>LISP>INIT, {ERIS}<JONES>INIT.DCOM, and {ERIS}<JONES>INIT.

Note: The file name "specifications" in USERGREETFILES should be fully qualified, including all host and directory information. The directory search path (the value of DIRECTORIES, page 24.31) is not used to find the user greet files.

**GREETDATES**

*Variable*

The value of GREETDATES can be used to specify special greeting messages for various dates. GREETDATES is a list of elements of
the form (DATESTRING . STRING), e.g. ("25-DEC" . "Merry Christmas"). The user can add entries to this list in his/her INIT.LISP file by using a ADDVARS file package command like (ADDVARS (GREETDATES ("8-FEB" . "Happy Birthday"))). On the specified date, the GREET will use the indicated salutation.

Note: Users should try to make sure that their init file is "undoable". If they use the file package command "P" (page 17.40) to put expressions on the file to be evaluated, they should use the "undoable" version, e.g. /SETSYNTAX rather than SETSYNTAX, etc (see page 13.26). This is so another user can come up, do a (GREET) and have the first user's initialization undone.

It is impossible to give a complete list of all of the variables and functions that users may want to set in their init files. The default values for system variables are chosen in the hope that they will be correct for the majority of users, so many users get along with very small init files. The following describes some of the variables that users may want to reset in their init files:

Directories

The variables DIRECTORIES and LISPUSERSDIRECTORIES (page 24.31) contain lists of directories used when searching for files. LOGINHOST/DIR (page 24.11) determines the default directory used when calling CONN with no argument.

Fonts and Printing

The variables DISPLAYFONTDIRECTORIES, DISPLAYFONTEXTENSIONS, INTERPRESSFONTDIRECTORIES, and PRESSFONTWIDTHSFILES (page 27.31) must be set before fonts can be automatically loaded from files. DEFAULTPRINTINGHOST (page 29.4) should be set before attempting to generate hardcopy to a printer.

Network Systems

CH.DEFAUT.ORGANIZATION and CH.DEFAUT.DOMAIN (page 31.8) should be set to the default NS organization and domain, when using NS network communications. If CH.NET.HINT (page 31.9) is set, it can reduce the amount of time spent searching for a clearinghouse.

Interlisp-D Executive

The variable PROMPT#FLG (page 13.22) determines whether an "event number" is printed at the beginning of every input line. The function CHANGESLICE (page 13.21) can be used to change the number of events that are remembered on the history list.

Copyright Notices

COPYRIGHTFLG, COPYRIGHTOWNERS, and DEFAULTCOPYRIGHTOWNER (page 17.53) control the inclusion of copyright notices on source files.

Printing Functions

**COMMENT**FLG (page 26.43) determines how program comments are printed. FIRSTCOL, PRETTYFLG, and CLISPIFYPRETTYFLG (page 26.47) are among the many variables controlling how functions are pretty printed.
12.2 Idle Mode

The Interlisp-D environment runs on small single-user computers, usually located in users’ offices. Often, users leave their computers up and running for days, which can cause several problems. First, the phosphor in the video display screen can be permanently marked if the same pattern is displayed for a long time (weeks). Second, if the user goes away, leaving an Interlisp-D system running, another person could possibly walk up and use the environment, taking advantage of any passwords that had been entered. To solve these problems, the Interlisp-D environment implements the concept of “idle mode.”

If no keyboard or mouse action has occurred for a specified time, the Interlisp-D environment automatically enters idle mode. While idle mode is on, the display screen is blacked out, to protect the phosphor. Idle mode also runs a program to display some moving pattern on the black screen, so the screen doesn’t appear broken. Usually, idle mode can be exited by pressing any key on the keyboard or mouse. However, the user can optionally specify that idle mode should erase the current password cache when it is entered, and require the next user to supply a password to exit idle mode.

Note: If either shift key is pressed while Interlisp-D is in idle mode, the current user name and the amount of time spent idling are displayed in the prompt window (which appears as long as the shift key is held down).

Idle mode can also be entered by calling the function IDLE, or by selecting the Idle menu command from the background menu (page 28.6). The Idle menu command has subitems that allow the user to interactively set the idle options (display program, erasing password, etc.) specified by the variable IDLE.PROFILE:

<table>
<thead>
<tr>
<th>IDLE.PROFILE</th>
<th>[Variable]</th>
</tr>
</thead>
<tbody>
<tr>
<td>The value of this variable is a property list (page 3.15) which controls most aspects of idle mode. The following properties are recognized:</td>
<td></td>
</tr>
<tr>
<td>TIME OUT</td>
<td>Value is a number that determines how long (in minutes) Interlisp-D will wait before automatically entering idle mode. If NIL, idle mode will never be entered automatically. Default is 10 minutes.</td>
</tr>
</tbody>
</table>
FORGET

If non-NIL, the user's password will be erased when idle mode is entered. Default is NIL (don't erase password).

Note: If the password is erased, any programs left running when idle mode is entered will fail if they try doing anything requiring passwords (such as accessing file servers).

ALLOWED.LOGINS

Determines who can exit idle mode, as follows:

If the value is NIL, idle mode is exited without requesting login.

If the value is LOGIN (the default), login is required, but anyone is allowed to exit idle mode. This will overwrite the previous user's user name and password each time idle mode is exited.

If the value is one of AUTHENTICATE, NS.AUTHENTICATE, or GV.AUTHENTICATE, login is required and the password is checked with the net. Only allow users with accounts to exit idle mode. NS.AUTHENTICATE or GV.AUTHENTICATE specify that NS or grapevine authentication must be used, respectively. AUTHENTICATE indicates that either type of authentication can be tried.

If the value is a list, it should be a list of group and/or user names. The value T in the list means the user who was using the machine before idle mode was entered. If the value is a list, idle mode will only be exited if: (a) the new user's user name is in this list, (b) the new user is a member of a group whose name is on this list, or (c) if T is a member of the list, and the same user logs in with the same password.

DISPLAYFN

The value of this property, which should be a function name or lambda expression, is called to display a moving pattern on the screen while in idle mode. This function is called with one argument, a window covering the whole screen. The default is IDLE.BOUNCING.BOX (below).

Note: Any function used as a DISPLAYFN should call BLOCK (page 23.5) frequently, so other programs can run during idle mode.

SAVEVM

Value is a number that determines how long (in minutes) after idle mode is entered that SAVEVM (page 12.7) will be called to save the virtual memory. If NIL, SAVEVM is never called automatically from idle mode. Default is 10 minutes.

RESETVARS

Value is a list of two-element lists: \((VAR_1 \; EXP_1) \; (VAR_2 \; EXP_2) \ldots\). On entering idle mode, each variable \(VAR_N\) is bound to the value of the corresponding expression \(EXP_N\). When idle mode is exited, each variable \(VAR_N\) is reset to its original value.

SUSPEND.PROCESS.NAMES

Value is a list of names. For each name on this list, if a process by that name is found, it will be suspended upon entering idle mode and woken upon exiting idle mode.
**IDLE FUNCTIONS**

The value of this variable determines the menu raised by selecting the Display subitem of the Idle background menu command. It should be in the format used for the ITEMS field of a menu (page 28.39), with the selection of an item returning the appropriate display function.

**IDLE.BOUNCING.BOX WINDOW BOX WAIT**

This is the default display function used for idle mode. BOX is bounced about WINDOW, with bounces taking place every WAIT milliseconds. BOX can be a string, a bitmap, a window (whose image will be bounced about), or a list containing any number of these (which will be cycled through). BOX defaults to the value of the variable IDLE.BOUNCING.BOX, which is initially the string "Interlisp-D". WAIT defaults to 1000 (one second).

### 12.3 Saving Virtual Memory State

Interlisp storage allocation occurs within a virtual memory space that is usually much larger than the physical memory on the computer. The virtual memory is stored as a large file on the computer’s hard disk, called the virtual memory file. Interlisp controls the swapping of pages between this file and the real memory, swapping in virtual memory pages as they are accessed, and swapping out pages that have been modified. At any moment, the total state of the Interlisp virtual memory is stored partially in the virtual memory file, and partially in the real physical memory.

Interlisp provides facilities for saving the total state of the virtual memory, either on the virtual memory file, or in a file on an arbitrary file device. The function LOGOUT is used to write all altered (dirty) pages from the real memory to the virtual memory file and stop Interlisp, so that Interlisp can be restarted from the state of the LOGOUT. SAVEVM updates the virtual memory file without stopping Interlisp, which puts the virtual memory file into a consistant state (temporarily), so it could be restarted if the system crashes. SYSOUT and MAKESYS are used to save a copy of the total virtual memory state on a file, which can be loaded into another machine to restore the Interlisp state. VMEM.PURE.STATE can be used to “freeze” the current state of the virtual memory, so that Interlisp will come up in that state if it is restarted.
(LOGOUT FAST)  [Function]

Stops Interlisp, and returns control to the operating system. If Interlisp is restarted, it should come up in the same state as when the LOGOUT was called. LOGOUT will not affect the state of open files.

LOGOUT writes out all altered pages from real memory to the virtual memory file. If FAST is T, Interlisp is stopped without updating the virtual memory file. Note that after doing LOGOUT T) it will not be possible to restart Interlisp from the point of the LOGOUT, and it may not be possible to restart it at all. Typing (LOGOUT T) is preferable to just booting the machine, because it also does other cleanup operations (closing network connections, etc.).

If FAST is the litatom ?, LOGOUT acts like FLG = T if the virtual memory file is consistant, otherwise it acts like FLG = NIL. This insures that the virtual memory image can be restarted as of some previous state, not necessarily as of the LOGOUT.

(SAVEVM —)  [Function]

This function is similar to logging out and continuing, but faster. It takes about as long as a logout, which can be as brief as 10 seconds or so if you have already written out most of your dirty pages by virtue of being idle a while. After the SAVEVM, and until the pagefault handler is next forced to write out a dirty page, your virtual memory image will be continuable (as of the SAVEVM) should there be a system crash or other disaster.

If the system has been idle long enough (no keyboard or mouse activity), there are dirty pages to be written, and there are few enough dirty pages left to write that a SAVEVM would be quick, SAVEVM is automatically called. When SAVEVM is called automatically, the cursor is changed to a special cursor: $rt~G, stored in the variable SAVINGCURSOR. You can control how often SAVEVM is automatically called by setting the following two global variables:

SAVEVMWAIT  [Variable]

SAVEVMMAX  [Variable]

The system will call SAVEVM after being idle for SAVEVMWAIT seconds (initially 300) if there are fewer than SAVEVMMAX pages dirty (initially 600). These values are fairly conservative. If you want to be extremely wary, you can set SAVEVMWAIT = 0 and SAVEVMMAX = 10000, in which case SAVEVM will be called the first chance available after the first dirty page has been written.
The function `SYSOUT` saves the current state of the Interlisp virtual memory on a file, known as a "sysout file", or simply a "sysout". The file package can be used to save particular function definitions and other arbitrary objects on files, but `SYSOUT` saves the total state of the system. This capability can be useful in many situations: for creating customized systems for other people to use, or to save a particular system state for debugging purposes. Note that a sysout file can be very large (thousands of pages), and can take a long time to create, so it is not to be done lightly. The file produced by `SYSOUT` can be loaded into the Interlisp virtual memory and restarted to restore the virtual memory to the exact state that it had when the sysout file was made. The exact method of loading a sysout depend on the implementation. For more information on loading sysout files, see the users guide for your computer.

**Function**

`SYSOUT FILE` saves the current state of the interlisp virtual memory on the file `FILE`, in a form that can be subsequently restarted. The current state of program execution is saved in the sysout file, so `(PROGN (SYSOUT 'FOO) (PRINT 'HELLO))` will cause HELLO to be printed after the sysout file is restarted.

`SYSOUT` can take a very long time (ten or fifteen minutes), particularly when storing a file on a remote file server. To display some indication that something is happening, the cursor is changed to: OUT. Also, as the sysout file is being written, the cursor is inverted line by line, to show that activity is taking place, and how much of the sysout has completed. For example, after the `SYSOUT` is about two-thirds done, the cursor would look like: ₫. The `SYSOUT` cursor is stored in the variable `SYSOUTCURSOR`.

If `FILE` is non-NIL, the variable `SYSOUTFILE` is set to the body of `FILE`. If `FILE` is NIL, then the value of `SYSOUTFILE` instead. Therefore, `(SYSOUT)` will save the current state on the next higher version of a file with the same name as the previous `SYSOUT`. Also, if the extension for `FILE` is not specified, the value of `SYSOUT.EXT` is used. `SYSOUT` sets `SYSOUTDATE` (page 12.13) to `(DATE)`, the time and date that the `SYSOUT` was performed.

If `SYSOUT` was not able to create the sysout file, because of disk or computer error, or because there was not enough space on the directory, `SYSOUT` returns NIL. Otherwise it returns the full file name of `FILE`.

Actually, `SYSOUT` "returns" twice; when the sysout file is first created, and when it is subsequently restarted. In the latter case, `SYSOUT` returns a list whose CAR is the full file name of `FILE`. For example, `(if (LISTP (SYSOUT 'FOO)) then (PRINT 'HELLO))` will
cause HELLO to be printed when the sysout file is restarted, but not when SYSOUT is initially performed.

Note: SYSOUT does not save the state of any open files. WHENCLOSE (page 24.20) can be used to associate certain operations with open files so that when a SYSOUT is started up, these files will be reopened, and file pointers repositioned.

SYSOUT evaluates the expressions on BEFORESYSOUTFORMS before creating the sysout file. This variable initially includes expressions to: (1) Set the variables SYSOUTDATE and SYSOUTFILE as described above; (2) Default the sysout file name FILE according to the values of the variables SYSOUTFILE and SYSOUT.EXT, as described above; and (3) Perform any necessary operations on open files as specified by calls to WHENCLOSE (page 24.20).

After a sysout file is restarted (but not when it is initially created), SYSOUT evaluates the expressions on AFTERSYSOUTFORMS. This initially includes expressions to: (1) Perform any necessary operations on previously-opened files as specified by calls to WHENCLOSE (page 24.20); (2) Possibly print a message, as determined by the value of SYSOUTGAG (see below); and (3) Call SETINITIALS to reset the initials used for time-stamping (page 16.76).

SYSOUTGAG [Variable]
The value of SYSOUTGAG determines what is printed when a sysout file is restarted. If the value of SYSOUTGAG is a list, the list is evaluated, and no additional message is printed. This allows the user to print a message. If SYSOUTGAG is non-NIL and not a list, no message is printed. Finally, if SYSOUTGAG is NIL (its initial value), and the sysout file is being restarted by the same user that made the sysout originally, the user is greeted by printing the value of HERALDSTRING (see below) followed by a greeting message. If the sysout file was made by a different user, a message is printed, warning that the currently-loaded user init file may be incorrect for the current user (see page 12.1);

(MAKESYS FILE NAME) [Function]
Used to store a new Interlisp system on the "makesys file" FILE. Similar to SYSOUT, except that before the file is made, the system is "initialized" by undoing the greet history, and clearing the display.

When the system is first started up, a "herald" is printed identifying the system, typically "Interlisp-XX DATE ...". If NAME is non-NIL, MAKESYS will use it instead of Interlisp-XX in the herald. MAKESYS sets HERALDSTRING to the herald string printed out.
MAKESYS also sets the variable MAKESYSDATE (page 12.13) to (DATE), i.e. the time and date the system was made.

Interlisp-D contains a routine that writes out dirty pages of the virtual memory during I/O wait, assuming that swapping has caused at least one dirty page to be written back into the virtual memory file (making it non-continuable). The frequency with which this routine runs is determined by:

**BACKGROUNDPAGEFREQ**

This variable determines how often the routine that writes out dirty pages is run. The higher BACKGROUNDPAGEFREQ is set, the greater the time between running the dirty page writing routine. Initially it is set to 4. The lower BACKGROUNDPAGEFREQ is set, the less responsiveness you get at typein, so it may not be desirable to set it all the way down to 1.

**VMEM.PURE.STATE**

VMEM.PURE.STATE modifies the swapper's page replacement algorithm so that dirty pages are only written at the end of the virtual memory backing file. This "freezes" a given virtual memory state, so that Interlisp will come up in that state whenever it is restarted. This can be used to set up a "clean" environment on a pool machine, allowing each user to initialize the system simply by rebooting the computer.

The way to use VMEM.PURE.STATE is to set up the environment as you wish it to be "frozen," evaluate (VMEM.PURE.STATE T), and then call any function that saves the virtual memory state (LOGOUT, SAVEVM, SYSOUT, or MAKESYS). From that point on, whenever the system is restarted, it will return to the state as of the saving operation. Future LOGOUT, SAVEVM, etc. operations will not reset this state.

Note: When the system is running in "pure state" mode, it uses a significant amount of the virtual memory backing file to save the "frozen" memory image, so this will reduce the amount of virtual memory space available for use.

(VMEM.PURE.STATE) returns T if the system is running in "pure state" mode, NIL otherwise.

**REALMEMORYSIZE**

Returns the number of real memory pages in the computer.
(VMEMSIZE)  [Function]
Returns the number of pages in use in the virtual memory. This is
the roughly the same as the number of pages required to make a
sysout file on the local disk (see SYSOUT, page 12.8).

\LASTVMEMFILEPAGE  [Variable]
Value is the total size of the virtual memory backing file. This
variable is set when the system is started. It should not be set by
the user.

Note: When the virtual memory expands to the point where the
virtual memory backing file is almost full, a break will occur with
the warning message "Your virtual memory backing file is
almost full. Save your work & reload asap." When this happens,
it is strongly suggested that you save any important work and
reload the system. If you continue working past this point, the
system will start slowing down considerably, and it will
eventually stop working.

12.4 System Version Information
Interlisp-D runs on a number of different machines, with many
possible hardware configurations. There have been a number of
different releases of the Interlisp-D software. These facts make it
difficult to answer the important question "what
software/hardware environment are you running?" when
reporting bugs. The following functions allow the novice to
collect this information.

(PRINT-LISP-INFORMATION STREAM FILESTRING)  [NoSpread Function]
Prints out a summary of the software and hardware environment
that Interlisp-D is running in, and a list of all loaded patch files:

Interlisp-D version KOTO of 10-Sep-85 08:25:46
on 1108, microcode 5658, 8191 pages,
machine 222#0.125000.34652#0 on
Interlisp-D version 9-Sep-85 18:54:29
Patch files: GCPATCH dated 11-Sep-85 10:56:37

STREAM is the stream used to print the summary. If not given, it
defaults to T.

FILESTRING is a string used to determine what loaded files should
be listed as "patch files." All file names on LOADEDFILELST
(page 17.20) that have FILESTRING as a substring as listed. If
FILESTRING is not given, it defaults to the string "PATCH".
(LISP-IMPLEMENTATION-TYPE) [Function]
Returns a string identifying the type of Interlisp implementation that is running, e.g., "Interlisp-D".

(LISP-IMPLEMENTATION-VERSION) [Function]
Returns a string identifying the version of Interlisp that is running. Currently gives the system name and date, e.g., "KOTO of 10-Sep-85 08:25:46".
This uses the variables MAKESYSNAME and MAKESYSDATE (below), so it will change if the user uses MAKESYS (page 12.9) to create a custom sysout file, or explicitly changes these variables.

(SOFTWARE-TYPE) [Function]
Returns a string identifying the operating system that Interlisp is running under. Currently returns the string "Interlisp-D".

(SOFTWARE-VERSION) [Function]
Returns a string identifying the version of the operating system that Interlisp is running under. Currently, this returns the date that the Interlisp-D release was originally created, so it doesn't change over MAKESYS or SYSOUT.

(MACHINE-TYPE) [Function]
Returns a string identifying the type of computer hardware that Interlisp-D is running on, i.e., "1108", "1132", "1186", etc.

(MACHINE-VERSION) [Function]
Returns a string identifying the version of the computer hardware that Interlisp-D is running on. Currently returns the microcode version and real memory size.

(MACHINE-INSTANCE) [Function]
Returns a string identifying the particular machine that Interlisp-D is running on. Currently returns the machine's NS address.

(SHORT-SITE-NAME) [Function]
Returns a short string identifying the site where the machine is located. Currently returns (ETHERHOSTNAME) (if non-NIL) or the string "unknown".

(LONG-SITE-NAME) [Function]
Returns a long string identifying the site where the machine is located. Currently returns the same as SHORT-SITE-NAME.
12.5 Date And Time Functions

**DATE FORMAT**

Returns the current date and time as a string with format "DD-MM-YY HH:MMM:SS", where DD is day, MM is month, YY year, HH hours, MMM minutes, SS seconds, e.g., "7-Jun-85 15:49:34".

If FORMAT is a date format as returned by DATEFORMAT (below), it is used to modify the format of the date string returned by DATE.

**IDATE STR**

STR is a date and time string. IDATE returns STR converted to a number such that if DATE1 is before (earlier than) DATE2, then (IDATE DATE1) < (IDATE DATE2). If STR is NIL, the current date and time is used.
DATE AND TIME FUNCTIONS

Note that different Interlisp implementations can have different internal date formats. However, IDATE always has the essential property that (IDATE X) is less than (IDATE Y) if X is before Y, and (IDATE (GDATE N)) equals N. Programs which do arithmetic other than numerical comparisons between IDATE numbers may not work when moved from one implementation to another.

Generally, it is possible to increment an IDATE number by an integral number of days by computing a "1 day" constant, the difference between two convenient IDATE's, e.g. (IDIFFERENCE (IDATE "2-JAN-80 12:00") (IDATE "1-JAN-80 12:00")). This "1 day" constant can be evaluated at compile time.

IDATE is guaranteed to accept as input the dates that DATE will output. It will ignore the parenthesized day of the week (if any). IDATE also correctly handles time zone specifications for those time zones registered in the list TIME.ZONES (page 12.15).

(GDATE DATE FORMAT —) [Function]
Like DATE, except that DATE can be a number in internal date and time format as returned by IDATE. If DATE is NIL, the current time and date is used.

(DATEFORMAT KEY1 ... KEYN) [N Lambda NoSpread Function]
DATEFORMAT returns a date format suitable as a parameter to DATE and GDATE. KEY1 ... KEYN are a set of keywords (unevaluated). Each keyword affects the format of the date independently (except for SLASHES and SPACES). If the date returned by (DATE) with the default formatting was "7-Jun-85 15:49:34", the keywords would affect the formatting as follows:

NO.DATE Doesn't include the date information, e.g. "15:49:34".
NUMBER.OF.MONTH Shows the month as a number instead of a name, e.g. "7-06-85 15:49:34".
YEAR.LONG Prints the year using four digits, e.g. "7-Jun-1985 15:49:34".
SLASHES Separates the day, month, and year fields with slashes, e.g. "7/Jun/85 15:49:34".
SPACES Separates the day, month, and year fields with spaces, e.g. "7 Jun 85 15:49:34".
NO.LEADING.SPACES By default, the day field will always be two characters long. If NO.LEADING.SPACES is specified, the day field will be one character for dates earlier than the 10th, e.g. "7-Jun-85 15:49:34" instead of "7-Jun-85 15:49:34".
NO.TIME Doesn't include the time information, e.g. "7-Jun-85".
TIME.ZONE Includes the time zone in the time specification, e.g. "7-Jun-85 15:49:34 PDT".
NO.SECONDS Doesn't include the seconds, e.g. "7-Jun-85 15:49".
DAY.OF.WEEK includes the day of the week in the time specification, e.g. "7-Jun-85 15:49:34 PDT (Friday)".

DAY.SHORT If DAY.OF.WEEK is specified to include the day of the week, the week day is shortened to the first three letters, e.g. "7-Jun-85 15:49:34 PDT (Fri)". Note that DAY.SHORT has no effect unless DAY.OF.WEEK is also specified.

(CLOCK N —) [Function]

If N = 0, CLOCK returns the current value of the time of day clock i.e., the number of milliseconds since last system start up.

If N = 1, returns the value of the time of day clock when the user started up this Interlisp, i.e., difference between (CLOCK 0) and (CLOCK 1) is number of milliseconds (real time) since this Interlisp system was started.

If N = 2, returns the number of milliseconds of compute time since user started up this Interlisp (garbage collection time is subtracted off).

If N = 3, returns the number of milliseconds of compute time spent in garbage collections (all types).

(SETTIME DT) [Function]

Sets the internal time-of-day clock. If DT = NIL, SETTIME attempts to get the time from the communications net; if it fails, the user is prompted for the time. If DT is a string in a form that IDATE recognizes, it is used to set the time.

The following variables are used to interpret times in different time zones. \TimeZoneComp, \BeginDST, and \EndDST are normally set automatically if your machine is connected to a network with a time server. For standalone machines, it may be necessary to set them by hand (or in your init file, see page 12.1) if you are not in the Pacific time zone.

TIME.ZONES [Variable]

Value is an association list that associates time zone specifications (PDT, EST, GMT, etc.) with the number of hours west of Greenwich (negative if east). If the time zone specification is a single letter, it is appended to "DT" or "ST" depending on whether daylight saving time is in effect. Initially set to:

\{(8 . P) (7 . M) (6 . C) (5 . E) (0 . GMT)\}

This list is used by DATE and GDATe when generating a date with the TIME.ZONE format is specified, and by IDATE when parsing dates.
12.6 Timers and Duration Functions

Often one needs to loop over some code, stopping when a certain interval of time has passed. Some systems provide an "alarm clock" facility, which provides an asynchronous interrupt when a time interval runs out. This is not particularly feasible in the current Interlisp-D environment, so the following facilities are supplied for efficiently testing for the expiration of a time interval in a loop context.

Three functions are provided: SETUPTIMER, SETUPTIMER.DATE, and TIMEREXPIRED?. Also several new i.s.oprs have been defined: forDuration, during, untilDate, timerUnits, usingTimer, and resourceName (reasonable variations on upper/lower case are permissible).

These functions use an object called a timer, which encodes a future clock time at which a signal is desired. A timer is constructed by the functions SETUPTIMER and SETUPTIMER.DATE, and is created with a basic clock "unit" selected from among SECONDS, MILLISECONDS, or TICKS. The first two timer units provide a machine/system independent interface, and the latter provides access to the "real", basic strobe unit of the machine's clock on which the program is running. The default unit is MILLISECONDS.

Currently, the TICKS unit is a function of the particular machine that Interlisp-D is running on. The Xerox 1132 has about 1680 ticks per millisecond; the Xerox 1108 has about 34.746 ticks per millisecond; the Xerox 1185 and 1186 have about 62.5 ticks per
millisecond. The advantage of using TICKS rather than one of the uniform interfaces is primarily speed; e.g., it may take over 400 microseconds to read the milliseconds clock (a software facility that uses the real clock), whereas reading the real clock itself may take less than ten microseconds. The disadvantage of the TICKS unit is its short roll-over interval (about 20 minutes) compared to the MILLISECONDS roll-over interval (about two weeks), and also the dependency on particular machine parameters.

\[(\text{SETUPTIMER INTERVAL } \text{OldTimer?} \ \text{timerUnits} \ \text{intervalUnits})\]  

\text{SETUPTIMER} returns a timer that will "go off" (as tested by \text{TIMEREXPIRED?}) after a specified time-interval measured from the current clock time. \text{SETUPTIMER} has one required and three optional arguments:

\text{INTERVAL} must be an integer specifying how long an interval is desired. \text{timerUnits} specifies the units of measure for the interval (defaults to MILLISECONDS).

If \text{OldTimer?} is a timer, it will be reused and returned, rather than allocating a new timer. \text{intervalUnits} specifies the units in which the \text{OldTimer?} is expressed (defaults to the value of \text{timerUnits}).

\[(\text{SETUPTIMER.DATE } \text{DTS} \ \text{OldTimer?})\]  

\text{SETUPTIMER.DATE} returns a timer (using the SECONDS time unit) that will "go off" at a specified date and time. \text{DTS} is a Date/Time string such as IDATE accepts (page 12.14). If \text{OldTimer?} is a timer, it will be reused and returned, rather than allocating a new timer.

\text{SETUPTIMER.DATE} operates by first subtracting (IDATE) from (IDATE \ DTS), so there may be some large integer creation involved, even if OLDTIMER? is given.

\[(\text{TIMEREXPIRED? } \text{TIMER} \ \text{ClockValue.or.timerUnits})\]  

\text{TIMEREXPIRED?} returns true if \text{TIMER} has "gone off". \text{ClockValue.or.timerUnits} can also be a timer, in which case \text{TIMEREXPIRED?} compares the two timers (which must be in the same timer units). If \text{X} and \text{Y} are timers, then \text{TIMEREXPIRED? X Y} is true if \text{X} is set for an earlier time than \text{Y}.

There are a number of i.s.oprs that make it easier to use timers in iterative statements (page 9.9). These i.s.oprs are given below in the "canonical" form, with the second "word" capitalized, but the all-caps and all-lower-case versions are also acceptable.
forDuration INTERVAL  [I.S. Operator]

during INTERVAL  [I.S. Operator]

INTERVAL is an integer specifying an interval of time during which the iterative statement will loop.

timerUnits UNITS  [I.S. Operator]

UNITS specifies the time units of the INTERVAL specified in forDuration.

untilDate DTS  [I.S. Operator]

DTS is a Date/Time string (such as IDATE accepts) specifying when the iterative statement should stop looping.

usingTimer TIMER  [I.S. Operator]

If usingTimer is given, TIMER is reused as the timer for forDuration or untilDate, rather than creating a new timer. This can reduce allocation if one of these i.s.ops is used within another loop.

resourceName RESOURCE  [I.S. Operator]

RESOURCE specifies a resource name to be used as the timer storage (see page 17.24). If RESOURCE = T, it will be converted to an internal name.

Some examples:

(during 6MONTHS timerUnits 'SECONDS
until (TENANT-VACATED? HouseHolder)
do (DISMISS < for-about-a-day >)
(HARRASS HouseHolder)
finally (if (NOT (TENANT-VACATED? HouseHolder))
then (EVICT-TENANT HouseHolder)))

This example shows that how is is possible to have two termination condition: (1) when the time interval of 6MONTHS has elapsed, or (2) when the predicate (TENANT-VACATED? HouseHolder) becomes true. Note that the "finally" clause is executed regardless of which termination condition caused it.

Also note that since the millisecond clock will "roll over" about every two weeks, "6MONTHS" wouldn't be an appropriate interval if the timer units were the default case, namely MILLISECONDS.

(do (forDuration (CONSTANT (ITIMES 10 24 60 60 1000))
do (CARRY.ON.AS.USUAL)
finally (PROMPTPRINT "Have you had your 10-day check-up?"))
This infinite loop breaks out with a warning message every 10 days. One could question whether the millisecond clock, which is used by default, is appropriate for this loop, since it rolls-over about every two weeks.

```
(SETQ \RandomTimer (SETUPTIMER 0))
(untilDate "31-DEC-83 23:59:59" usingTimer \RandomTimer
  when (WINNING?) do (RETURN)
  finally (ERROR "You’ve been losing this whole year!"))
```

Here we see a usage of an explicit date for the time interval; also, the user has squirreled away some storage (as the value of \RandomTimer) for use by the call to SETUPTIMER in this loop.

```
(forDuration SOMEINTERVAL
  resourceName \INNERLOOPBOX
  timerunits 'TICKS
  do (CRITICAL.INNER.LOOP))
```

For this loop, the user doesn’t want any CONSing to take place, so \INNERLOOPBOX will be defined as a resource which "caches" a timer cell (if it isn’t already so defined), and wraps the entire statement in a WITH-RESOURCES call. Furthermore, he has specified a time unit of TICKS, for lower overhead in this critical inner loop. In fact specifying a resourceName of \T would have been the same as specifying it to be \ForDurationOfBox; this is just a simpler way to specify that a resource is wanted, without having to think up a name.

### 12.7 Resources

Interlisp is based on the use of a storage-management system which allocates memory space for new data objects, and automatically reclaims the space when no longer in use. More generally, Interlisp manages shared "resources", such as files, semaphors for processes, etc. The protocols for allocating and freeing such resources resemble those of ordinary storage management.

Sometimes users need to explicitly manage the allocation of resources. They may desire the efficiency of explicit reclamation of certain temporary data; or it may be expensive to initialize a complex data object; or there may be an application that must not allocate new cells during some critical section of code.

The file package type RESOURCES is available to help with the definition and usage of such classes of data; the definition of a RESOURCE specifies prototype code to do the basic management operations. The filepkg command RESOURCES (page 17.39) is
used to save such definitions on files, and INITRESOURCES (page 17.39) causes the initialization code to be output.

The basic needs of resource management are (1) obtaining a data item from the Lisp memory management system and configuring it to be a totally new instance of the resource in question, (2) freeing up an instance which is no longer needed, (3) getting an instance of the resource for temporary usage [whether "fresh" or a formerly freed-up instance], and (4) setting up any prerequisite global data structures and variables. A resources definition consists of four "methods": INIT, NEW, GET, and FREE; each "method" is a form that will specialize the definition for four corresponding user-level macros INITRESOURCE, NEWRESOURCE, GETRESOURCE, and FREERESOURCE. PUTDEF is used to make a resources definition, and the four components are specified in a proplist:

(PUTDEF
  'RESOURCENAME
  'RESOURCES
  '(NEW NEW-INSTANCE-GENERATION-CODE
    FREE FREEING-UP-CODE
    GET GET-INSTANCE-CODE
    INIT INITIALIZATION-CODE))

Each of the xxx-CODE forms is a form that will appear as if it were the body of a substitution macro definition for the corresponding macro [see the discussion on the macros below].

12.7.1 A Simple Example

Suppose one has several pieces of code which use a 256-character string as a scratch string. One could simply generate a new string each time, but that would be inefficient if done repeatedly. If the user can guarantee that there are no re-entrant uses of the scratch string, then it could simply be stored in a global variable. However, if the code might be re-entrant on occasion, the program has to take precautions that two programs do not use the same scratch string at the same time. [Note: this consideration becomes very important in a multi-process environment. It is hard to guarantee that two processes won’t be running the same code at the same time, without using elaborate locks.] A typical tactic would be to store the scratch string in a global variable, and set the variable to NIL whenever the string is in use (so that re-entrant usages would know to get a "new" instance). For example, assuming the global variable TEMPSTRINGBUFFER is initialized to NIL:

[DEFINEQ (WITHSTRING NIL
  (PROG ((BUF (OR (PROG1 TEMPSTRINGBUFFER
                       (SETQ TEMPSTRINGBUFFER NIL)))

12.20
(ALLOCSTRING 256)))
... use the scratch string in the variable BUF ...
(SETQ TEMPSTRINGBUFFER BUF)
(RETURN]

Here, the basic elements of a "resource" usage may be seen: (1) a
call (ALLOCSTRING 256) allocates fresh instances of "buffer", (2) after usage is completed the instance is returned to the "free"
state, by putting it back in the global variable TEMPSTRINGBUFFER where a subsequent call will find it, (3) the
prog-binding of BUF will get an existing instance of a string buffer if there is one -- otherwise it will get a new instance which
will later be available for reuse, and (4) some initialization is
performed before usage of the resource (in this case, it is the
setting of the global variable TEMPSTRINGBUFFER).

Given the following resources definition:

(PUTDEF
 'STRINGBUFFER
 'RESOURCES
 '(NEW (ALLOCSTRING 256)
   FREE (setq TEMPSTRINGBUFFER (PROG1 . ARGS))
   GET (OR (PROG1 TEMPSTRINGBUFFER
     (setq TEMPSTRINGBUFFER NIL))
     (NEWRESOURCE TEMPSTRINGBUFFER)))
   INIT (setq TEMPSTRINGBUFFER NIL))
we could then redo the example above as

(DEFINEQ (WITHSTRING NIL
  (PROG ((BUF (GETRESOURCE STRINGBUFFER)))
    ... use the string in the variable BUF ...
    (FREERESOURCE STRINGBUFFER BUF)
    (RETURN]

The advantage of doing the coding this way is that the resource
management part of WITHSTRING is fully contained in the
expansions of GETRESOURCE and FREERESOURCE, and thus
there is no confusion between what is WITHSTRING code and
what is resource management code. This particular advantage
will be multiplied if there are other functions which need a
"temporary" string buffer; and of course, the resultant
modularity makes it much easier to contemplate minor
variations on, as well as multiple clients of, the STRINGBUFFER
resource.

In fact, the scenario just shown above in the WITHSTRING
example is so commonly useful that an abbreviation has been
added; if a resources definition is made with *only* a NEW
method, then appropriate FREE, GET, and INIT methods will be
inferred, along with a coordinated globalvar, to be parallel to
the above definition. So the above definition could be more
simply written
(PUTDEF 'STRINGBUFFER
   'RESOURCES
   '(NEW (ALLOCSTRING 256)))

and everything would work the same.

The macro WITH-RESOURCES simplifies the common scoping case, where at the beginning of some piece of code, there are one or more GETRESOURCE calls the results of which are each bound to a lambda variable; and at the ending of that code a FREERESOURCE call is done on each instance. Since the resources are locally bound to variables with the same name as the resource itself, the definition for WITHSTRING then simplifies to

(DEFINEQ (WITHSTRING NIL
   (WITH-RESOURCES (STRINGBUFFER)
   ... use the string in the variable STRINGBUFFER ...])

12.7.2 Trade-offs in More Complicated Cases

This simple example presumes that the various functions which use the resource are generally not re-entrant. While an occasional re-entrant use will be handled correctly (another example of the resource will simply be created), if this were to happen too often, then many of the resource requests will create and throw away new objects, which defeats one of the major purposes of using resources. A slightly more complex GET and FREE method can be of much benefit in maintaining a pool of available resources; if the resource were defined to maintain a list of "free" instances, then the GET method could simply take one off the list and the FREE method could just push it back onto the list. In this simple example, the SETQ in the FREE method defined above would just become a "push", and the first clause of the GET method would just be (pop TEMPSTRINGBUFFER)

A word of caution: if the datatype of the resource is something very small that Interlisp system is "good" at allocating and reclaiming, then explicit user storage management will probably not do much better than the combination of cons/createcell and the garbage collector. This would especially be so if more complicated GET and FREE methods were to be used, since their overhead would be closer to that of the built-in system facilities. Finally, it must be considered whether retaining multiple instances of the resource is a net gain; if the re-entrant case is truly rare, it may be more worthwhile to retain at most one instance, and simply let the instances created by the rarely-used case be reclaimed in the normal course of garbage collection.
12.7.3 Macros for Accessing Resources

Four user-level macros are defined for accessing resources:

- **(NEWRESOURCE RESOURCENAME . ARGS)** [Macro]
- **(FREERESOURCE RESOURCENAME . ARGS)** [Macro]
- **(GETRESOURCE RESOURCENAME . ARGS)** [Macro]
- **(INITRESOURCE RESOURCENAME . ARGS)** [Macro]

Each of these macros behave as if they were defined as a substitution macro of the form

```
((RESOURCENAME . ARGS) MACROBODY)
```

where the expression `MACROBODY` is selected by using the "code" supplied by the corresponding method from the `RESOURCENAME` definition.

Note that it is possible to pass "arguments" to the user's resource allocation macros. For example, if the GET method for the resource `FOO` is `(GETFOO . ARGS)`, then `(GETRESOURCE FOO X Y)` is transformed into `(GETFOO X Y)`. This form was used in the FREE method of the `STRINGBUFFER` resource described above, to pass the old `STRINGBUFFER` object to be freed.

- **(WITH-RESOURCES (RESOURCE1 RESOURCE2 ...) FORM1 FORM2 ...)** [Macro]

The `WITH-RESOURCES` macro binds lambda variables of the same name as the resources (for each of the resources `RESOURCE1`, `RESOURCE2`, etc.) to the result of the `GETRESOURCE` macro; then executes the forms `FORM1`, `FORM2`, etc., does a `FREERESOURCE` on each instance, and returns the value of the last form (evaluated and saved before the `FREERESOURCES`).

Note: `(WITH-RESOURCES RESOURCE ...)` is interpreted the same as `(WITH-RESOURCES (RESOURCE ...) ...). Also, the singular name `WITH-RESOURCE` is accepted as a synonym for `WITH-RESOURCES`.

12.7.4 Saving Resources in a File

Resources definitions may be saved on files using the `RESOURCES` file package command (page 17.39). Typically, one only needs the full definition available when compiling or interpreting the code, so it is appropriate to put the file package command in a `(DECLARE: EVAL@COMPILE DONTCOPY ...)` declaration, just as one might do for a `RECORDS` declaration. But
just as certain record declarations need *some* initialization in the run-time environment, so do most resources. This initialization is specified by the resource's INIT method, which is executed automatically when the resource is defined by the PUTDEF output by the RESOURCES command. However, if the RESOURCES command is in a DONTCOPY expression and thus is not included in the compiled file, then it is necessary to include a separate INITRESOURCES command (page 17.39) in the filecoms to insure that the resource is properly initialized.

12.8 Pattern Matching

Interlisp provides a fairly general pattern match facility that allows the user to specify certain tests that would otherwise be clumsy to write, by giving a pattern which the datum is supposed to match. Essentially, the user writes "Does the (expression) X look like (the pattern) P?" For example, (match X with (& 'A -- 'B)) asks whether the second element of X is an A, and the last element a B. The implementation of the matching is performed by computing (once) the equivalent Interlisp expression which will perform the indicated operation, and substituting this for the pattern, and not by invoking each time a general purpose capability such as that found in FLIP or PLANNER. For example, the translation of (match X with (& 'A -- 'B)) is:

\[
\begin{align*}
\text{(AND (EQ (CAOR X) 'A) } \\
\text{(EQ (CAR (LAST (CDOR X))) 'B))}
\end{align*}
\]

Thus the pattern match facility is really a pattern match compiler, and the emphasis in its design and implementation has been more on the efficiency of object code than on generality and sophistication of its matching capabilities. The goal was to provide a facility that could and would be used even where efficiency was paramount, e.g., in inner loops. As a result, the pattern match facility does not contain (yet) some of the more esoteric features of other pattern match languages, such as repeated patterns, disjunctive and conjunctive patterns, recursion, etc. However, the user can be confident that what facilities it does provide will result in Interlisp expressions comparable to those he would generate by hand. Wherever possible, already existing Interlisp functions are used in the translation, e.g., the translation of (match X with 'A) uses MEMB, (match X with '(A $)) uses ASSOC, etc.

The syntax for pattern match expressions is (match FORM with PATTERN), where PATTERN is a list as described below. If FORM appears more than once in the translation, and it is not either a
variable, or an expression that is easy to (re)compute, such as (CAR Y), (CDDR Z), etc., a dummy variable will be generated and bound to the value of FORM so that FORM is not evaluated a multiple number of times. For example, the translation of (match (FOO X) with ($ 'A $)) is simply (MEMB 'A (FOO X)), while the translation of (match (FOO X) with ('A 'B --)) is:

(PROG ($$2)
  (RETURN
    (AND (EQ (CAR (SETQ $$2 (Faa X»)
      'A)
    (EQ (CADR $$2) 'B]

In the interests of efficiency, the pattern match compiler assumes that all lists end in NIL, i.e., there are no LISTP checks inserted in the translation to check tails. For example, the translation of (match X with ('A & --)) is (AND (EQ (CAR X) (QUOTE A)) (CDR X)), which will match with (A B) as well as (A . B). Similarly, the pattern match compiler does not insert LISTP checks on elements, e.g., (match X with ([A --]) translates simply as (EQ (CAAR X) 'A), and (match X with (($1 $1 --)) as (CDAR X). Note that the user can explicitly insert LISTP checks himself by using @, as described below, e.g., (match X with (($1 $1 --)@LISTP --)) translates as (CDR (LISTP (CAR X))).

Note: The insertion of LISTP checks for elements is controlled by the variable PATLISTPCHECK. When PATLISTPCHECK is T, LISTP checks are inserted, e.g., (match X with ([A --]) translates as: (EQ (CAR (LISTP (CAR (LISTP X)))) 'A). PATLISTPCHECK is initially NIL. Its value can be changed within a particular function by using a local CLISP declaration (see page 21.13).

Note: Pattern match expressions are translated using the DWIM and CLISP facilities, using all CLISP declarations in effect (standard/fast/undoable) (see page 21.12).

12.8.1 Pattern Elements

A pattern consists of a list of pattern elements. Each pattern element is said to match either an element of a data structure or a segment. For example, in the editor's pattern matcher, "--" (page 16.19) matches any arbitrary segment of a list, while & or a subpattern match only one element of a list. Those patterns which may match a segment of a list are called segment patterns; those that match a single element are called element patterns.

12.8.2 Element Patterns

There are several types of element patterns, best given by their syntax:
$1$ or & Matches an arbitrary element of a list.

'EXPRESSION Matches only an element which is equal to the given expression e.g., 'A, '(A B).

EQ, MEMB, and ASSOC are automatically used in the translation when the quoted expression is atomic, otherwise EQUAL, MEMBER, and SASSOC.

= FORM Matches only an element which is EQUAL to the value of FORM, e.g., = X, = (REVERSE Y).

\[=\] FORM Same as =, but uses an EQ check instead of EQUAL.

ATOM The treatment depends on setting of PATVARDEFAUlt. If PATVARDEFAUlt is ' or QUOTE, same as 'ATOM. If PATVARDEFAUlt is = or EQUAL, same as =ATOM. If PATVARDEFAUlt is \[=\] or EQ, same as \[=\]ATOM. If PATVARDEFAUlt is \[\[\]\] or SETQ, same as ATOM\[\[\]\-&.

PATVARDEFAUlt is initially '.

PATVARDEFAUlt can be changed within a particular function by using a local CLISP declaration (see page 21.13).

Note: numbers and strings are always interpreted as though PATVARDEFAUlt were =, regardless of its setting. EQ, MEMB, and ASSOC are used for comparisons involving small integers.

(PATTERN1 ... PATTERNn) Matches a list which matches the given patterns, e.g., (& &), (\[\[\]\] 'A).

ELEMENT-PATTERN@FN Matches an element if ELEMENT-PATTERN matches it, and FN (name of a function or a LAMBDA expression) applied to that element returns non-NIL. For example, &@NUMBERP matches a number and ('A \[\[\]\])@FOO matches a list whose first element is A, and for which FOO applied to that list is non-NIL.

For "simple" tests, the function-object is applied before a match is attempted with the pattern, e.g., ((\[\[\]\] 'A \[\[\]\])@LISTP \[\[\]\]) translates as (AND (LISTP (CAR X)) (MEMB 'A (CAR X))), not the other way around. FN may also be a FORM in terms of the variable @, e.g., &@ (EQ @ 3) is equivalent to = 3.

* Matches any arbitrary element. If the entire match succeeds, the element which matched the * will be returned as the value of the match.

Note: Normally, the pattern match compiler constructs an expression whose value is guaranteed to be non-NIL if the match succeeds and NIL if it fails. However, if a * appears in the pattern, the expression generated could also return NIL if the match succeeds and * was matched to NIL. For example, (match X with ('A * \[\[\]\])) translates as (AND (EQ (CAR X) 'A) (CADR X)), so if X is equal to (A NIL B) then (match X with ('A * \[\[\]\])) returns NIL even though the match succeeded.
"ELEMENT-PATTERN" Matches an element if the element is not matched by ELEMENT-PATTERN, e.g., "A," = X, "(-- A --)."

(*ANY* ELEMENT-PATTERN ELEMENT-PATTERN ...) Matches if any of the contained patterns match.

12.8.3 Segment Patterns

$ or -- Matches any segment of a list (including one of zero length).

The difference between $ and -- is in the type of search they generate. For example, (match X with ($ 'A 'B $)) translates as (EQ (CADR (MEMB 'A X)) 'B), whereas (match X with (-- 'A 'B $)) translates as:

[SOME X (FUNCTION (LAMBDA ($$2 $$1)
(AND (EQ $$2 • A)
(EQ (CADR $$1) 'B)

Thus, a paraphrase of ($ 'A 'B $) would be "Is the element following the first A a B?", whereas a paraphrase of (-- 'A 'B $) would be "Is there any A immediately followed by a B?" Note that the pattern employing $ will result in a more efficient search than that employing --. However, ($ 'A 'B $) will not match with (X Y Z A M O A B C), but (-- 'A 'B $) will.

Essentially, once a pattern following a $ matches, the $ never resumes searching, whereas -- produces a translation that will always continue searching until there is no possibility of success. However, if the pattern match compiler can deduce from the pattern that continuing a search after a particular failure cannot possibly succeed, then the translations for both -- and $ will be the same. For example, both (match X with ($ 'A S3 $)) and (match X with (-- 'A S3 --)) translate as (CDDD (MEMB (QUOTE A) X)), because if there are not three elements following the first A, there certainly will not be three elements following subsequent A's, so there is no reason to continue searching, even for --. Similarly, ($ 'A $ 'B $) and (-- 'A -- 'B --) are equivalent.

$2, $3, etc. Matches a segment of the given length. Note that $1 is not a segment pattern.

!ELEMENT-PATTERN Matches any segment which ELEMENT-PATTERN would match as a list. For example, if the value of FOO is (A B C), ! = FOO will match the segment ... A B C ... etc.

Note: Since ! appearing in front of the last pattern specifies a match with some tail of the given expression, it also makes sense in this case for a ! to appear in front of a pattern that can only match with an atom, e.g., ($2 !'A) means match if CDDR of the expression is the atom A. Similarly, (match X with ($ !'A)) translates to (EQ (CDR (LAST X)) 'A).

!ATOM treatment depends on setting of PATVARDEFAULT. If PATVARDEFAULT is ' or QUOTE, same as '!ATOM (see above
discussion). If PATVARDEFAULT is = or EQUAL, same as ! = ATOM. If PATVARDEFAULT is = = or EQ, same as ! = ATOM. If PATVARDEFAULT is ← or SETQ, same as ATOM←$.

The atom "." is treated exactly like ".". In addition, if a pattern ends in an atom, the "." is first changed to ".". e.g., ($1 . A) and ($1 ! A) are equivalent, even though the atom "." does not explicitly appear in the pattern.

One exception where "." is not treated like ".": "." preceding an assignment does not have the special interpretation that "." has preceding an assignment (see below). For example, (match X with ('A . FOO←'B)) translates as:

\[
\text{(AND (EQ (CAR X) 'A)
       (EQ (CDR X) 'B)
       (SETQ FOO (CDR X)))}
\]

but (match X with ('A ! FOO←'B)) translates as:

\[
\text{(AND (EQ (CAR X) 'A)
       (NULL (CDDR X))
       (EQ (CADR X) 'B)
       (SETQ FOO (CDR X)))}
\]

**SEGMENT-PATTERN@FUNCTION-OBJECT**

Matches a segment if the segment-pattern matches it, and the function object applied to the corresponding segment (as a list) returns non-NIL. For example, ($@CDDR 'D $) matches (A B C D E) but not (A B D E), since CDDR of (A B) is NIL.

Note: an @ pattern applied to a segment will require computing the corresponding structure (with LDIFF) each time the predicate is applied (except when the segment in question is a tail of the list being matched).

### 12.8.4 Assignments

Any pattern element may be preceded by "VARIABLE←"", meaning that if the match succeeds (i.e., everything matches), VARIABLE is to be set to the thing that matches that pattern element. For example, if X is (A B C D E), (match X with ($2 Y←$3)) will set Y to (C D E). Note that assignments are not performed until the entire match has succeeded, so assignments cannot be used to specify a search for an element found earlier in the match, e.g., (match X with (Y←$1 = Y --)) will not match with (A A B C ...), unless, of course, the value of Y was A before the match started. This type of match is achieved by using place-markers, described below.

If the variable is preceded by a !, the assignment is to the tail of the list as of that point in the pattern, i.e., that portion of the list matched by the remainder of the pattern. For example, if X is (A B C D E), (match X with ($ !Y←'C 'D $)) sets Y to (C D E), i.e., CDDR
of X. In other words, when ! precedes an assignment, it acts as a modifier to the ↔, and has no effect whatsoever on the pattern itself, e.g., (match X with ('A 'B)) and (match X with ('A !FOO→'B)) match identically, and in the latter case, FOO will be set to CDR of X.

Note: *↔-PATTERN-ELEMENT and !*↔-PATTERN-ELEMENT are acceptable, e.g., (match X with (A *↔(B --)) transposes as:

[PROG ($$2) (RETURN
(AND (EQ (CAADR (SETQ $$2 (MEMB 'A X)) 'B)
(CADR $$2)

12.8.5 Place-Markers

Variables of the form #N, N a number, are called place-markers, and are interpreted specially by the pattern match compiler. Place-markers are used in a pattern to mark or refer to a particular pattern element. Functionally, they are used like ordinary variables, i.e., they can be assigned values, or used freely in forms appearing in the pattern, e.g., (match X with (#1↔$1 = (ADD1 #1))) will match the list (2 3). However, they are not really variables in the sense that they are not bound, nor can a function called from within the pattern expect to be able to obtain their values. For convenience, regardless of the setting of PATVARDEFAULT, the first appearance of a defaulted place-marker is interpreted as though PATVARDEFAULT were ←. Thus the above pattern could have been written as (match X with (1 = (ADD1 1))). Subsequent appearances of a place-marker are interpreted as though PATVARDEFAULT were =. For example, (match X with (#1 #1 ←)) is equivalent to (match X with (#1↔$1 = #1 ←)), and translates as (AND (CDR X) (EQUAL (CAR X) (CADR X)). (Note that (EQUAL (CAR X) (CADR X)) would incorrectly match with (NIL).)

12.8.6 Replacements

The construct PATTERN-ELEMENT↔FORM specifies that if the match succeeds, the part of the data that matched is to be replaced with the value of FORM. For example, if X = (A B C D E), (match X with (S 'C S$1↔Y $1)) will replace the third element of X with the value of Y. As with assignments, replacements are not performed until after it is determined that the entire match will be successful.

Replacements involving segments splice the corresponding structure into the list being matched, e.g., if X is (A B C D E F) and FOO is (1 2 3), after the pattern ('A $↔FOO 'D $) is matched with
X, X will be (A 1 2 3 D E F), and FOO will be EQ to CDR of X, i.e., (1 2 3 D E F).

Note that ($ FOO←FIE $) is ambiguous, since it is not clear whether FOO or FIE is the pattern element, i.e., whether ← specifies assignment or replacement. For example, if PATVARDEFAULT is =, this pattern can be interpreted as ($ FOO←FIE $), meaning search for the value of FIE, and if found set FOO to it, or ($ = FOO←FIE $) meaning search for the value of FOO, and if found, store the value of FIE into the corresponding position. In such cases, the user should disambiguate by not using the PATVARDEFAULT option, i.e., by specifying ' or =.

Note: Replacements are normally done with RPLACA or RPLACD. The user can specify that /RPLACA and /RPLACD should be used, or FRPLACA and FRPLACD, by means of CLISP declarations (see page 21.12).

12.8.7 Reconstruction

The user can specify a value for a pattern match operation other than what is returned by the match by writing (match FORM1 with PATTERN = > FORM2). For example, (match X with (FOO←$ 'A _ ) = > (REVERSE FOO)) translates as:

(PROG ($$2)
  (RETURN
    (COND ((SETQ $$2 (MEMB 'A X))
        (SETQ FOO (LDIFF X $$2))
        (REVERSE FOO)
    ))
)

Place-markers in the pattern can be referred to from within FORM, e.g., the above could also have been written as (match X with (!#1 'A _ ) = > (REVERSE #1)). If -> is used in place of = >, the expression being matched is also physically changed to the value of FORM. For example, (match X with (#1 'A !#2) -> (CONS #1 #2)) would remove the second element from X, if it were equal to A.

In general, (match FORM1 with PATTERN -> FORM2) is translated so as to compute FORM2 if the match is successful, and then smash its value into the first node of FORM1. However, whenever possible, the translation does not actually require FORM2 to be computed in its entirety, but instead the pattern match compiler uses FORM2 as an indication of what should be done to FORM1. For example, (match X with (#1 'A !#2) -> (CONS #1 #2)) translates as (AND (EQ (CADR X) 'A) (RPLACD X (CDDR X))).
12.8.8 Examples

Example: (match X with (\-- 'A \--))

\-- matches any arbitrary segment. 'A matches only an A, and the second \-- again matches an arbitrary segment; thus this translates to (MEMB 'A X).

Example: (match X with (\-- 'A))

Again, \-- matches an arbitrary segment; however, since there is no \-- after the 'A, A must be the last element of X. Thus this translates to: (EQ (CAR (LAST X)) 'A).

Example: (match X with ('A 'B \-- 'C $3 \--))

CAR of X must be A, and CADR must be B, and there must be at least three elements after the first C, so the translation is:

(AND (EQ (CAR X) 'A)
     (EQ (CADR X) 'B)
     (CDDR (MEMB 'C (CDDR X))))

Example: (match X with ('A 'B 'C Y \-- $))

Since ('A 'B) does not end in $ or \--, (CDDAR X) must be NIL. The translation is:

(COND
  ((AND (EQ (CAAR X) 'A)
      (EQ (CADAR X) 'B)
      (NULL (CDDAR X))
      (EQ (CADR X) 'C)
      (CDDR X))
   (SETQ Y (CADDR X))
   T))

Example: (match X with (#1 'A $ 'B 'C #1 $))

#1 is implicitly assigned to the first element in the list. The $ searches for the first B following A. This B must be followed by a C, and the C by an expression equal to the first element. The translation is:

[PROG ($$2)
  (RETURN
   (AND (EQ (CADR X) 'A)
        (EQ (CADR (SETQ $$2 (MEMB 'B (CDDR X) 'C))
             (CDDR $$2))
            (EQUAL (CADDR $$2) (CAR X))]

Example: (match X with (#1 'A -- 'B 'C #1 $))

Similar to the pattern above, except that \-- specifies a search for any B followed by a C followed by the first element, so the translation is:

[AND (EQ (CADR X) 'A)
   (SOME (CDDR X)
(FUNCTION (LAMBDA ($$2 $$1)
  (AND (EQ $$2 'B)
    (EQ (CADR $$1) 'C)
    (CDDR $$1)
    (EQUAL (CADDR $$1) (CAR X])

INDEX

A
(A \( E_1 \ldots E_M \)) (Editor Command) II: 16.32
A00n (gensym) I: 2.11
ABBREVLST (Variable) III: 26.46; 26.47
(ABS X) I: 7.4
ACCESS (File Attribute) III: 24.19
Access chain (on stack) I: 11.3
ACCESSFNS (Record Type) III: 8.12; 8.14
?ACTIVATEFLG (Variable) III: 26.36
Active frame I: 11.3
(ADD DATUM ITEM1 ITEM2 \ldots) (Change Word) I: 8.18
ADD (File Package Command Property) II: 17.45
(ADD.PACKET.FILTER FILTER) (Function) III: 31.40
(ADD.PROCESS FORM PROP1 VALUE1 \ldots PROP N VALUE N) II: 23.2
(ADD1 X) I: 7.6
(ADDFILE FILE \ldots) II: 17.19
(ADDMENU MENU WINDOW POSITION DONTOPENFLG) III: 28.38
(ADDDPST ATM PROP NEW FLG) I: 2.6
(ADDSPELL X SPLST N) II: 20.21; 20.23
ADDSPELLFLG (Variable) II: 17.19; 17.20; 17.16,22
(ADDTOCOMS COMS NAME TYPE NEAR LISTNAME) II: 17.48
(ADDTOFILE NAME TYPE FILE NEAR LISTNAME) II: 17.48
(ADDTOFILES? \ldots) II: 17.13
(ADDTOSCRATCHLIST VALUE) I: 3.8
(ADDTOVAR VAR X_1 X_2 \ldots X_N) II: 17.54; 17.36
(ADDVARS (VAR_1 . LST_1) \ldots (VAR_N . LST_N)) (File Package Command) II: 17.36
(ADIEU VAL) I: 11.21
(ADJUSTCURSORPOSITION DELTA X DELTA Y) III: 30.17
ADV-PROG (Function) II: 15.10-11
ADV-RETURN (Function) II: 15.10-11
ADV-SETQ (Function) II: 15.10-11
(ADVICE FN_1 \ldots FN_N) (File Package Command) II: 17.35; 15.13
ADVICE (File Package Type) II: 17.22
ADVICE (Property Name) II: 15.12-13; 17.18
Advice to functions II: 15.9
ADVINFOFLST (Variable) II: 15.12-13
(ADVISE FN_1 \ldots FN_N) (File Package Command) II: 17.34; 15.13
(ADVISE FN WHEN WHERE WHAT) II: 15.11; 15.10
ADVISED (Property Name) I: 10.9; II: 15.11
ADVISEDFNS (Variable) II: 15.11-12
(ADVISEDUMP X FLG) II: 15.13
Advising functions II: 15.9
AFTER (as argument to ADVISE) II: 15.10; 15.11
AFTER (as argument to BREAKIN) II: 15.6; 14.5
After (DEdit Command) II: 16.7
AFTER (in INSERT editor command) II: 16.33
AFTER (in MOVE editor command) II: 16.38
AFTER LITATOM (Prog. Asst. Command) II: 13.15; 13.24,33
AFTEREXIT (Process Property) II: 23.3
AFTERMOVEFN (Window Property) III: 28.20
AFTERSYSOUTFORMS (Variable) I: 12.9
ALIAS (Property Name) II: 15.5; 15.8
ALINK (in stack frame) I: 11.3
(ALISTS (VAR_1 KEY_1 KEY_2 \ldots) \ldots) (File Package Command) II: 17.37
ALISTS (File Package Type) II: 17.22
ALL (in event specification) II: 13.7
ALL (in PROP file package command) II: 17.37
(ALLATTACHEDWINDOWS WINDOW) III: 28.48
(ALLOCATE.ETHERPACKAGE) (Function) III: 31.39
(ALLOCATE.PUP) III: 31.28
(ALLOCATE.XIP) III: 31.36
(ALLOCSTRING N INITCHAR OLD FATFLG) I: 4.2
&ALLOW-OTHER-KEYS (DEFSMACRO keyword) I: 10.26
(ALLOW.BUTTON.EVENTS) II: 23.15
ALLPROP (Litatom) I: 10.10; II: 13.29; 17.5,54
ALONE (type of read macro) III: 25.40
(ALPHORDER A B CASEARRAY) I: 3.17
already undone (Printed by System) II: 13.13; 13.42
ALWAYS FORM (I.S. Operator) I: 9.11
ALWAYS (type of read macro) III: 25.40
AMBIGUOUS (printed by DWIM) II: 20.16
AMBIGUOUS DATA PATH (Error Message) I: 8.3

INDEX
INDEX

AMBIGUOUS RECORD FIELD (Error Message) I: 8.2
AMONG (Masterscope Path Option) II: 19.16
ANALYZE SET (Masterscope Command) II: 19.4
(AND X₁ X₂ ... Xₙ) I: 9.3
AND (in event specification) II: 13.7
AND (in USE command) II: 13.10
ANSWER (Variable) III: 26.15
(ANTilog X) I: 7.13
*ANY* (in edit pattern) II: 16.18
APPEND (File access) III: 24.2
(APPEND X₁ X₂ ... Xₙ) II: 3.5
(APPENDTOVAR VAR X₁ X₂ ... Xₙ) II: 17.55; 17.36
(APPENDVARS (VAR₁ . LST₁) ... (VARₙ . LSTₙ)) (File Package Command) II: 17.36
(APPLY FN ARGLIST —) I: 10.11; II: 18.19
(APPLY* FN ARG₁ ARG₂ ... ARGₙ) I: 10.12; II: 18.19
APPY-format input II: 13.4
Applying functions to arguments I: 10.11
Approval of DWM corrections I: 20.4; 20.3
APPROVEFLG (Variable) II: 20.14; 20.22,24
(APPROPOS STRING ALLFLG QUIETFLG OUTPUT) I: 2.11
Arbitrary-size integers I: 7.1
(ARGCONS X RADIANSLG) I: 7.14
ARGCONS: ARG NOT IN RANGE (Error Message) I: 7.14
*ARCHIVE* (history list property) II: 13.33
ARCHIVE EventSpec (Prog. Asst. Command) II: 13.16
ARCHIVEFLG (Variable) II: 13.23
ARCHIVEFN (Variable) II: 13.23; 13.16
ARCHIVELST (Variable) I: 13.31; 13.16
(ARGCAND X RADIANSLG) I: 7.14
ARCSIN: ARG NOT IN RANGE (Error Message) I: 7.14
(ARGTAN X RADIANSLG) I: 7.14
(ARGTAN2 Y X RADIANSLG) I: 7.14
SET ARE SET (Masterscope Command) II: 19.5
(ARG VAR M) I: 10.5
*ARGN (Stack blip) I: 11.15
ARG NOT ARRAY (Error Message) I: 5.1-2; II: 14.30
ARG NOT HARRAY (Error Message) II: 14.31
ARG NOT LST (Error Message) I: 3.2,5,15-16; II: 14.28
ARG NOT LITATOM (Error Message) I: 2.3,5,7; 9.8; 10.3,11; II: 14.28; 17.54
(ARGLIST FN) I: 10.8; II: 14.10
ARGNAMES (Property Name) I: 10.8
ARGS (Break Command) II: 14.10
...ARGS (history list property) II: 13.33
ARGS NOT AVAILABLE (Error Message) I: 10.8
(ARGTYPE FN) I: 10.7
Argument lists of functions I: 10.2
*ARGVAL* (stack blip) I: 11.16
Arithmetic I: 7.1
AROUND (as argument to ADVISE) II: 15.10; 15.11-12
AROUND (as argument to BREAKIN) II: 15.6; 14.5
ARRAY SIZE TYPE INIT ORIG —) I: 5.1
ARRAYORIG ARRAY) I: 5.2
ARRAYYP X I: 5.1; 9.2
ARRAYRECORD (Record Type) I: 8.8
Arrays I: 5.1; 9.2
ARRAYS FULL (Error Message) I: 14.29; 22.5
ARRAYSIZE ARRAY) I: 5.2
ARRAYTYP ARRAY) I: 5.2
AS VAR (I.S. Operator) I: 9.15
ASCENT (Font property) III: 27.27
(ASKUSER WAIT DEFAULT MESS KEYLST TYPEAHEAD LISPXPRNITFLG OPTIONSFILE FILE) III: 26.12
ASKUSERTTBL (Variable) III: 26.17
Assignments in CLISP II: 21.9
Assignments in pattern matching I: 12.28
(ASSOC KEY ALST) I: 3.15
Association lists I: 3.15
Association lists in EVALA I: 10.13
ASSOCCRECORD (Record Type) I: 8.8
(ATOM X) I: 2.1; 9.1
ATOM HASH TABLE FULL (Error Message) II: 14.28
ATOM TOO LONG (Error Message) I: 2.2; II: 14.28
ATOMRECORD (Record Type) I: 8.9
Atoms I: 2.1; 9.1
(ATTACH X L) I: 3.5
Attached windows III: 28.45; 28.1
(ATTACHEDWINDOWS WINDOW COM) III: 28.47
ATTACHEDWINDOWS (Window Property) III: 28.54
(ATTACHMENU MENU MAINWINDOW EDGE POSITIONONEDGE NOOPENFLG) III: 28.48
(ATTACHWINDOW WINDOWTOATTACH MAINWINDOW EDGE POSITIONONEDGE WINDOWCOMACT) III: 28.45
ATTEMPT TO BIND NIL OR T (Error Message) I: 9.8; 10.3; II: 14.30

INDEX.2
INDEX

SOURCETYPE OPERATION TEXTURE CLIPPINGREGION) III: 27.14
(BITCLEAR N MASK) (Macro) I: 7.9
BITMAP (Data Type) III: 27.3
(BITMAPBIT BITMAP X Y NEWVALUE) III: 27.3
(BITMAPCOPY BITMAP) III: 27.4
(BITMAPCREATE WIDTH HEIGHT BITSPERPIXEL) III: 27.3
(BITMAPHEIGHT BITMAP) III: 27.3
(BITMAPIMAGESIZE BITMAP DIMENSION STREAM) III: 27.16
(BITMAP X) III: 27.3
Bitmaps III: 27.3
(BITMAPWIDTH BITMAP) III: 27.3
BITS (as a field specification) I: 8.21
BITS (record field type) I: 8.10
(BITSET N MASK) (Macro) I: 7.9
(BITSPERPIXEL BITMAP) III: 27.3
(BITTEST N MASK) (Macro) I: 7.9
(BK N) (Editor Command) II: 16.16
BK (Editor Command) II: 16.16
(BKLINBUF STR) III: 30.12
(BKSYSBUF X FLG RDTBL) III: 30.11; 30.12
BLACKSHADE (Variable) III: 27.7
BLINK (in stack frame) I: 11.3
Blips on the stack I: 11.14
(BLIPS CAN BLIPTYP IPOS) I: 11.16
(BLIPVAL BLIPTYP IPOS FLG) I: 11.16
BLKAPPLY (Function) II: 18.19
BLKAPPLY* (Function) II: 18.19
BLKAPPLYFNS (in Masterscope Set Specification) II: 19.12
BLKAPPLYFNS (Variable) II: 18.19; 18.18
BLKFNS (in Masterscope Set Specification) II: 19.12
BLKLIBRARY (Variable) II: 18.20; 18.18
BLKLIBRARYDEF (Property Name) II: 18.20
BLKNAME (Variable) II: 18.18
(BLOCK MSEC SWAIT TIMER) II: 23.5
Block compiling II: 18.17
Block compiling functions II: 18.20
Block declarations II: 18.17; 17.42
Block library II: 18.19
(BLOCKCOMPILE BLKNAME BLKFNS ENTRIES FLG) II: 18.20; 18.18
BLOCKED (Printed by Editor) II: 16.65
BLOCKRECORD (Record Type) I: 8.11
(BLOCKS BLOCK₁ ... BLOCKₙ) (File Package Command) II: 17.42; 18.17
(BLTSHADE TEXTURE DESTINATION DESTINATIONLEFT DESTINATIONB O T T O M WIDTH HEIGHT OPERATION CLIPPINGREGION) III: 27.16
(BO N) (Editor Command) II: 16.41
&BODY (DEFMACRO keyword) I: 10.25
BOLDITALIC (Font face) III: 27.26
BORDER (Window Property) III: 28.33
BOTH (File access) III: 24.2
(BOTH TEMPLATE₁ TEMPLATE₂) (in Masterscope template) II: 19.20
BOTTOM (as argument to ADVISE) II: 15.11
Bottom margin III: 27.11
(BOTTOMOFGRIDCOORD GRIDY GRIDSPEC) III: 27.23
(BOUNDP VAR) I: 2.3
(BOUT STREAM BYTE) III: 25.9
(BOXCOUNT TYPE N) II: 22.8
BOXCURSOR (Variable) III: 28.9; 30.15
Boxing numbers I: 7.1
Boyer-Moore fast string searching algorithm III: 25.21
BQUOTE (Function) III: 25.42
Break (DEdit Command) II: 16.9
BREAK (Error Message) II: 14.29
(BREAK X) II: 15.5; 14.5; 15.1,7
**BREAK** (in backtrace) II: 14.9
BREAK (Interrupt Channel) II: 23.15; III: 30.3
BREAK (Syntax Class) III: 25.37
Break characters III: 25.36; 25.4; 30.10
Break commands II: 14.5; 14.17
Break expression II: 14.5; 14.12
BREAK INSERTED AFTER (Printed by BREAKIN) II: 15.7
Break package II: 14.1
Break windows II: 14.3; 14.1
Break within a break on FN (Printed by system) II: 14.16
(BREAK.NSFILING.CONNECTION HOST) III: 24.38
(BREAKFN WHEN COMS — —) II: 15.4; 15.5,8
(BREAK1 BRKEXP BRKWHEN BRKFN BRKCOMS BRKTYPE ERRORN) II: 14.16; 14.20; 15.1,3-6; 20.24
BREAKCHAR (Syntax Class) III: 25.35
(BREAKCHECK ERRORPOS ERXN) II: 14.13; 14.19,22,27
BREAKCHK (Variable) II: 14.23
BREAKCOMSLST (Variable) II: 14.17
BREAKCONNECTION (Function) III: 24.37
INDEX 6

.CH.1SMEMBER GROUPNAME PROPERTY  
SECONDARYPROPERTY NAME) III: 31.12
.CH.IST.ALIASES OBJECTNAMEPATTERN) III: 31.11
.CH.IST.ALIASES.OBJECTNAMEPATTERN) III: 31.11
.CH.IST.DOMAINS DOMIANPATTERN) III: 31.11
.CH.IST.OBJECTS OBJECTPATTERN PROPERTY) III: 31.11
.CH.IST.Organizations  
ORGANIZATIONPATTERN) III: 31.11
.CH.LOOKUP.OBJECTOBJECTPATTERN) III: 31.10
.CH.NET.HINT (Variable) I: 12.3; III: 31.9
.CH.RETRIEVE.ITEM OBJECTPATTERN PROPERTY  
INTERPRETATION) III: 31.11
.CH.RETRIEVE.MEMBERS OBJECTPATTERN  
PROPERTY —) III: 31.11
.CHanges DATUM FORM) (Change Word) I: 8.19
.CHANGE @ TO $1 ... $M) (Editor Command) II: 16.34
.CHANGEBACKGROUND SHADE —) III: 30.22
.CHANGEBACKGROUND BORDER SHADE —) III: 30.23
.CHANGECALLERS OLD NEW TYPES FILES METHOD)  
I: 17.28
.CHANGECHAR (Variable) II: 16.30; III: 26.49
.CHANGED (MARKASCHANGED reason) II: 17.18
changed, but not unsaved (Printed by Editor) II: 16.69
.CHANGEFONT (Font class) III: 27.32
.CHANGEFONT FONT STREAM) III: 27.34
.CHANGENAME FN FROM TO) II: 15.8
.CHANGEOFFSETFLG (Menu Field) III: 28.42
.CHANGETPROP X PROP1 PROP2) II: 2.6
.CHANGESARRAY (Variable) II: 16.30
.CHANGESLICE N HISTORY —) I: 12.3; II: 13.21;
13.31
.CHANGETRAN I: 8.17
.CHANGEWORD (Property Name) I: 8.19
.CHARACTER N) II: 2.13
Character codes II: 2.12
Character echoing III: 30.6
Character I/O III: 25.22
Character sets II: 2.14; III: 25.22
CHARACTERNAMES (Variable) II: 2.14
Characters II: 2.12
CHARACTERSETNAMES (Variable) II: 2.14
.CHARCODE CHAR) II: 2.13
.CHARDELETE (syntax class) III: 30.5,8
.CHARSET STREAM CHARACTERSET) III: 25.23
.CHARWIDTH CHARCODE FONT) III: 27.30
.CHARWIDTHY CHARCODE FONT) III: 27.30
.CHCONX FLG RDTBL) I: 2.13
.CHCON1 X) I: 2.13
.CHKSET (Masterscope Command) II: 19.7
.CHKIMPORTS FILES NOASKFLG) II: 17.43
.CHKSUM BASE NWORDS INITSUM) (Function)  
III: 31.40
.CHOOZ (Function) II: 20.19
.CH (Editor Command) II: 16.55; 21.27
.CH:FLG (Variable) II: 21.23
.CLDISABLE OP) I: 9.11; II: 21.26
.CLEAPPOSLS PLST) I: 11.21
.CLEANUP FILE1 FILE2 ... FILEN) II: 17.12
.CLEANUPTIONS (Variable) II: 17.12
.Clear (DEdit Command) II: 16.8
.Clear (Window Menu Command) III: 28.4
.CLEARBUF FILE FLG) III: 30.11; 30.12
.Clearinghouse III: 31.8
.CLEARPUP PUP) III: 31.28
.CLEARSTK FLG) II: 11.9
.CLEARSTKLST (Variable) II: 11.9
.CLEARW WINDOW) III: 28.31
.CLINK (in stack frame) I: 11.3
.Clipping region III: 27.11
.CLISP II: 21.1; 20.8,10-11
.CLISP (as CAR of form) II: 21.17
.CLISP (in Masterscope template) II: 19.20
.CLISP (MARKASCHANGED reason) II: 17.18
.CLISP and compiler II: 18.9,14
.CLISP declarations II: 21.12; 21.17
.CLISP interaction with user II: 21.6
.CLISP internal conventions II: 21.27
.CLISP operation II: 21.14
.CLISP words II: 20.9
.CLISP: (Editor Command) II: 21.26; 21.17
.CLISPARRAY (Variable) II: 21.25; 21.17,26
INDEX

CLISPCHARARRAY (Variable) II: 21.25
CLISPCHARS (Variable) II: 21.25
(CLISPDEC DECLST) II: 21.12; 21.25
CLISPFLAG (Variable) II: 21.25
CLISPFONT (Font class) III: 27.32
CLISPFORWARDPLIST (Variable) II: 9.10
CLISPFHELPFLAG (Variable) II: 21.21; 21.6
CLISPI S.GAG (Variable) II: 9.20
CLISPIFTRANFLAG (Variable) II: 21.26
CLISPIFWORDPLIST (Variable) II: 9.5
(CLISPIFY XEDITCHAIN) II: 21.22; 21.23; 17.11; 21.14
CLISPIFY (MAKEFILE option) II: 17.11; 21.26
(CLISPIFYFNS F N1 ... FNn) II: 21.23
CLISPIFYPACKFLG (Variable) II: 21.24
CLISPIFYPRETTYFLG (Variable) II: 12.3; II: 21.26; 17.11; III: 26.48
CLISPIFYUSERFN (Variable) II: 21.24
CLISPINFIX (Property Name) II: 21.29
CLISPINFIXSLIST (Variable) II: 21.25; 21.9
CLISPRECORDTYPES (Variable) II: 8.15
CLISPRETRANFLAG (Variable) II: 21.22; 21.17
(CLISPRTRAN XTRAN) II: 21.25
CLISPTYPE (Property Name) II: 21.27; 21.28
CLISWORD (Property Name) II: 8.19; II: 21.29
(CLOCK N — ) I: 12.15
Close (Window Menu Command) III: 28.3
(CLOSEALL ALLFLG) III: 24.5; 24.20
CLOSEBREAKWINDOWFLAG (Variable) II: 14.15
(CLOSEF FILE) III: 24.4
(CLOSEF FILE) III: 24.4
CLOSEFN (Window Property) III: 28.15
(CLOSENSOCKET NSOC NOWERRORFLG) III: 31.37
(CLOSEPUPSOCKET PUPSOC NOWERRORFLG) III: 31.29
(CLOSEWINDOW WINDOW) III: 28.15
Closing and reopening files III: 24.20
CLREMPARSLFLG (Variable) II: 21.23
(CLRESHASH HARRAY) I: 6.2
(CLPRPROMPT) I: 28.3
(CNDIR HOST/DIR) III: 24.10
CNTRLV (syntax class) III: 30.6
CODE (Property Name) II: 17.27
CODERDTBL (Variable) III: 25.34
COLLECT FORM (I.S. Operator) I: 9.10
COMMAND (Variable) III: 26.38
**COMMENT** (printed by editor) II: 16.48
**COMMENT** (printed by system) III: 26.43
Comment pointers II: 16.55; III: 26.44
COMMENT USED FOR VALUE (Error Message) II: 18.23
**COMMENT**FLG (Variable) III: 26.43
(COMMENTI L — ) III: 26.43
COMMENTFLG (Variable) III: 26.43; 26.45
COMMENTFONT (Font class) III: 27.32
COMMENTLINELENGTH (Variable) III: 27.34
Comments in functions III: 26.42
(COMPAR NAME1 NAME2 TYPE SOURCE1 SOURCE2) II: 17.29
(COMPA REDEFS NAME TYPE SOURCES) II: 17.29
(COMPAIRLISTS X Y) I: 3.19
Comparing lists I: 3.19
( COMPIL EX FLG) II: 18.14
COMPILE.EXT (Variable) II: 18.13
( COMPIL EFN DEF — ) II: 18.14
Compiled files II: 18.13
Compiled function objects I: 10.6
COMPIL ON (printed when file is loaded) II: 18.13
( COMPIL EL FILES FILE1 FILE2 ... FILEn) II: 17.14
COMPILEHEADER (Variable) II: 18.13
Compiler II: 18.1
Compiler error messages II: 18.22
Compiler functions II: 18.13; 18.20
Compiler printout II: 18.3
Compiler questions II: 18.1
COMPILEMACROPROPS (Variable) I: 10.22
COMPILETYPENSLST (Variable) I: 10.14; II: 18.11; 18.9
COMPILEUSERFN (Function) II: 18.12
COMPILEUSERFN (Variable) II: 18.9; 18.11
Compiling CLISP II: 18.11; 18.9,14
Compiling data types II: 18.11
Compiling files II: 18.14; 18.21
Compiling FUNCTION II: 18.10
Compiling function calls II: 18.8
Compiling functional arguments II: 18.10
Compiling open functions II: 18.11
COMPLETEON (ASKUSER option) III: 26.16
COMPSET (Function) II: 18.1
Computed macros I: 10.23
(COMS X1 ... XM) (Editor Command) II: 16.59
(COMS COM1 ... COMn) (File Package Command) II: 17.40
(COMSQ COM1 ... COMn) (Editor Command) II: 16.59
(CONC AX1 ... AXn) I: 4.4
(CONCATLIST L) I: 4.4
INDEX

(COURIER.BROADCAST.CALL DESTSOCKET# PROGRAM PROCEDURE ARGS RESULTFN NETHINT MESSAGE) III: 31.23
(COURIER.CALL STREAM PROGRAM PROCEDURE ARG1 ... ARGN NOERRORFLG) III: 31.21
(COURIER.CALL TYPE FIELDNAME = VALUE ... FIELDNAME = VALUE) (Macro) III: 31.18
(COURIER.EXPEDITED.CALL ADDRESS SOCKET# PROGRAM PROCEDURE ARG1 ... ARGN NOERRORFLG) III: 31.22
(COURIER.FETCH TYPE FIELD OBJECT) (Macro) III: 31.19
(COURIER.OPEN HOSTNAME SERVERTYPE NOERRORFLG NAME WHENCLOSEDFN OTHERPROPS) III: 31.20
(COURIER.READ STREAM PROGRAM TYPE) III: 31.25
(COURIER.READ.BULKDATA STREAM PROGRAM TYPE DONTCLOSE) III: 31.25
(COURIER.READ.REP LIST.OF.WORDS PROGRAM TYPE) III: 31.26
(COURIER.READ.SEQUENCE STREAM PROGRAM TYPE) III: 31.25
(COURIER.WRITE STREAM ITEM PROGRAM TYPE) III: 31.25
(COURIER.WRITE.REP VALUE PROGRAM TYPE) III: 31.26
(COURIER.WRITE.SEQUENCE STREAM ITEM PROGRAM TYPE) III: 31.26
(COURIER.WRITE.SEQUENCE.UNSPECIFIED STREAM ITEM PROGRAM TYPE) III: 31.26
(COURIERDEF Property Name) III: 31.19
(COURIERPROGRAM NAME ...) III: 31.15
(COURIERPROGRAMS NAME1 ... NAMEN) (File Package Command) II: 17.39; III: 31.15
COURIERPROGRAMS (File Package Type) II: 17.23; III: 31.15
COUTFILE (Variable) II: 18.4
CREATE (in Masterscope template) II: 19.20
CREATE (in record declarations) I: 8.14
CREATE (Masterscope Relation) II: 19.9
CREATE (Record Operator) I: 8.3; 8.14
CREATE NOT DEFINED FOR THIS RECORD (Error Message) I: 8.13
(CREATE.EVENT NAME) II: 23.7
(CREATE.MONITORLOCK NAME —) II: 23.8
(CREATEDSKDIRECTORY VOLUMENAME —) III: 24.22

(CREATEMENUEDWINDOW MENU WINDOWTITLE LOCATION WINDOWSPEC) III: 28.49
(CREATREGION LEFT BOTTOM WIDTH HEIGHT) III: 27.2
(CREATETEXTUREFROMBITMAP BITMAP) III: 27.7
(CREATEW REGION TITLE BORDERSIZE NOOPENFLG) III: 28.13
CREATIONDATE (File Attribute) III: 24.17
CROSSHAIRS (Variable) III: 28.9; 30.15
CTRLV (syntax class) III: 30.6
CTRLVFLG (Variable) III: 26.31
Current expression in editor II: 16.13; 16.20
Current position of image stream III: 27.13
CURRENTITEM (Window Property) III: 26.8
Cursor III: 30.13
(CURSOR NEWCURSOR —) III: 30.14
CURSOR (Record) III: 30.14
(CURSORBITMAP) III: 30.13
(CURSORCREATE BITMAP X Y) III: 30.14
CURSORHEIGHT (Variable) III: 30.14
CURSORINFN (Window Property) III: 28.28; 28.38
CURSORMOVEDFN (Window Property) III: 28.28; 28.38
CURSOROUTFNFN (Window Property) III: 28.28
(CURSORPOSITION NEWPOSITION DISPLAYSTREAM OLDPOSITION) III: 30.17
CURSORS (File Package Command) III: 30.14
CURSORWIDTH (Variable) III: 30.14

D
D (Editor Command) II: 16.57
Dashing of curves III: 27.18
(DASSEM.SAVELOCALVARS FN) II: 18.6
Data fragmentation II: 22.1
Data type compiling II: 18.11
Data type evaluating I: 10.13
Data type names I: 8.20
Data types I: 8.20; II: 22.13
DATA TYPES FULL (Error Message) II: 14.30
DATABASECOMS (Variable) II: 19.24
DATATYPE (Record Type) I: 8.9
(DATATYPES ...) I: 8.20
(DATE FORMAT) I: 12.13
(DATEFORMAT KEY1 ... KEYN) I: 12.14
DATUM (in Changeran) I: 8.19
DATUM (Variable) I: 8.12,14
DATUM (Window Property) III: 26.8
DATUM OF INCORRECT TYPE (Error Message) I: 8.22
INDEX

| (DC FILE)          | II: 16.3 |
| (DCHCON X SCRATCHLIST FLG RDTBL) | I: 2.13 |
| DCOM (file name extension) | II: 18.13; 18.14,21 |
| **DEALLOC** (data type name) | I: 8.21 |
| Debugging functions | II: 15.1 |
| Declarations in CLISP | II: 21.12 |
| DECLARE (Function) | II: 18.5; 21.19 |
| DECLARE DECL (I.S. Operator) | I: 9.17 |
| DECLARE AS LOCALVAR (Masterscope Relation) | II: 19.10 |
| DECLARE AS SPECVAR (Masterscope Relation) | II: 19.10 |
| DECLARE: . FILEPKGCMDS/FLAGS (File Package Command) | II: 17.40; 18.14,17 |
| DECLARE: (Function) | II: 17.41 |
| DECLARE: DECL (I.S. Operator) | I: 9.17 |
| DECLEDATATYPE TYPENAME FIELDSPECS | I: 8.21 |
| DECLARETAGSLST (Variable) | II: 17.42 |
| (DECODE.WINDOW.ARG WHERESPEC WIDTH HEIGHT TITLE BORDER NOOPENFLG) | III: 28.14 |
| (DECODE.WINDOW/OR/DISPLAYSTREAM DSORW WINDOWVAR TITLE BORDER) | III: 28.32 |
| (DECODEBUTTONS BUTTONSTATE) | III: 30.19 |
| Dedit | II: 16.1 |
| DEDITL (Function) | II: 16.4 |
| DeditLinger (Variable) | II: 16.12 |
| DEDITRDTBL (Variable) | III: 25.34 |
| DEDITTYPEINCOMS (Variable) | II: 16.12 |
| Deep binding | I: 11.1; 2.4; II: 22.6 |
| DEFAULT.INPECTW.PROPCOMMANDFN (Function) | III: 26.7 |
| DEFAULT.INPECTW.TITLECOMMANDFN (Function) | III: 26.8 |
| DEFAULT.INPECTW.VALUECOMMANDFN (Function) | III: 26.8 |
| DEFAULTCARET (Variable) | III: 28.31 |
| DEFAULTCARETVALUE (Variable) | III: 28.31 |
| DEFAULTCOPYRIGHTOWNER (Variable) | I: 12.3; II: 17.54 |
| DEFAULTCURSOR (Variable) | III: 30.14; 30.15 |
| DEFAULTEOFCLOSE (Variable) | III: 24.21 |
| DEFAULTFILETYPE (Variable) | III: 24.18 |
| DEFAULTFONT (Font class) | III: 27.32 |
| DEFAULTFONTEEVICEFONT | I: 17.29 |
| DEFAULTINITIALS (Variable) | II: 16.76 |
| DEFAULTMAKENEWCOM (Function) | II: 17.31 |
| DEFAULTMENUHELDFN (Function) | III: 28.40 |
| DEFAULTPAGEREGION (Variable) | III: 27.10; 29.2 |
| DEFAULTPRINTERTYPE (Variable) | III: 29.5 |
| DEFAULTPRINTINGHOST (Variable) | I: 12.3; III: 29.4 |
| DEFAULTPROMPT (Variable) | III: 26.30 |
| DEFAULTRENAMEMETHOD (Variable) | II: 17.29 |
| DEFAULTSUBITEMFN (Function) | III: 28.39 |
| DEFAULTTTYREGION (Variable) | II: 23.10 |
| DEFAULTWHENSELECTEDFN (Function) | III: 28.40 |
| DEFC (Function) | II: 13.27 |
| (DEREFERENCEFLG X) | II: 18.8 |
| (DEFERVAL TYPE FN) | I: 10.13 |
| Defgroups | II: 17.1 |
| (DEFINE X —) | I: 10.9 |
| DEFINED (MARKASCHANGED reason) | II: 17.18 |
| DEFINED, THEREFORE DISABLED IN CLISP (Error Message) | I: 9.10; II: 21.6 |
| (DEFINEQ X1 X2 ... XN) | I: 10.9 |
| Defining file package commands | II: 17.45 |
| Defining file package types | II: 17.29 |
| Defining functions | I: 10.9 |
| Defining iterative statement operators | I: 9.20 |
| Definition groups | II: 17.1 |
| (DEFLIST L PROP) | I: 2.6 |
| (DEFMACRO NAME ARGS FORM) | I: 10.24 |
| (DEPRINT TYPE FN) | III: 25.16 |
| (DELPACKET FILTER FILTER) (Function) | III: 31.40 |
| (DELPACKETFILTER FILTER) (Function) | III: 23.4 |
| DELDEF (File Package Type Property) | II: 17.31 |
| (DELDEF NAME TYPE) | II: 17.27 |
| Delete | III: 30.11; 26.23 |
| Delete (EDIT Command) | II: 16.7 |
| (DELETE . @) (Editor Command) | II: 16.34 |
| DELETE (Editor Command) | II: 16.32; 16.30 |
| DELETE (File Package Command Property) | II: 17.46 |
| DELETE (Interrupt Character) | II: 23.15; III: 30.3 |
| (DELETECONTROL TYPE MESSAGE TTBL) | III: 30.8 |
| DELETED (MARKASCHANGED reason) | II: 17.18 |
| (DELETEMENU MENU CLOSEFLG FROMWINDOW) | III: 28.38 |
| Deleting files | III: 24.31 |
| (DELFILE FILE) | III: 24.31 |
| (DELFROMCOMS COMS NAME TYPE) | II: 17.49 |
| (DELFROMFILES NAME TYPE FILES) | II: 17.48 |
| (DEPOSITBYTE NPOS SIZE VAL) | I: 7.10 |
| (DELETEQ @) (Function) | III: 31.40 |
| DESCENT (Font property) | III: 27.27 |
| DESCRIBE SET (Masterscope Command) | II: 19.6 |
| DESCRIBELST (Variable) | II: 19.6 |
| DESCRIPTION (File Package Type Property) | II: 17.32 |
INDEX

Destination bitmap III: 27.23
DESTINATION IS INSIDE EXPRESSION BEING MOVED (Printed by Editor) II: 16.38
Destructive functions I: 3.13,19; II: 22.14
Destructuring argument lists I: 10.27
(DETACHALLWINDOWS MAINWINDOW) III: 28.47
(DETACHWINDOW WINDOWTODETACH) III: 28.47
Determiners in Masterscope II: 19.13
DEVICE (Filename field) III: 24.5
DEVICE (Font property) III: 27.27
Device-independent graphics III: 27.42
DEVICE$PEC (Font property) III: 27.28
(DF NEW?) II: 16.2
DFNFLG (Variable) I: 10.10; II: 13.29; 16.69; 17.5,28
(DIFFERENCE X Y) II: 7.3
different expression (Printed by Editor) II: 16.66
DIG (Device-Independent Graphics) III: 27.42
(DIR FILEGROUP COM ... COMN) III: 24.35
DIRCOMMANDS (Variable) III: 24.35
Directories III: 24.31
DIRECTORIES (Variable) I: 12.3; II: 17.16; III: 24.31;
  24.32
DIRECTORY (Filename field) III: 24.6
(DIRECTORY FILES COMMANDS DEFAULTTEXT
  DEFAULTVARS) III: 24.33
(DIRECTORYNAME DIRNAME STRPTR —) III: 24.11
(DIRECTORYNAMEP DIRNAME HOSTNAME) III: 24.11
Disabling CLISP operators II: 21.26
(DISCARDPUS SOC) III: 31.30
(DISCARDXPS NSOC) III: 31.38
(DISKFREEPAGES VOLUMENAME —) III: 24.23;
  24.21
(DISKPARTITION) III: 24.23; 24.21
(DISMISS MSEC WAIT TIMER NOBLOCK) II: 23.5
DISPLAY (Image stream type) III: 27.23; 27.8
Display screens I: 12.4; III: 30.22
Display streams III: 27.23; 27.8
(DISPLAYDOWN FORM NSCANLINES) III: 30.24
(DISPLAYFN IMAGEOBJ IMAGESTREAM
  IMAGESTREAMTYPE HOSTSTREAM)
  (IMAGEFNS Method) III: 27.37
DISPLAYFONTDIRECTORIES (Variable) I: 12.3; III: 27.31
DISPLAYFONTEXTENSIONS (Variable) I: 12.3; III:
  27.31
DISPLAYHELP (Function) III: 26.30
DISPLAYTYPES (Variable) III: 26.39
Division by zero I: 7.2
DMACRO (Property Name) I: 10.21
(DMPHASH HARRAY1 HARRAY2 ... HARRAYN) I: 6.3
DO COM (Editor Command) II: 16.54; 13.43
DO FORM (I.S. Operator) I: 9.10
(DOBACKGROUNDCOM) III: 28.7
(DOCOLLECT ITEM LST) II: 3.7
DOCOPY (DECLARE: Option) II: 17.41
Document printing III: 29.1
DO@EVAL@LOAD (DECLARE: Option) II: 17.42
DO@EVAL@LOAD (DECLARE: Option) II: 17.41
DON'T.CHANGE.DATE (OPENSTREAM parameter)
  III: 24.3
DONTCOMPLETEFNS (Variable) II: 18.14; 18.15,18
DONTCOPY (DECLARE: Option) II: 17.41
DONTEVAL@COMPILE (DECLARE: Option) II: 17.42
DONTEVAL@LOAD (DECLARE: Option) II: 17.41
(DOSELECTEDITEM MENU ITEM BUTTON) III: 28.43
DOSHAPEFN (Window Property) III: 28.18
DOVER (Printer type) III: 29.5
(DRAWDOWNCOM WINDOW) III: 28.7
DOWINDOWCOMFN (Window Property) III: 28.7
(DP NAME PROP) II: 16.2
(DPB N BYTESPEC VAL) (Macro) I: 7.10
(DRAWBETWEEN POSITION1 POSITION2 WIDTH
  OPERATION STREAM COLOR DASHING)
  III: 27.17
(DRAWCIRCLE CENTERX CENTERY RADIUS BRUSH
  DASHING STREAM) III: 27.19
(DRAWCURVE KNOTS CLOSED BRUSH DASHING
  STREAM) III: 27.19
(DRAWELLIPSE CENTERX CENTERY SEMIMINORRADIUS
  SEMIMAJORRADIUS ORIENTATION BRUSH DASHING STREAM)
  III: 27.19
(DRAWLINE X1 Y1 X2 Y2 WIDTH OPERATION
  STREAM COLOR DASHING) III: 27.17
(DRAWPOINT X Y BRUSH STREAM OPERATION)
  III: 27.20
(DRAWTO X Y WIDTH OPERATION STREAM COLOR
  DASHING) III: 27.17
(DREMOVE X L) I: 3.19
(DREVERSE L) I: 3.19
(DRIBBLE FILE APPENDFLG THAWEDFLG) III: 30.12
Dribble files III: 30.12
(DRIBBLEFILE) III: 30.13
DSK (file device) III: 24.21
(DSKDISPLAY NEWSTATE) III: 24.23
DSKDISPLAY.POSITION (Variable) III: 24.23
INDEX

DSP (Window Property) III: 28.34
(DSPBACKCOLOR COLOR STREAM) III: 27.13
(DSPBACKUP WIDTH DISPLAYSTREAM) III: 27.25
(DSPBOTTOMMARGIN YPOSITION STREAM) III: 27.11
(DSPCLIPPINGREGION REGION STREAM) III: 27.11
(DSPCOLOR COLOR STREAM) III: 27.13
(DSPCREATE DESTINATION) III: 27.23
(DSPDESTINATION DESTINATION DISPLAYSTREAM) III: 27.23
(DSPFILL REGION TEXTURE OPERATION STREAM) III: 27.20
(DSPFONT FONT STREAM) III: 27.11
(DSPLEFTMARGIN XPOSITION STREAM) III: 27.11
(DSPLINEFEED DELTAY STREAM) III: 27.12
(DSPNEWPAGE STREAM) III: 27.21
(DSPOPOPERATION OPERATION STREAM) III: 27.12
(DSPRESET STREAM) III: 27.21
(DSPRIGHTMARGIN XPOSITION STREAM) III: 27.11
(DSPSCALE SCALE STREAM) III: 27.12
(DSPSCROLL SWITCHSETTING DISPLAYSTREAM) III: 27.24
(DSPSOURCETYPE SOURCETYPE DISPLAYSTREAM) III: 27.24
(DSPSPACEFACTOR FACTOR STREAM) III: 27.12
(DSPTEXTURE TEXTURE DISPLAYSTREAM) III: 27.24
(DSPTOPMARGIN YPOSITION STREAM) III: 27.11
(DSPXOFFSET XOFFSET DISPLAYSTREAM) III: 27.23
(DSPXPOSITION XPOSITION STREAM) III: 27.13
(DSPYOFFSET YOFFSET DISPLAYSTREAM) III: 27.23
(DSPYPOSITION YPOSITION STREAM) III: 27.13
(DSUBLIS ALST EXPR FLG) I: 3.14
(DSUBST NEW OLD EXPR) I: 3.13
DT.EDITMACROS (Variable) II: 16.12
DUMMY-EDIT-FUNCTION-BODY (Variable) II: 16.70; 16.2
(DUMMYFRAMEP POS) I: 11.13
(DUMPDATABASE FNILST) II: 19.24
(DUNPACK X SCRATCHLIST FLG RDTBL) I: 2.9
Duration Functions I: 12.16
during INTERVAL (I.S. Operator) I: 12.18
(DV VAR) II: 16.2
DW (Editor Command) II: 16.55; 21.27
DWIM II: 20.1
(DWIM X) II: 20.4
DWIM interaction with user II: 20.4
DWIM variables II: 20.12
DWIMCHECK#ARGSFLG (Variable) II: 21.22

DWIMCHECKPROGLABELSFLG (Variable) II: 21.22; 19.19
DWIMESSGAG (Variable) II: 21.22; 18.12
DWIMFLG (Variable) II: 20.14; 16.66,68,71; 20.23
(DWIMIFY X QUIETFLG) II: 21.18; 21.20; 21.15
DWIMIFYCOMPFLG (Variable) II: 21.22;
18.12,15,21
DWIMIFYFLG (Variable) II: 20.13
(DWIMIFYFN $FNF$) II: 21.20; 21.19
DWIMINMACROSFLG (Variable) II: 21.20
DWIMLOADFNS? (Function) II: 20.13
DWIMLOADFNSFLG (Variable) II: 20.14; 20.13
DWIMUSERFORMS (Variable) II: 20.11; 20.9-10
DWIMWAIT (Variable) II: 20.13; 20.5-6

E
(EXT) (Editor Command) II: 16.58
(E) (Editor Command) II: 16.58
E (Editor Command) II: 16.57; 13.43; 16.55
(E FORM$_1$ ... FORM$_N$) (File Package Command) II: 17.40
E (in a floating point number) I: 7.11; III: 25.3
E (use in comments) III: 26.43
EACHTIME FORM (I.S. Operator) I: 9.16; 9.18
(ECHOCHAR CHARCODE MODE TTBL) III: 30.6
(ECHOCONTROL CHAR MODE TTBL) III: 30.7
Echoing characters III: 30.6
(ECHOMODE FLG TTBL) III: 30.7
ED (Editor Command) III: 26.29
RELATIONED BY SET (Masterscope Set Specification) II: 19.12
RELATIONED IN SET (Masterscope Set Specification) II: 19.12
EDIT (Break Command) II: 14.11; 14.12-13
EDIT (Break Window Command) II: 14.3
Edit (DEdit Command) II: 16.9
(EDIT NAME —) II: 16.68
EDIT (Litatom) II: 16.50
EDIT SET [- EDITCOMS] (Masterscope Command) II: 19.6
edit (Printed by Editor) II: 16.72
Edit chain II: 16.13; 16.20
Edit macros II: 16.62
EDIT WHERE SET relation SET [- EDITCOMS]
(Masterscope Command) II: 19.6
EDIT-SAVE (Property Name) II: 16.49-50
(EDIT$4$ PAT X —) II: 16.72
(EDIT$4$ BMSPEC) III: 27.4
(EDITCALLERS ATOMS FILES COMS) II: 16.74
INDEX

(EXTTRACT @1 FROM @2) (Editor Command) II: 16.36
$SEXTRM (Variable) I: 9.12

F
F PATTERN NIL (Editor Command) II: 16.22
(F PATTERN N) (Editor Command) II: 16.22
(F PATTERN) (Editor Command) II: 16.22
F PATTERN T (Editor Command) II: 16.21
F PATTERN N (Editor Command) II: 16.21; 16.55
F (in event address) II: 13.6
.FFORMAT NUMBER (PRINTOUT command) III: 25.30
F (Response to Compiler Question) II: 18.2
F PATTERN (Editor Command) II: 16.21
F/L (as a DWIM construct) II: 20.9
(F = EXPRESSION X) (Editor Command) II: 16.22
FACE (Font property) III: 27.27
FAMILY (Font property) III: 27.27
(FASSOC KEY ALST) I: 3.15; II: 21.13
FAST (MAKEFILE option) II: 17.11
Fast functions II: 22.14
FASYPEFLG (Variable) II: 20.21
FAULT IN EVAL (Error Message) II: 14.29
FAULTAPPLY (Function) II: 20.7; 20.11
FAULTAPPLYFLG (Variable) II: 20.12
FAULTARGS (Variable) II: 20.12
FAULTENV (Function) II: 20.7; 14.29; 20.11
FAULTFN (Variable) II: 20.12
FAULTX (Variable) II: 20.12
(FCHARACTER N) I: 2.13
(FDIFFERENCE X Y) I: 7.12
(FEQP X Y) I: 7.12
FETCH (in Masterscope template) II: 19.19
FETCH (Masterscope Relation) II: 19.9
FETCH (Record Operator) I: 8.2; II: 21.9
(FETCHFIELD DESCRIPTOR DATUM) I: 8.21
FETCHFN (Window Property) III: 26.8
FEXPR (Litatom) I: 10.7
FEXPR* (Litatom) I: 10.7; 10.8
FFETCH (Record Operator) I: 8.3
(FFILEPOS PATTERN FILE START END SKIP TAIL CASEARRAY) III: 25.21
(FGREATERP X Y) I: 7.12
(FIELDLOOK FIELDNAME) I: 8.16
FIELDS (File Package Type) II: 17.23
FIELDS OF SET (Masterscope Set Specification) II: 19.12
(FILDIR FILEGROUP) III: 24.35

FILE (GETFN Property) III: 27.40
FILE (Property Name) II: 17.19
File access rights III: 24.2
File attributes III: 24.2
File devices III: 24.1
File directories III: 24.17
File enumeration III: 24.33
File maps II: 17.55
File names II: 22.13; III: 24.5; 24.19; 12-13
FILE NOT FOUND (Error Message) II: 14.29; III: 24.3,31
FILE NOT OPEN (Error Message) II: 14.28; III: 24.4,14; 25.2,6,20
File package II: 17.1
File package commands II: 17.32
File package types II: 17.21
File pointers III: 25.18; 25.19,23
File servers III: 24.36
FILE SYSTEM RESOURCES EXCEEDED (Error Message) II: 14.29; III: 24.3,13
FILE WON'T OPEN (Error Message) II: 14.28; III: 24.3
FILE: (Compiler Question) II: 18.1
(FILECHANGES FILE TYPE) II: 17.52
FILECHANGES (Property Name) II: 17.20; 17.15
Filecoms II: 17.32; 17.4-5,48
(FILECOMS FILE TYPE) II: 17.49
(FILECOMSLST FILE TYPE —) II: 17.49
(FILECREATED X) II: 17.51; 18.13
(FILEDATE FILE —) II: 17.52
FILEDATES (Property Name) II: 17.20; 17.15,51
FILEDEF (Property Name) II: 20.10
(FILEFNSLST FILE) II: 17.49
FILEGETDEF (File Package Type Property) II: 17.30
FILEGROUP (Property Name) II: 17.12
FILELENGTH (Variable) III: 25.11; 26.48
FILELST (Variable) II: 17.20; 17.6,12; 20.24
FILEMAP (Property Name) II: 17.20; 17.55
FILEMAP DOES NOT AGREE WITH CONTENTS OF (Error Message) II: 17.56
(FILENAMEFIELD FILENAME FIELDNAME) III: 24.8
\FILEOUTCHARFN (Function) III: 27.48
FILEPKG.SCRATCH (file) II: 17.30
(FILEPKGCHANGES TYPE LST) II: 17.18
(FILEPKGCOM COMMANDNAME PROP1 VAL1 ... PROPn VALN) II: 17.47
(FILEPKGCOMS LITATOM1 ... LITATOMN) (File Package Command) II: 17.39
FILEPKGCOMS (File Package Type) II: 17.23
(FNS FN₁ ... FNₙ) (File Package Command) II: 17.34
FNS (File Package Type) II: 17.23
/FNS (Variable) II: 13.26
(FNTH X N) I: 3.9
(FNTYP FN) I: 10.7; II: 17.27
.FONT (Font Spec) (PRINTOUT command) III: 25.27
Font configurations III: 27.33
Font descriptors III: 27.26
FONT NOT FOUND (Error Message) III: 27.27
FONTCHANGeflg (Variable) III: 27.34
(FONTCOPY OLDFONT PROP₁ VAL₁ PROP₂ VAL₂ ...) III: 27.28
(FONTCREATE FAMILY SIZE FACE ROTATION DEVICE NOERRORF LG CHARSET) III: 27.26
(FONTCREATEFN FAMILY SIZE FACE ROTATION DEVICE) (Image Stream Method) III: 27.43
FONTDEFS (Variable) III: 27.34
FONTDEFSVARS (Variable) III: 27.34
FONTESCAPECHAR (Variable) III: 27.34
FONTFNs (Variable) III: 27.32
.FONTNAME NAME) III: 27.33
(FONTP X) III: 27.27
(FONTPROFILE PROFILE) III: 27.32
FONTPROFILE (Variable) III: 27.33
(FONTPROP FONT PROP) III: 27.27
Fonts III: 27.25; 27.11
FONT$WIDTHS (File name) III: 27.29,31
(FONTSAVAILABLE FAMILY SIZE FACE ROTATION DEVICE CHECKFILESTOO?) III: 27.28
(FONTSAVAILABLEFN FAMILY SIZE FACE ROTATION DEVICE) (Image Stream Method) III: 27.43
.FONTSET NAME) III: 27.34
(FOO BAR BAZ —) I: 1.8
FOR VARS (I.S. Operator) I: 9.12
FOR VAR (I.S. Operator) I: 9.12
FOR (in INSERT editor command) II: 16.33
FOR (in USE command) II: 13.9
FOR VARIABLE SET I.S.TAIL (Masterscope Command) II: 19.7
FOR OLD VAR (I.S. Operator) I: 9.12
(FORCEOUTPUT STREAM WAITFORFINISH) III: 25.10
FORCEPS (Variable) III: 30.15
forDuration INTERVAL (I.S. Operator) I: 12.18
FORGET EventsSpec (Prog. Asst. Command) II: 13.16; 13.21
FORM (Process Property) II: 23.2
*FORM* (stack blip) I: 11.16
Form-feed III: 25.26
(FPLUS X₁ X₂ ... Xₙ) I: 7.12
(FQUOTIENT X Y) I: 7.12
.FR POS EXPR (PRINTOUT command) III: 25.29
.FR2 POS EXPR (PRINTOUT command) III: 25.29
Fragmentation of data space II: 22.1
Frame extensions of stack frames I: 11.3
Frame names of stack frames I: 11.3
Frames on the stack I: 11.2
.FRAMESCAN ATOM POS) I: 11.7
Free variable access II: 22.5
(FREEATTACHEDWINDOW WINDOW) III: 28.47
FREELY (use in Masterscope) II: 19.8
(FREERESOURCE RESOURCESNAMES ARGs) (Macro) I: 12.23
(FREEVARS FN USEDATABASE) II: 19.22
(FREEMARKER X Y) I: 7.12
FREPLACE (Record Operator) I: 8.3
(FRESHLINE STREAM) III: 25.10
FROM FORM (I.S. Operator) I: 9.14; 9.15
FROM (in event specification) II: 13.7
FROM (in EXTRACT editor command) II: 16.36
FROM SET (Masterscope Path Option) II: 19.16
(FRPLACA X Y) I: 3.3; II: 21.13
(FRPLACD X Y) I: 3.3; II: 21.13
(FRPLNODE X A D) I: 3.3
(FRPLNODE2 X Y) I: 3.3
(FRPTQ N FORM₁ FORM₂ ... FORMₙ) I: 10.15
(FSP PATTERN₁ ... PATTERNₙ) (Editor Command) II: 16.22
(FTIMES X₁ X₂ ... Xₙ) I: 7.12
\FTPAVAILABLE (Variable) III: 24.36
Full file names III: 24.12
(FULLNAME X RECQG) III: 24.12
FULLPRESS (Printer type) III: 29.5
FUNARG (Litatom) I: 10.19; 10.7
(FUNCTION FN ENV) I: 10.18
FUNCTION (in Masterscope template) II: 19.19
Function debugging II: 15.1
Function definition cells I: 10.9; 2.5
Function definitions I: 10.2; 10.9
Function types I: 10.2
FUNCTIONAL (in Masterscope template) II: 19.19
Functional arguments I: 10.18; II: 18.10
FUNNYATOMLST (Variable) II: 21.24
G (GAINSPACE) II: 22.12
GAINSPACEFORMS (Variable) II: 22.12
Garbage collection II: 22.1
INDEX

(GATHEREXPORTS FROMFILES TOFILE FLG) II: 17.43
(GCD N1 N2 ) I: 7.7
(GCGAG MESSAGE) II: 22.3
(GCTRIG) II: 22.3
(GDATE DATE FORMAT — ) I: 12.14
(GENERATE HANDLE VAL) I: 11.17
(GENERATOR FORM COMVAR) I: 11.17
Generator handles I: 11.17
Generators I: 11.16
Generators for spelling correction II: 20.19
Generic arithmetic I: 7.3
GENNUN (Variable) I: 2.11
(GENSYM PREFIX — — — ) I: 2.10; II: 15.10-11
(GEQ X Y ) I: 7.4
GET (old name for LISTGET1) I: 3.16
GET* (Editor Command) II: 16.55; III: 26.44
(GETATOMVAL VAR) II: 2.4
(GETBOXPOSITION BOXWIDTH BOXHEIGHT ORGX ORGY WINDOW PROMPTMSG) III: 28.9
(GETBOXREGION WIDTH HEIGHT ORGX ORGY WINDOW PROMPTMSG) III: 28.11
(GETBRK RDTBL) III: 25.38
(GETCASEARRAY CASEARRAY FROMCODE) III: 25.22
(GETCHARBITMAP CHARCODE FONT) III: 27.30
(GETCOMMENT X DESTFL — ) III: 26.44
(GETCONTROL TTBL) III: 30.10
GETD (Editor Command) II: 16.56
(GETD FN) I: 10.10
GETDEF (File Package Type Property) II: 17.30
(GETDEF NAME TYPE SOURCE OPTIONS ) II: 17.25
(GETDELETECONTROL TYPE TTBL) III: 30.9
(GETDESCRIPTORS TYPENAME) I: 8.22
GETDUMMYVAR (Function) I: 9.20
(GETECHOMODE TTBL) III: 30.7
(GETEOFPTR FILE) III: 25.20
(GETFIELDSPECS TYPENAME) III: 8.22
(GETFILEINFO FILE ATTRIB) III: 24.17
(GETFILEPTR FILE) III: 25.19
(GETFN FILESTREAM) (IMAGEFNS Method ) III: 27.37
(GETHASH KEY HARRAY) I: 6.2; II: 21.17
(GETLIS X PROPS) I: 2.7
(GETMENUPROP MENU PROPERTY) III: 28.43
(GETMOUSESTATE) III: 30.19
GETP (old name of GETPROP) I: 2.5
(GETPOSITION WINDOW CURSOR) III: 28.9
(GETPROMPTWINDOW MAINWINDOW #LINES FONT DONTCREATE) III: 28.50
(GETPROP ATM PROP) I: 2.5
(GETPROPLIST ATM) I: 2.7
(GETPUP PUPSOC WAIT) III: 31.30
(GETPUPBYTE PUP BYTE #) III: 31.31
(GETPUPSTRING PUP OFFSET) III: 31.32
(GETPUPWORD PUP WORD #) III: 31.31
(GETRAISE TTBL) III: 30.8
(GETREADTABLE RDTBL) III: 25.34
(GETREGION MINWIDTH MINHEIGHT OLDREGION NEWREGION FN NEWREGIONFNARG INITCORNERS) III: 28.10
(GETRELATION ITEM RELATION INVERTED) II: 19.23
(GETRESOURCE RESOURCENAME . ARGS) (Macro) I: 12.23
(GETSEPR RDTBL) III: 25.38
(GETSTREAM FILE ACCESS) III: 25.2
(GETSYNTAX CH TABLE) III: 25.36
(GETTEMPLATE FN) II: 19.21
(GETTERMTABLE TTBL) III: 30.5
(GETTOPVAL VAR) I: 2.4
GETVAL (Editor Command) II: 16.58
(GETXIP NSOC WAIT) III: 31.37
(GIVE.TTY.PROCESS WINDOW) II: 23.13
(GLC X) I: 4.3
Global variables II: 18.4; 21.19; 22.5
GLOBALVAR (Property Name) II: 18.4; 21.19
Globalvars II: 18.4
(GLOBALVARS VAR 1 ... VAR N) (File Package Command) II: 17.37; 18.4
GLOBALVARS (in Masterscope Set Specification) II: 19.12
GLOBALVARS (Variable) II: 18.4; 18.18; 21.19
(GNC X) I: 4.3
GO (Break Command) II: 14.5; 14.6
(GO LABEL) (Editor Command) II: 16.23
(GO U) I: 9.8
GO (in iterative statement) I: 9.18
$GO (escape-GO) (TYPE-AHEAD command) II: 13.18
GRAYSHADE (Variable) III: 27.7
(GREATERP X Y ) I: 7.3
(GREET NAME — ) I: 12.2
GREEDATES (Variable) I: 12.2
GREETFILENAME USER) I: 12.2
Greeting I: 12.1

INDEX 18
INDEX

(IMCHARWIDTHY STREAM CHARCODE) (Image Stream Method) III: 27.46
(IMCLIPPINGREGION STREAM REGION) (Image Stream Method) III: 27.47
(IMCLOSEFN STREAM) (Image Stream Method) III: 27.44
(IMCOLOR STREAM COLOR) (Image Stream Method) III: 27.48
(IMDRAWCIRCLE STREAM CENTERX CENTERY RADIUS BRUSH DASHING) (Image Stream Method) III: 27.44
(IMDRAWCURVE STREAM KNOTS CLOSED BRUSH DASHING) (Image Stream Method) III: 27.44
(IMDRAWELLIPSE STREAM CENTERX CENTERY SEMIMINORRADIUS SEMIMAJORRADIUS ORIENTATION BRUSH DASHING) (Image Stream Method) III: 27.45
(IMDRAWLINE STREAM X1 Y1 X2 Y2 WIDTH OPERATION COLOR DASHING) (Image Stream Method) III: 27.44
(IMFILLCIRCLE STREAM CENTERX CENTERY RADIUS TEXTURE) (Image Stream Method) III: 27.45
(IMFILLPOLYGON STREAM POINTS TEXTURE) (Image Stream Method) III: 27.45
(IMFONT STREAM FONT) (Image Stream Method) III: 27.47
(IMFONTCREATE (IMAGEOPS Field) III: 27.44
(IMIN X1 X2 ... Xn) I: 7.7
(IMINUS X) I: 7.6
(IMLEFTMARGIN STREAM LEFTMARGIN) (Image Stream Method) III: 27.47
(IMLINEFEED STREAM DELTA) (Image Stream Method) III: 27.47
(IMMED (type of read macro) III: 25.41
(IMMEDIATE (type of read macro) III: 25.41
(IMMOVETO STREAM X Y) (Image Stream Method) III: 27.45
(IMNEWPAGE STREAM) (Image Stream Method) III: 27.46
(IMOD X N) I: 7.6
(IMOPERATION STREAM OPERATION) (Image Stream Method) III: 27.48
(IMPORTFILE FILE RETURNFLG) II: 17.43
(IMRESET STREAM) (Image Stream Method) III: 27.46
(IMRIGHTMARGIN STREAM RIGHTMARGIN) (Image Stream Method) III: 27.47
(IMSCALE STREAM SCALE) (Image Stream Method) III: 27.48; 27.44
(IMSCALEDBITBLT SOURCEBITMAP SOURCELEFT SOURCEBOTTOM STREAM DESTINATIONLEFT DESTINATIONBOTTOM WIDTH HEIGHT SOURCETYPE OPERATION TEXTURE CLIPPINGREGION CLIPPEDSOURCELEFT CLIPPEDSOURCEBOTTOM SCALE) (Image Stream Method) III: 27.45
(IMSPACEFACTOR STREAM FACTOR) (Image Stream Method) III: 27.48
(IMSTRINGWIDTH STREAM STR RDTBL) (Image Stream Method) III: 27.46
(IMTERPRI STREAM) (Image Stream Method) III: 27.46
(IMTOPMARGIN STREAM YPOSITION) (Image Stream Method) III: 27.47
(IMXPOSITION STREAM XPOSITION) (Image Stream Method) III: 27.47
(IMYPOSITION STREAM YPOSITION) (Image Stream Method) III: 27.47
(FN1 IN FN2) (arg to BREAK0) II: 15.4
IN FORM (I.S. Operator) I: 9.13; 9.14; 18
IN (in EMBED editor command) II: 16.37
IN (in USE command) II: 13.9
IN EXPRESSION (Masterscope Set Specification) II: 19.11
ON OLD (VAR←FORM) (I.S. Operator) I: 9.13
IN OLD (VAR←FORM) (I.S. Operator) I: 9.13
IN OLD VAR (I.S. Operator) I: 9.13
IN? (Break Command) II: 14.13
Incomplete file names II: 22.13; III: 24.9; 24.14
INCORRECT DEFINING FORM (Error Message) I: 10.9
(INFILE FILE) III: 24.15
(INFILECOMS? NAME TYPE COMS —) II: 17.48
(INFILEP FILE) III: 24.13
INFX (type of read macro) III: 25.39
Infix operators in CLISP II: 21.7
INFO (Property Name) I: 10.4; II: 21.21; 13.41; 21.18; 23
INFOHOOK (Process Property) II: 23.16; 23.3
RELATIONING SET (Masterscope Set Specification) II: 19.11
INIT (in record declarations) I: 8.14
Init files II: 12.1
INIT.LISP (File name) I: 12.1
INITCORNERSFN (Window Property) III: 28.18
Initialization files II: 12.1
INITIALS (Variable) II: 16.76
INITIALSLS (Variable) I: 12.4; II: 16.76

INDEX
INDEX

(INITRECORDS REC₁ ... REC_N) (File Package Command) I: 8.11; II: 17.38

(INITRESOURCE RESOURCE_NAME . ARGS) (Macro) I: 12.23

(INITRESOURCES RESOURCE₁ ... RESOURCE_N) (File Package Command) I: 12.20,24; II: 17.39

(INITVARS VAR₁ ... VAR_N) (File Package Command) I: 12.3; III: 28, 31

INDEX I: 12.36

INPUT (File access) III: 24.2

(INPUT FILE) III: 25.3

Input buffer II: 14.16; III: 30.11; 25.6

Input functions III: 25.2

Input/Output functions III: 25.1

(INREADMACROP) III: 25.42

(INSERT E₁ ... E_M BEFORE . @) (Editor Command) II: 16.33

(INSERT E₁ ... E_M AFTER . @) (Editor Command) II: 16.33

(INSERT E₁ ... E_M FOR . @) (Editor Command) II: 16.33

INSIDE FORM (I.S. Operator) I: 9.13

INSIDEF REGION POSORX Y) III: 27.3

(INPECT OBJECT ASTYPE WHERE) III: 26.2

INSPECTARRAY (Function) III: 26.5

INSPECTARRAYSFGL (Variable) III: 26.6

INSPECTCODE FN WHERE — — —) III: 26.2

INSPECTMACROS (Variable) III: 26.6

Inspector III: 26.1

INSPECTPRINTLEVEL (Variable) III: 26.5

(INPECTW.CREATE DATUM PROPERTIES FETCHFN STOREFN PROPCOMMANDFN VALUECOMMANDFN TITLECOMMANDFN TITLE SELECTIONFN WHERE PROPPRINTFN) III: 26.7

(INPECTW.REDISPLAY INSPECTW PROPS — —) III: 26.9

(INPECTW.REPLACE INSPECTW PROPERTY NEWVALUE) III: 26.9

(INPECTW.SELECTITEM INSPECTW PROPERTY VALUEFLG) III: 26.9

INSPECTWTITLE (Window Property) III: 26.8

(INSTALLBRUSH BRUSHNAME BRUSHFN BRUSHARRAY) III: 27.19

INSTRUCTIONS (Litatom) I: 10.23

INTEGER (record field type) I: 8.10

Integer arithmetic I: 7.5

Integer input syntax I: 7.4; III: 25.3, 9

(INTEGERLENGTH X) I: 7.9

Integers I: 7.4; 9.1

Interlisp-D executive II: 13.1

Interlisp-D executive window III: 28.3

INTERPRESS (Image stream type) III: 27.8

Interpress format I: 12.3; III: 27.8-10, 12, 31, 33; 29.1, 5

INTERPRESSFONTDIRECTORIES (Variable) I: 12.3; III: 27.31

Interpreter and the stack I: 11.14

Interpreting expressions I: 10.11

Interpreters blips on the stack I: 11.14

INTERRUPT (Litatom) II: 14.16

Interrupt characters III: 30.1

(INTERRUPTABLE FLAG) III: 30.4

(INTERRUPTCHAR CHAR TYPIFORM HARDFLG — —) III: 30.3

INTERSECTION X Y) I: 3.11

INTERSECTREGIONS REGION₁ REGION₂ ... REGION_N) III: 27.2

Inverted cursor III: 30.16

(INVERTW WINDOW SHADE) III: 28.31

(IOFILE FILE) III: 24.15

(IPLUS X₁ X₂ ... X_N) I: 7.6

(IQUOTIENT X Y) I: 7.6

IREADDATE (File Attribute) III: 24.18

(IREFERENCE X Y) I: 7.6

SETIS SET (Masterscope Command) II: 19.5

ISTHERE (I.S. Operator) I: 9.22

IT (Variable) II: 13.20

ITALIC (Font face) III: 27.26

ITEMHEIGHT (Menu Field) III: 28.41

ITEMS (Menu Field) III: 28.39

ITEMWIDTH (Menu Field) III: 28.41

Iterative statements I: 9.9

(ITIMES X₁ X₂ ... X_N) I: 7.6

IT₁—datum (Inspect Window Command) III: 26.4

IT₁—selection (Inspect Window Command) III: 26.5

IWRITEDATE (File Attribute) III: 24.18

J

JMACRO (Property Name) I: 10.21

JOIN FORM (I.S. Operator) I: 9.11

JOINC (Editor Command) II: 16.53

K

&KEY (DEFMACRO keyword) I: 10.25

Key names III: 30.19

(KEYACTION KEYNAME ACTIONS — — ) III: 30.20

Keyboard III: 30.19

(KEYDOWNP KEYNAME) III: 30.19
KEYLST (ASKUSER argument) III: 26.13
KEYLST (ASKUSER option) III: 26.15
Keys on mouse III: 30.17
KEYSTRING (ASKUSER option) III: 26.16
Keyword macro arguments I: 10.24
KNOWN (Masterscope Set Specification) II: 19.12
(KWOTE X) I: 10.13

L
(L-CASE X FLG) I: 2.10; II: 16.52
LABELS (Litatom) II: 21.21,23
LAMBDA (Litatom) I: 10.2
LAMBDA (Macro Type) I: 10.22
Lambda functions I: 10.2
Lambda-nospread functions I: 10.5
Lambda-spread functions I: 10.3

LAMBDADAFONT (Font class) III: 27.32
LAMBDASPLST (Variable) I: 10.8; II: 20.14; 20.9-11
LAMS (Variable) II: 18.9; 18.14
Landscape fonts III: 27.27

LAPFLG (Variable) II: 18.1
Large integers I: 7.1; 7.2; 9.1
LARGEST FORM (I.S. Operator) I: 9.12
LAST (as argument to ADVISE) II: 15.11
(LAST X) I: 3.9
LASTTAIL (Variable) II: 16.14; 16.15,21,72
(LASTC FILE) III: 25.5
LASTKEYBOARD (Variable) III: 30.19
LASTMOUSEBUTTONS (Variable) III: 30.18

(LASTMOUSESTATE BUTTONFORM) (Macro) III: 30.18
(LASTMOUSEX DISPLAYSTREAM) III: 30.18
LASTMOUSEX (Variable) III: 30.18
(LASTMOUSEY DISPLAYSTREAM) III: 30.18
LASTMOUSEY (Variable) III: 30.18
(LASTN L N) I: 3.10
LASTPOS (Variable) II: 14.6; 14.4,7-10,12
LASTVALUE (Property Name) II: 16.50

LASTVMEMFILEPAGE (Variable) I: 12.11
LASTWORD (Variable) II: 20.18; 20.21-23; 21.10
(LC. @) (Editor Command) II: 16.24
LCASELST (Variable) III: 26.46

LCFIL (Variable) II: 18.1-2
(LCL . @) (Editor Command) II: 16.24
(LCONC PTR X) I: 3.6; 3.7
(LDB BYTESVAL) (Macro) I: 7.10
LDFLG (Argument to LOAD) II: 17.5
(LDIFF LST TAIL ADD) I: 3.12
LDIFF: NOT A TAIL (Error Message) I: 3.12

(LDIFFERENCE X Y) I: 3.11
LE (CLISP Operator) II: 21.8
LEFT (key indicator) III: 30.17
Left margin III: 27.11
LEFTBRACKET (Syntax Class) III: 25.35

(LEFTOFGRIDCOORD GRIDX GRIDSPEC) III: 27.23
LEFTPAREN (Syntax Class) III: 25.35

LENGTH (File Attribute) III: 24.17
(LENGTH X) I: 3.10
(LEQ X Y) I: 7.4
(LESP X Y) I: 7.4

(LET VARLIST E₁ E₂ ... Eₙ) (Macro) I: 9.9

(LET* VARLIST E₁ E₂ ... Eₙ) (Macro) I: 9.9

(LI N) (Editor Command) II: 16.41
LIKE ATOM (Masterscope Set Specification) II: 19.11

(LINBUF FLG) III: 30.11; 30.12
LINE (Variable) III: 26.38
Line buffer III: 30.9; 30.11
Line length III: 27.12
Line-buffering III: 30.9; 25.3-6
line-feed (Editor Command) II: 16.18

LINEDELDELETE (syntax class) III: 30.5,8
(LINELENGTH N FILE) III: 25.11; 27.12

LINESLENGTH N (Masterscope Path Option) II: 19.17
(LISP-IMPLEMENTATION-TYPE) I: 12.12
(LISP-IMPLEMENTATION-VERSION) I: 12.12
(LISP_DIRECTORYP VOLUMENAME) III: 24.23

LISPFCN (Property Name) II: 21.28
(LISP_INTERRUPTS) III: 30.4
(LISPSOURCEFILEFILE) II: 17.52

LISPUSERSDIRECTORIES (Variable) I: 12.3; II: 17.9; III: 24.32
(LISPXLISPXXLISPXXLISPXXMACROS
LISPXXUSERFN LISPXXFLG) II: 13.35;
13.12,19,32-34,36,43; 16.51,57; 20.4,17,24

LISPX Printing Functions II: 13.25

(LISPX/ X FN VARS) II: 13.41; 13.27
LISPXCOMS (Variable) II: 13.35; 17.39

(LISPX_EVAL LISPXXFORM LISPXXID) II: 13.36
(LISPX_FIND HISTORY LINE TYPE BACKUP —) II:
13.39; 13.44

(LISPX_FINDSPLST (Variable) II: 13.8
LISPXHIST (Variable) II: 13.33; 13.30,34,42
LISPXHISTORY (Variable) II: 13.31; 13.35,43
LISPXHISTORYMACROS (Variable) II: 13.23

LISPXLINE (Variable) II: 13.23
(LISPXMACROS LITATOM₁ ... LITATOMₕ) (File
Package Command) II: 17.39
Lower case in CLISP  II: 21.27
Lower case input  III: 30.8
(LOWERCASE FLG)  II: 21.27
LowerLeftCursor (Variable)  III: 30.15
LowerRightCursor (Variable)  III: 30.15
(LP COMS₁ ... COMS₇) (Editor Command)  II: 16.60; 16.61
LPARKEY (Variable)  II: 20.14; 20.6
(LPQ COMS₁ ... COMS₇) (Editor Command)  II: 16.61
LPT (printer device)  III: 29.4
(LRSH X N)  I: 7.8
(LSH X N)  I: 7.8
LSTFIL (Variable)  II: 18.1
(LSUBST NEW OLD EXPR)  I: 3.13
LT (CLISP Operator)  II: 21.8
(LVLPRIN1 X FILE CARVL CDRLVL TAIL)  III: 25.13
(LVLPRIN2 X FILE CARVL CDRLVL TAIL)  III: 25.13
(LVLPRINT X FILE CARVL CDRLVL TAIL)  III: 25.13
 M
(M C (ARG₁ ... ARG₇) COMS₁ ... COMS₇) (Editor Command)  II: 16.62
(M C ARG COMS₁ ... COMS₇) (Editor Command)  II: 16.62
(M C COMS₁ ... COMS₇) (Editor Command)  II: 16.62
(MACHINE-INSTANCE)  I: 12.12
(MACHINE-TYPE)  I: 12.12
(MACHINE-VERSION)  I: 12.12
(MACHINETYPE)  I: 12.13
MACRO (File Package Command Property)  II: 17.45
(MACRO . MACRO) (in Masterscope template)  II: 19.21
MACRO (Property Name)  I: 10.21; II: 17.18; 18.11
MACRO (type of read macro)  III: 25.39
Macro expansion in Masterscope  II: 19.17
MACROCHARS (ASKUSER option)  III: 26.17
MACROPROPS (Variable)  I: 10.21
Macros  I: 10.21
(MACROS LITATOM₁ ... LITATOM₇) (File Package Command)  II: 17.35
MACROS (File Package Type)  II: 17.24
Macros in the editor  II: 16.62
Maintanance panel  III: 30.24
(MAINWINDOW WINDOW RECURSEFLG)  III: 28.47
MAINWINDOW (Window Property)  III: 28.54
MAINWINDOWMAXSIZE (Window Property)  III: 28.54
MAINWINDOWMINSIZE (Window Property)  III: 28.54
(MAKE ARGNAME EXP) (Editor Command)  II: 16.57
(MAKEBITTABLE L NEG A)  I: 4.6
(MAKEFILE FILE OPTIONS REPRINTFNS SOURCEFILE)  II: 17.10; 17.14; 18.16; 20.24
MAKEFILE and CLISP  II: 21.26
MAKEFILEFORMS (Variable)  II: 17.12
MAKEFILEOPTIONS (Variable)  II: 17.10
MAKEFILEREMAKEFLG (Variable)  II: 17.15; 17.11
(MAKEFILES OPTIONS FILES)  II: 17.12
(MAKEFN (FN . ACTUALARGS) ARGLIST N₁ N₂) (Editor Command)  II: 16.56
(MAKEKEYLIST LST DEFAULTKEY LCASEFLG AUTOCOMPLETFLG)  III: 26.13
(MAKENEWCOM NAME TYPE ...)  II: 17.49
(MAKESYS FILE NAME)  I: 12.9
MAKESYSDATE (Variable)  I: 12.13; 12.10
MAKESYSDATE (Variable)  I: 12.13
(MAKEWITHINREGION REGION LIMITREGION)  III: 27.2
Manipulating file names  III: 24.5
(MAP MAPX MAPFN1 MAPFN2)  I: 10.15
(MAP.PROCESSES MAPFN)  II: 23.5
(MAP2C MAPX MAPFN1 MAPFN2)  I: 10.16
(MAP2CAR MAPX MAPY MAPFN1 MAPFN2)  I: 10.16
(MAPATOMS FN)  I: 2.11
(MAPC MAPX MAPFN1 MAPFN2)  I: 10.15
(MAPCAR MAPX MAPFN1 MAPFN2)  I: 10.15
(MAPCON MAPX MAPFN1 MAPFN2)  I: 10.15; II: 21.13
(MAPCONC MAPX MAPFN1 MAPFN2)  I: 10.16; II: 21.13
(MAPDLMAPDLFN MAPDLPPOS)  I: 11.13
(MAPHASH HARRAY MAPHFN)  I: 6.3
(MAPLIST MAPX MAPFN1 MAPFN2)  I: 10.15
(MAPRELATION MAPFN)  II: 19.24
(MAPPRINT LST FILE LEFT RIGHT SEP PFN LISPXPRINTERFLG)  I: 10.17
(MARK LITATOM) (Editor Command)  II: 16.28
MARK (Editor Command)  II: 16.27; 16.28
Mark-and-sweep garbage collection  II: 22.1
(MARKASCHANGED NAME TYPE REASON)  II: 17.17
MARKASCHANGEDFNS (Variable)  II: 17.18
Marking changes  II: 17.17
INDEX

MARKLST (Variable) II: 16.27; 16.72
(MASK.0’S POSITION SIZE) (Macro) I: 7.9
(MASK.1’S POSITION SIZE) (Macro) I: 7.9
Masterscope II: 19.1
(MASTERSCOPE COMMAND —) II: 19.22
Masterscope commands II: 19.4
Masterscope templates II: 19.18
MATCH (Pattern Matching Operator) I: 12.24
(MAX X₁ X₂...Xₙ) I: 7.4
MAX.FIXP (Variable) I: 7.5
MAX.FLOAT (Variable) I: 7.11; 7.12
MAX.INTEGER (Variable) I: 7.5; 7.7
MAX.SMALLP (Variable) I: 7.5
MaxBkMenuHeight (Variable) II: 14.15
MaxBkMenuHeight (Variable) II: 14.15
MAXINSPECTARRAYLEVEL (Variable) III: 26.5
MAXINSPECTCDRLEVEL (Variable) III: 26.5
MAXLEVEL (Variable) II: 16.20; 16.23
MAXLOOP (Variable) II: 16.61
MAXLOOP EXCEEDED (Printed by Editor) II: 16.61
(MAXMENUITEMHEIGHT MENU) III: 28.42
(MAXMENUITEMWIDTH MENU) III: 28.42
MAXSIZE (Window Property) III: 28.53
(MBD E₁...Eₘ) (Editor Command) II: 16.36
(MEMB X Y) I: 3.12
(MEMBER X Y) I: 3.13
MEMBERS (Clearinghouse Group property) III: 31.12
(MENU MENU POSITION RELEASECONTROLFLG —) III: 28.37
MENUBORDERSIZE (Menu Field) III: 28.41
MENUBUTTONFN (Function) III: 28.38
MENUCOLUMNS (Menu Field) III: 28.41
MENUFONT (Menu Field) III: 28.41
MENUFONT (Variable) III: 28.8,41
MENUHELDWAIT (Variable) III: 28.40
(MENUITEMREGION ITEM MENU) III: 28.43
MENUOFFSET (Menu Field) III: 28.40
MENOUTLINESIZE (Menu Field) III: 28.42
MENUPosition (Menu Field) III: 28.40
(MENUREGION MENU) III: 28.42
MENUROWS (Menu Field) III: 28.41
Menus III: 30.13; 28.1
MENUTITLEFONT (Menu Field) III: 28.41
(MENUWINDOW MENU VERTFLG) III: 28.48
(MERGE A B COMPAREFN) I: 3.17
(MERGEINSERT NEW LST ONEFLG) I: 3.18
Meta-character echoing III: 30.6
(METASHIFT FLG) III: 30.22
MIDDLE (key indicator) III: 30.17
Middle-blank key III: 26.23, 25
MILLISECONDS (Timer Unit) I: 12.16
(MIN X₁ X₂...Xₙ) I: 7.4
MIN.FIXP (Variable) I: 7.5
MIN.FLOAT (Variable) I: 7.11; 7.13
MIN.INTEGER (Variable) I: 7.5; 7.7
MIN.SMALLP (Variable) I: 7.5
(MINATTACHEDWINDOWEXTENT WINDOW) III: 28.48
(MINIMUMWINDOWSIZE WINDOW) III: 28.33
MINSIZE (Window Property) III: 28.53; 28.33
(MINUS X) I: 7.3
(MINUSP X) I: 7.4
MIR (Font face) III: 27.26
MISSING OPERAND (DWIM error message) II: 21.15
MISSING OPERATOR (CLISP error message) II: 21.15
(MISSPELLED? XWORD REL SPLST FLG TAIL FN) II: 20.22; 20.23-24
(MKATOM X) I: 2.8
(MKLIST X) I: 3.4
(MKSTRING X FLG RDTBL) I: 4.2
MODIFIER (Litatom) I: 9.22
(MODIFY.KEYACTIONS KEYACTIONS SAVECURRENT?) III: 30.21
Modules II: 17.1
(MONITOR.AWAIT.EVENT RELEASELOCK EVENT TIMEOUT TIMER) II: 23.8
Mouse III: 30.13
Mouse buttons III: 30.17
Mouse Keys III: 30.17
(MOUSECONFIRM PROMPTSTRING HELPSTRING WINDOW DON'TCLEARWINDOWFLG) III: 28.11
MOUSECONFIRMCURSOR (Variable) III: 28.11; 30.15
(MOUSESTATE BUTTONFORM) (Macro) III: 30.17
(MOV? FROM TO COPYFLG —) II: 10.11
(MOVE FROM TO COPYFLG —) II: 10.11
(MOVE @₁ TO COM .@₂) (Editor Command) II: 16.38; 16.37
Move (Window Menu Command) III: 28.5
MOVEFN (Window Property) III: 28.20
(MOVETO X Y STREAM) III: 27.13
(MOVETOFILE TOFILE NAME TYPE FROMFILE) II: 17.49
(MOVETOUSENDERLEFT STREAM REGION) III: 27.14
(MOVETEWINDOWPOS¥ORX Y) III: 28.19
INDEX

MRR (Font face) III: 27.26
MSMACROPROPS (Variable) II: 19.17
(MSMARKCHANGED NAME TYPE REASON) II:
19.24
(MSNEEDUNSAVE FNS MSG MARKCHANGEDFLG) II:
19.24
MSNEEDUNSAVE (Variable) II: 19.25
MSPRINTFLG (Variable) II: 19.2
Multiple streams to a file III: 24.15
MULTIPLY DEFINED TAG (Error Message) II: 18.23
MULTIPLY DEFINED TAG, ASSEMBLE (Error
Message) II: 18.23
MULTIPLY DEFINED TAG, LADP (Error Message) II:
18.23

N
(-N E₁ ... Eₘ) (N > = 1) (Editor Command) II: 16.29
(N E₁ ... Eₘ) (N > = 1) (Editor Command) II: 16.29
(N E₁ ... Eₘ) (Editor Command) II: 16.29
(N) (N > = 1) (Editor Command) II: 16.29
-N(N > = 1) (Editor Command) II: 16.15
N(N > = 1) (Editor Command) II: 16.15; 16.29;
16.55
-N(N a number) (PRINTOUT command) III: 25.26
N(N a number) (PRINTOUT command) III: 25.25;
25.30
NAME (File name field) III: 24.6
NAME (Process Property) II: 23.2
NAME LITATOM ARG₁ ... ARGₙ : EventSpec (Prog.
Asst. Command) II: 13.14
NAME LITATOM ARG₁ ... ARGₙ : EventSpec (Prog.
Asst. Command) II: 13.14
NAME LITATOM EventSpec (Prog. Asst. Command)
II: 13.14; 13.16,33
NAMES RESTORED (Printed by System) II: 15.9
NAMESCHANGED (Property Name) II: 15.5
(NARGS FN) I: 10.8
(NCHARS X FLG RDTBL) I: 2.9; 4.2
(NCONC X₁ X₂ ... Xₙ) I: 3.5; 3.6; II: 21.13
(NCONC1 LST X) I: 3.5; 3.6; II: 21.13
(NCREATE TYPE OLDDB) I: 8.22
(NDIR FILEGROUP COM₁ ... COMₙ) III: 24.35
NEGATE (Editor Command) II: 16.54
(NEGATE X) I: 3.20; II: 16.54
(NEQ X Y) I: 9.3
NETWORKSTYPES (Variable) III: 24.38
NEVER FORM (I.S. Operator) I: 9.11
NEW (MAKEFILE option) II: 17.11
(NEW/FN FN) II: 13.41
NEWCOM (File Package Type Property) II: 17.31
NEWREGIONFN (Window Property) III: 28.18
(NEWRESOURCE RESOURCE NAME . ARG) (Macro)
I: 12.23
NEWVALUE (Variable) I: 8.12
(NEX COM) (Editor Command) II: 16.26
NEL (Editor Command) II: 16.26
NIL (Editor Command) II: 16.55; 16.59
NIL (in block declarations) II: 18.18
NIL (in Masterscope template) II: 19.18
NIL (Litatom) I: 2.3; 9.2
NIL (Primary stream) III: 25.1
NILCOMS (Variable) II: 17.13
(NILL X₁ ... Xₙ) I: 10.18
NILNPRINTFLG (Variable) III: 25.16
NLAMA (Variable) II: 18.9; 18.14
NLAMBD(A (Litatom) I: 10.2
NLAMBD(A (Macro Type) I: 10.22
Nlambda functions I: 10.2
Nlambda-nospread functions II: 10.6
Nlambda-spread functions II: 10.4
(NLAMBA..ARGS X) I: 10.13
NLAML (Variable) II: 18.9; 18.14
(NLEFT L N TAIL) I: 3.9
(NLISTP X) I: 3.1; 9.2
(NLSETQ FORM) I: 9.9; II: 14.22; 13.30
NLSETQGAG (Variable) II: 14.22
NO BINARY CODE GENERATED OR LOADED (Error
Message) II: 18.23
(FN - NO BREAK INFORMATION SAVED) (value of
REBREAK) II: 15.8
NO DO, COLLECT, OR JOIN (Error Message) I: 9.19
NO FILE PACKAGE COMMAND FOR (Error Message)
II: 17.40
NO LONGER INTERPRETED AS FUNCTIONAL
ARGUMENT (Error Message) II: 18.23
NO PROPERTY FOR (Error Message) II: 17.38
NO USMCREMACRO FOR (Error Message) II: 17.34
NO VALUE SAVED (Error Message) II: 13.29
NOBIND (Litatom) I: 2.2; 11.8; II: 13.28-29; 17.5
NOBREAKS (Variable) II: 15.7
NOCASEFLG (AskUSER option) III: 26.15
NOCLEARSTKLST (Variable) I: 11.10
NODIRCORE (file device) III: 24.30
NOECHOFLG (AskUSER option) III: 26.16
NOESC (type of read macro) III: 25.40
NOESCAPEQUOTE (type of read macro) III: 25.40
NOEVAL (Litatom) II: 21.21
INDEX

NOFILESPELLFLG (Variable) III: 24.32
NOFIXFNSLST (Variable) II: 21.21; 17.8; 18.12; 21.19
NOFIXVARSLST (Variable) II: 21.21; 17.8; 18.12; 21.15, 19
NON-ATOMIC CAR OF FORM (Error Message) II: 18.23
Non-existent directory (Error Message) III: 24.10
NON-NUCLEAR ARG (Error Message) I: 5.2; 7.3, 6, 11; II: 14.28
NONE (syntax class) III: 30.6
NONIMMED (type of read macro) III: 25.41
NONIMMEDIATE (type of read macro) III: 25.41
NOPRINT (Litatom) II: 13.29
(NORMALCOMMENTS FLG) III: 26.44; 26.45
NOSAVE (Function) II: 13.41
NOSAVE (Litatom) II: 13.29, 40
NOSCROLLBARS (Window Property) III: 28.26; 28.25
NOSPELLFLG (Variable) II: 20.13; 21.21; III: 24.32
Nospread functions II: 10.3
NOSTACKUNDO (Litatom) II: 13.29
(NOT X) II: 9.3
NOT A BINDABLE VARIABLE (Error Message) II: 18.23
NOT A FUNCTION (Error Message) I: 10.8; II: 15.11
NOT BLOCKED (Printed by Editor) II: 16.65
(NOT BROKEN) (value of UNBREAK0) II: 15.8
not changed, so not unsaved (Printed by Editor) II: 16.69
NOT COMPILABLE (Error Message) II: 18.22; 18.14, 18
(FILE NOT DUMPED) (returned by MAKEFILE) II: 17.12
not editable (Error Message) II: 16.70-71
NOT FOUND (Error Message) II: 18.22 .
(FN NOT FOUND) (printed by break) II: 14.7
(NOT FOUND) (printed by BREAKIN) II: 15.6-7
FILENAME NOT FOUND (printed by LISTFILES) II: 17.14
(FN1 NOT FOUND IN FN2) (value of BREAK0) II: 15.4
NOT FOUND, SO IT WILL BE WRITTEN ANEW (Error Message) II: 17.51
NOT IN FILE - USING DEFINITION IN CORE (Error Message) II: 18.22
NOT ON BLKFNS (Error Message) II: 18.22; 18.19-20
NOT ON FILE, COMPILING IN CORE DEFINITION (Error Message) II: 18.18
(FN NOT PRINTABLE) (returned by PRETTYPRINT) III: 26.40
NOT-FOUND (Litatom) II: 17.7
(NOT ANY SOMEX SOMEFN1 SOMEFN2) II: 10.17
NOTCOMPILABLEFILES (Variable) II: 17.14; 17.10-11
(NOTE VAL LSTFLG) II: 11.20
NOTE: BRKEXP NOT CHANGED. (Printed by Break) II: 14.12
(NOTEVER EVERYX EVERYFN1 EVERYFN2) II: 10.17
NOTFIRST (DECLARE: Option) II: 17.42
nothing saved (Printed by Editor) II: 16.64-65
nothing saved (Printed by System) II: 13.26; 13.13
Noticing files II: 17.19
(NOTIFY.EVENT EVENT ONCEONLY) II: 23.7
NOTLISTEDFILES (Variable) II: 17.14; 17.10
NOTRACE SET (Masterscope Path Option) II: 19.16
NS character I/O III: 25.22; 25.6, 9, 19
NS characters II: 2.12; 4.2; III: 25.19-20, 36; 27.27; 30.3, 6-7, 20
NS.ECHOUNEDITOR (Function) III: 31.38
NSADDRESS (Data type) III: 31.7; 31.17
NSNAME (Data type) III: 31.8; 31.17-18
(NSNAME.TO.STRING NSNAME FULLNAMEFLG) III: 31.9
(NSOCKETEVENT NSOC) III: 31.37
(NSOCKETNUMBER NSOC) III: 31.37
(NSPRINT PRINTER FILE OPTIONS) III: 31.12
NSPRINT.DEFAULT.MEDIUM (Variable) III: 29.2
(NSPRINTER.PROPERTIES PRINTER) III: 31.12
(NSPRINTER.STATUS PRINTER) III: 31.12
(NTH COM) (Editor Command) II: 16.26
(NTH N) (Editor Command) II: 16.17; 16.26
(NTH X N) II: 3.9
(NTHCHAR X N FLG RDTBL) II: 2.10
(NTHCHARCODE X N FLG RDTBL) II: 2.13
NULL (file device) III: 24.30
(NULL X) II: 9.3
Null strings II: 4.1
NULLDEF (File Package Type Property) II: 17.30
(NUMBERP X) II: 7.2; 9.1
Numbers II: 7.1; 9.1; III: 25.4
(NX N) (Editor Command) II: 16.16
NX (Editor Command) II: 16.16

INDEX 28
O
(OTHER (Syntax Class) III: 25.35

INDEX

OBTAIN.MONITORLOCK LOCK DONTWAIT UNWINDSAVE) II: 23.9

OCCURRENCES (Printed by Editor) II: 16.61

Octal integers I: 7.4

(OCTALSTRING N) III: 31.36

(ODDP N MODULUS) I: 7.9

BLOCKTYPE OF FUNCTIONS (Masterscope Set Specification) II: 19.12

OK (Break Command) II: 14.5; 14.6,12

OK (Break Window Command) II: 14.3

OK (EDIT Command) II: 16.10

OK (Editor Command) II: 19.2

OK (Prog. Asst. Command) II: 13.36

OK TO REEVALUATE (printed by DWIM) II: 20.7

OKREEVALST (Variable) II: 20.14; 20.7

OLD (I.S. Operator) I: 9.13

OLDVALUE (Variable) II: 14.27

ON FORM (I.S. Operator) I: 9.13; 9.14

BLOCKTYPE ON FILES (Masterscope Set Specification) II: 19.12

ON OLD VAR (I.S. Operator) I: 9.13

ON PATH PATHOPTIONS (Masterscope Set Specification) II: 19.13

Only the compiled version ... was loaded
(MAKEFILE message) II: 17.16

(ONQUEUE ITEM Q) (Function) III: 31.41

OPCODE? - ASSEMBLE (Error Message) II: 18.23

Open functions II: 18.11

(OPENFILE FILE ACCESS RECOG PARAMETERS —) III: 24.15

OPENFN (Window Property) III: 28.15

(OPENIMAGESTREAM FILE IMAGETYPE OPTIONS) III: 27.9

OPENLAMBDA (Macro Type) I: 10.22

(OPENSOCKET SKT# IFCLASS) III: 31.37

(OPENP FILE ACCESS) III: 24.4

(OPENPUPSOCKET SKT# IFCLASS) III: 31.29

(OPENSTREAM FILE ACCESS RECOG PARAMETERS —) III: 24.2

(OPENSTREAMFN FILE OPTIONS) (Image Stream Method) III: 27.43

OPENSTRINGSTREAM STR ACCESS) III: 24.28

(OPENWINDOW) III: 28.15

(OPENPIOS) III: 28.15

(OPENWINP WINDOW) III: 28.15

OPERATION (BITBLT argument) III: 27.15

&OPTIONAL (DEFMACRO keyword) I: 10.25

Optional macro arguments I: 10.24

(OR X1 X2 ... XN) I: 9.4

Order of precedence of CLISP operators II: 21.12

(ORF PATTERN1 ... PATTERNN) (Editor Command) II: 16.22

ORIG (Litatom) III: 25.33

ORIGINAL (Break Command) II: 14.10

(ORIGINAL COMS1 ... COMS N) (Editor Command) II: 16.64

(ORIGINAL COM1 ... COMN) (File Package Command) II: 17.40

ORIGINAL I.S.OPR OPERAND (I.S. Operator) I: 9.17; 9.21

(ORR COMS1 ... COMSN) (Editor Command) II: 16.61

OTHER (Syntax Class) III: 25.35

(OUTCHARFN STREAM CHARCODE) (Stream Method) III: 27.48

(OUTFILE FILE) III: 24.15

(OUTFILEP FILE) III: 24.13

OUTOF FORM (I.S. Operator) I: 9.15; 11.18

OUTPUT (File access) III: 24.2

(OUTPUT FILE) III: 25.8

OUTPUT (Masterscope Command) II: 19.4

OUTPUT FILE? (Compiler Question) II: 18.2

Output functions III: 25.7

OVERFLOW (Error Message) I: 7.2; II: 14.31

(OVERFLOW FLG) I: 7.2

Overflow of floating point numbers I: 7.2

p

(P 0 N) (Editor Command) II: 16.48

(P M N) (Editor Command) II: 16.48

(P 0) (Editor Command) II: 16.48

(P M) (Editor Command) II: 16.47

P (Editor Command) II: 16.47; 16.28

(P EXP1 ... EXPN) (File Package Command) II: 17.40

P.A. II: 13.1

.P2 THING (PRINTOUT command) III: 25.28

(PACK X) I: 2.8

(PACK* X1 X2 ... XN) I: 2.9

(PACKC X) I: 2.13

\PACKET.PRINTERS (Variable) III: 31.41

(PACKFILENAME FIELD1 CONTENTS1 ... FIELDM CONTENTSN) III: 24.9

(PACKFILENAME.STRING FIELD1 CONTENTS1 ... FIELDM CONTENTSN) III: 24.8

.PAGE (PRINTOUT command) III: 25.26
PRETTYPRINTYPEMACROS (Variable) III: 26.48
PRETTYTABFLG (Variable) III: 26.47
Primary input stream III: 25.3; 24.4
Primary output stream III: 25.8; 24.4
Primary read table III: 25.33; 25.3.8; 30.6
Primary streams III: 25.1; 25.3.8
Primary terminal table III: 30.4; 30.6
(PRIN1 X FILE) III: 25.8; 25.11
(PRIN2 X FILE RDRTBL) III: 25.8; 25.11
PRIN2-names I: 2.8-9; 13; 4.2
(PRIN3 X FILE) III: 25.9
(PRIN4 X FILE RDRTBL) III: 25.9
(PRINT X FILE RDRTBL) III: 25.9; 25.11
*PRINT* (history list property) II: 13.33
Print names I: 2.7
(PRINT-LISP-INFORMATION STREAM FILESTRING) II: 12.11
(PRINTBELLS —) II: 20.3; III: 25.10
PRINTBINDINGS (Function) II: 13.17; 14.9
(PRINTBITMAP BITMAP FILE) III: 27.4
(PRINTCCODE CHARCODE FILE) III: 25.9
PRINTCODE (Function) III: 26.2
(PRINTCOMMENT X) III: 31.45
(PRINTCONSTANT X VAR CONSTANTLIST FILE PREFIX) III: 31.35
(PRINTDATE FILE CHANGES) II: 17.51
(PRINTDEF EXPR LEFT DEF TAILFLG FNSLIST FILE) III: 26.42; 26.48
(PRINTERSTATUS PRINTER) III: 29.4
(PRINTERTYPE HOST) III: 29.4
(PRINTERTYPE Property Name) III: 29.4
(PRINTTYPES (Variable) III: 29.5
(PRINTERTYPEFILE X —) III: 29.4
(PRINTFILETYPES (Variable) III: 29.6; 27.9
(PRINTFNS X —) II: 17.51
(PRINTHISTORY HISTORY LINE SKIPFN NOVALUES FILE) II: 13.42; 13.13
Printing circular lists III: 25.17
Printing documents III: 29.1
Printing numbers III: 25.13
Printing unusual data structures III: 25.17
(PRINTLEVEL CARVAL CDRVAL) III: 25.11
PRINTLEVEL (Interrupt Channel) III: 30.3
PRINTMSG (Variable) II: 14.23
(PRINTNUM FORMAT NUMBER FILE) III: 25.15; 25.14
PRINTOUT (CLISP word) III: 25.23
PRINTOUTMACROS (Variable) III: 25.31
(PRINT PACKET PACKET CALLER FILE PRE. NOTE DOFILTER) III: 31.41
(PRINTPACKETDATA BASE OFFSET MACRO LENGTH FILE) III: 31.35
(PRINTPARA LMARG RMARG LIST PZFLAG PARENFLAG FILE) III: 25.32
PRINTPROPS (Function) II: 13.17
(PRINTPUP PACKET CALLER FILE PRE. NOTE DOFILTER) III: 31.33
(PRINTPUPROUTE PACKET CALLER FILE) III: 31.35
(PRINTROUTINGTABLE TABLE SORT FILE) III: 31.31
PRINTXIP (Function) III: 31.38
PRINTXIPROUTE (Function) III: 31.38
PROCESS (Window Property) II: 23.13; III: 28.30
Process mechanism II: 23.1
Process status window II: 23.16
(PROCESS.APPLY PROC FN ARGS WAITFORRESULT) II: 23.6
(PROCESS.EVAL PROC FORM WAITFORRESULT) II: 23.6
(PROCESS.EVALV PROC VAR) II: 23.6
(PROCESS.FINISHEDP PROCESS) II: 23.4
(PROCESS.PROCESS RESULT WAITFORRESULT) II: 23.4
(PROCESS.RETURN VALUE) II: 23.4
(PROCESS.STATUS.WINDOW WHERE) II: 23.17
Processes II: 23.1
(PROCESSP PROC) II: 23.4
(PROCESSPROP PROC PROP NEWVALUE) II: 23.2
(PROCESSWORLD FLG) II: 23.1
(PRODUCE VAL) I: 11.17
(PROG VARLST E1 E2 ... EN) I: 9.8
PROG label I: 9.8
(PROG* VARLST E1 E2 ... EN) (Macro) I: 9.9
(PROG1 X1 X2 ... XN) I: 9.7
(PROG2 X1 X2 ... XN) I: 9.7
(PROGN X1 X2 ... XN) I: 9.8
Programmer's assistant II: 13.1
Programmer's assistant and the editor II: 13.43
Programmer's assistant commands applied to P.A. commands II: 13.20
Programmer's assistant commands that fail II: 13.20
Prompt character II: 13.38; 13.3,22; 14.1
Prompt window III: 28.3
PROMPT#FLG (Variable) I: 12.3; II: 13.22; 13.38
(PROMPTCHAR ID FLG HISTORY) II: 13.38; 13.22,43

INDEX

INDEX 31
INDEX

(RANDSET X) I: 7.14
(RATEST FLG) III: 25.4
(RATOM FILE RDTBL) III: 25.4; 25.36; 30.10
(RATOMS A FILE RDTBL) III: 25.4
RAVEN (Printer type) III: 29.5
(RC X Y) (Editor Command) II: 16.46
RC (MAKEFILE option) II: 17.10
(RC1 X Y) (Editor Command) II: 16.46
(READ FILE RDTBL FLG) III: 25.3; 30.10
Read macros III: 25.39
Read tables III: 25.33; 25.3.8
READ-MACRO CONTEXT ERROR (Error Message) II: 14.30
(READBITMAP FILE) III: 27.4
READBUF (Variable) II: 13.36; 13.38
(READC FILE RDTBL) III: 25.5; 30.10
(READCODE FILE RDTBL) III: 25.5
(READCOMMENT FL RDTBL LST) III: 26.45
REDATE (File Attribute) III: 24.18
(READFILE FILE RDTBL ENDTOKEN) III: 25.33
(READIMAGEOBJ STREAM GETFN NOERROR) III: 27.41
(READLINE RDTBL — — ) II: 13.36;
13.24,32,35,37,43; 16.67
(READMACROS FLG RDTBL) III: 25.42
(READP FILE FLG) III: 25.6
(READTABLEP RDTBL) III: 25.34
READVICE (Property Name) II: 15.12-13
(READVISE X) II: 15.12; 15.13; 17.35
(REALFRAMEP POS INTERPFLG) I: 11.13
(REALMEMORYSIZE) I: 12.10
(REALSTKNTH N POS INTERPFLG OLDPOS) I: 11.13
REANALYZE SET (Masterscope Command) II: 19.4
(REBREAK X) II: 15.8; 15.4
(REALCOM) II: 22.3
(REALCLAIMMIN N) II: 22.3
REALCLAIMWAIT (Variable) II: 22.3
(RECLOCK RECNAME — — — ) I: 8.16
Recognition of file versions III: 24.11
(RECOMPILE PFILE CFILE FNS) II: 18.15; 17.12;
18.14,18
RECOMPILEDDEFAULT (Variable) II: 18.16; 18.22
Reconstruction in pattern matching I: 12.30
RECORD (in Masterscope template) II: 19.20
RECORD (Record Type) I: 8.7
Record declarations I: 8.6
Record declarations in CLISP II: 21.14
Record package I: 8.1
Record types I: 8.7; 8.6
(RECORDACCESS FIELD DATUM DEC TYPE
NEWVALUE) I: 8.16
(RECORDACCESSFORM FIELD DATUM TYPE
NEWVALUE) I: 8.17
(RECORDCOUNTNAMES RECORDNAME — ) I: 8.16
(RECORDS REC ... REC) (File Package Command)
I: 8.2,11; II: 17.38
RECORDS (File Package Type) II: 17.24
REDEFINE? (Compiler Question) II: 18.1
(FN redefined) (printed by system) I: 10.10
Redisplay (Window Menu Command) III: 28.4
(REDIRE DISPLAYW WINDOW REGION ALWAYSFLG) III:
28.16
REDO EventSpec UNTIL FORM (Prog. Asst.
Command) II: 13.8
REDO EventSpec WHILE FORM (Prog. Asst.
Command) II: 13.8
REDO EventSpec N TIMES (Prog. Asst. Command)
II: 13.8
REDO EventSpec (Prog. Asst. Command) II: 13.8;
13.33
REDOCTN (Variable) II: 13.9
REFERENCE (Masterscope Relation) II: 19.8
Reference-counting garbage collection II: 22.2
ReFetch (Inspect Window Command) III: 26.4
REGION (Record) III: 27.1
REGION (Window Property) III: 28.34; 28.24
(REGIONP X) III: 27.2
Regions III: 27.1
(REGIONSINTERSECTP REGION1 REGION2) III: 27.2
Registering image objects III: 27.39
(REHASH OLDHARRAY NEWHARRAY) I: 6.3
REJECTMAINCOMS (Window Property) III: 28.51
SET RELATION SET (Masterscope Command) II:
19.5
Relations in Masterscope II: 19.7
(RELDRAWTO DX DY WIDTH OPERATION STREAM
COLOR DASHING) III: 27.18
(RELEASE.ETHERPACKET EPKT) (Function) III:
31.39
(RELEASE.MONITORLOCK LOCK EVENIFNOTMINE)
II: 23.9
(RELEASE.PUP PUP) III: 31.28
(RELEASE.XIP XIP) III: 31.36
Releasing stack pointers I: 11.9
(RELMOVETO DX DY STREAM) III: 27.14
(RELMOVIEW WINDOW POSITION) III: 28.19
(RELPROCESSP PROCHANDLE) II: 23.4
(RELSTK POS) I: 11.9; 11.10

INDEX
INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

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INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX
INDEX

(SHRINKW) III: 28.21
SIDE (History List Property) II: 13.33; 13.40-43
SIDE (Property Name) II: 13.34
SIGNEDWORD (as a field specification) II: 8.21
SIGNEDWORD (record field type) II: 8.10
(SIN X RADIANSLFGLG) II: 7.13
Site init file II: 12.1
SIZE (File Attribute) III: 24.17
SIZE (Font property) III: 27.27
SKIP LINES (PRINTOUT command) III: 25.26
(SKIPSEPR$ FILE RDTBL) III: 25.7
SKOR (Function) II: 20.20
(SKREAD FILE REREADSTRING RDTBL) III: 25.7
SLOPE (Font property) III: 27.27
Small integers II: 7.1; 9.1
SMALLEST (I.S. Operator) II: 9.12
(SMALLP) X: II: 7.1; 9.1
(SMARTARGFLIST FN EXPLAINFLG TAIL) II: 10.8
SMASH (in Masterscope template) II: 19.18
SMASH (Masterscope Relation) II: 19.8
(SMASHFILECOMS FILE) II: 17.49
SMASHING (in CREATE form) II: 8.4
SMASHPROPS (Variable) II: 22.12
SMASHPROPSLST (Variable) II: 22.12
SMASHPROPSTEMNU (Variable) II: 22.12
Snap (Background Menu Command) III: 28.6
Snap (Window Menu Command) III: 28.4
(SOFTWARE-TYPE) II: 12.12
(SOFTWARE-VERSION) II: 12.12
(SOME SOMEWHERE SOMEFLG) II: 10.17
SORRY, I CAN'T PARSE THAT (Error Message) II: 19.17
SORRY, NO FUNCTIONS HAVE BEEN ANALYZED
(Error Message) II: 19.17
SORRY, THAT ISN'T IMPLEMENTED (Error Message)
II: 19.17
(SORT DATA COMPARDFN) II: 3.17
(SORT.PUPHOSTS.BY.DISTANCE HOSTLIST) III:
31.30
SOURCETYPE (BITBLT argument) III: 27.15
.SP DISTANCE (PRINTOUT command) III: 25.26
Space factor III: 27.12
(SPACES N FILE) III: 25.9
Spaghetti stacks II: 11.2
(SPAWN.MOUSE —) II: 23.15
Speaker in terminal III: 30.24
SPEC (Font property) III: 27.28
Special variables II: 18.5; 22.5
Specvars II: 18.5; 14.26
(SPECVARS VAR$_1$ ... VAR$_N$) (File Package Command)
II: 17.37
SPECVARS (in Masterscope Set Specification) II:
19.12
SPECVARS (Variable) II: 18.5; 18.18
(SPELLFILE FILE NOPRINTFLG NSFLG DIRSTLIST) II:
14.23,29; III: 24.32; 24.3
Spelling correction II: 20.15; 13.8,35; 14.17;
16.66,68; 17.34,42; 20.2,19; 21.9,25
Spelling correction on file names II: 20.24; III:
24.32
Spelling correction protocol II: 20.4
Spelling lists II: 9.10; II: 20.16; 13.8,35; 14.17;
16.66,68; 17.6,34,42; 20.9-11; 21.9,25; III:
24.35
SPELLING1 (Variable) II: 20.17; 20.11,18,21
SPELLING2 (Variable) II: 20.17; 20.10-11,18,21
SPELLING3 (Variable) II: 20.17; 13.29; 20.9,18,21
SPELLSTR1 (Variable) II: 20.18
SPLICE (type of read macro) III: 25.39
(SPLITC X) (Editor Command) II: 16.54
(SPP.CLEARATTENTION STREAM NOERRORFLG)
III: 31.15
(SPP.CLEAREOM STREAM NOERRORFLG) III: 31.15
(SPP.DSTYPE STREAM DSTYPE) III: 31.14
(SPP.OPEN HOST SOCKET PROBE NAME PROPS)
III: 31.12
(SPP.SENDATTENTION STREAM ATTENTIONBYTE —
III: 31.14
(SPP.SENDEOM STREAM) III: 31.14
SPP.USER.TIMEOUT (Variable) III: 31.14
(SPPOUTPUTSTREAM STREAM) III: 31.14
Spread functions II: 10.3
SPRUCE (Printer type) III: 29.5
(SQRT N) II: 7.13
SQRT OF NEGATIVE VALUE (Error Message) II: 7.13
Square brackets inserted by PRETTYPRINT III:
26.47
ST (Response to Compiler Question) II: 18.2
Stack II: 11.1
Stack and the interpreter II: 11.14
Stack descriptors II: 11.4
Stack functions II: 11.4
STACK OVERFLOW (Error Message) II: 11.10; II:
14.28; 23.15
STACK POINTER HAS BEEN RELEASED (Error
Message) II: 11.5
Stack pointers II: 11.4; 11.5,9
Structure modification commands in the editor: 16.29

.SUB (PRINTOUT command) III: 25.27

(SUB) X I: 7.6

(SUBATOM X N M) I: 2.8

Subdeclarations I: 8.14

SUBITEMFN (Menu Field) III: 28.39

SUBITEMS (Litatom) III: 28.39

(SUBLIS ALST EXPR FLG) I: 3.14

(SUBPAIR OLD NEW EXPR FLG) I: 3.14

SUBRECORD (in record declarations) I: 8.14

(SUBREGIONP LARGEREGION SMALLREGION) III: 27.2

(SUBSET MAPX MAPFN1 MAPFN2) I: 10.17

(SUB NEW OLD EXPR) I: 3.13

Substitution macros I: 10.22

SUBSTRING X N M OLDPTR I: 4.3

SUCHTHAT (I.S. Operator) I: 9.22

SUCHTHAT (in event address) II: 13.6

SUM FORM (I.S. Operator) I: 9.11

.SUP (PRINTOUT command) III: 25.27

SURROUND (Editor Command) II: 16.37

SUSPEND (Process Property) II: 23.2

(SUSPEND.PROCESS PROC) II: 23.6

SUSPICIOUS PROG LABEL (Error Message) II: 21.19

SVFLG (Variable) II: 18.1-2

(SW N M) (Editor Command) II: 16.47

(SWAP DATUM1 DATUM2) (Change Word) I: 8.19

Swap (Edit Command) II: 16.8

(SWAP @1 @2) (Editor Command) II: 16.47

SWAPBLOCK TOO BIG FOR BUFFER (Error Message) II: 14.31

SWAPC (Editor Command) II: 16.54

(SWAPPUPPORTS PUP) III: 31.31

Switch (Edit Command) II: 16.7

Symbols I: 2.1

SYNONYM (in record declarations) I: 8.15

Synonyms for file package commands II: 17.47

Synonyms for file package types II: 17.32

Synonyms in spelling correction II: 20.16

Syntax classes III: 25.35

(SYNTAXP CODE CLASS TABLE) III: 25.37

SYSCursor I: 12.8

(SYSBUF FLG) III: 30.11; 30.12

SYSFILES (Variable) I: 17.6

SYSSHARRAY (Variable) I: 6.1

SYSLOAD (LOAD option) II: 17.5; 17.6; 20.10

(SYSOUT FILE) I: 12.8
INDEX

Sysout files  II: 12.8; III: 24.25
SYSOUT.EXT (Variable) II: 12.8
SYSOUTCURSOR (Variable) II: 12.8; III: 30.15
SYSOUTDATE (Variable) II: 12.13; 12.8
SYSOUTFILE (Variable) II: 12.8
SYSOUTGAG (Variable) II: 12.9
SYSPRETTYFLG (Variable) II: 11.12; II: 13.13,42; 14.8-9; III: 25.10
SYSPROPS (Variable) II: 2.5; II: 17.38
SYSTEM (in record declarations) II: 8.15
System buffer III: 30.9; 30.11
SYSTEM ERROR (Error Message) II: 14.27
System version information II: 12.11
SYSTEMFONT (Font class) III: 27.32
(SYSTEMTYPE) II: 12.13

T

T (Litatom) II: 2.3
T (Macro Type) II: 10.23
T (PRINTOUT command) III: 25.26
T (Terminal stream) III: 25.1; 25.2
T FIXED (printed by DWIM) II: 20.6
(TAB POS MINSACES FILE) III: 25.10
.TAB POS (PRINTOUT command) III: 25.25
.TAB0 POS (PRINTOUT command) III: 25.26
*TAIL (stack blip) II: 11.16
TAIL (Variable) II: 20.12
Tail of a list II: 3; 9
(TAILP X Y) II: 3.9
(TAN X RADIANSFLG) II: 7.13
(TCOMPL FILES) II: 18.14; 18.15,18.21
(TCONC PTR X) II: 3.6; 3.7
TCP/IP III: 24.36
Teletype list structure editor II: 16.1
(TEMPLATES LITATOM1 ... LITATOMM) (File Package Command) II: 17.39

TEMPLATES (File Package Type) II: 17.24
Templates in Masterscope II: 19.18
Terminal input/output III: 30.1; 25.3
Terminal streams III: 25.1; 25.2
Terminal syntax classes III: 30.5
Terminal tables III: 30.4
(TERTABLEP TTBL) III: 30.5
(TERPRI FILE) III: 25.9
TEST (Editor Command) II: 16.65
TEST (in Masterscope template) II: 19.19
TEST (Masterscope Relation) II: 19.8
(TESTRELATION ITEM RELATION ITEM2 INVERTED) II: 19.23

TESTRETURN (in Masterscope template) II: 19.19
(TEXTUREP OBJECT) III: 27.7
Textures III: 27.6
THEREIS FORM (I.S. Operator) II: 9.11
(THIS.PROCESS) II: 23.4
THOSE (Masterscope Set Specification) II: 19.12
(@1 THRU @2) (Editor Command) II: 16.42
(@1 THRU) (Editor Command) II: 16.42; 16.44
THRU (I.S. Operator) II: 9.22
THRU (in event specification) II: 13.7
TICKS (Timer Unit) II: 12.16
(TIME TIMEX TIMEN TIMETYP) II: 22.8
Time stamps II: 10.9; II: 16.76
Time-slice of history list II: 13.31; 13.21
TIME.ZONES (Variable) II: 12.15
(TIMEALL TIMEFORM NUMBEROFTIMES TIMEWHAT
INTERPFLG —) II: 22.7
(TIMEREPLIED? TIMER ClockValue or timerUnits)
I: 12.17
Timers I: 12.16
timerUnits UNITS (I.S. Operator) II: 12.18
(TIMES X1 X2 ... XN) II: 7.3
TIMES (used with REDO) II: 13.8
\TimeZoneComp (Variable) I: 12.16
TITLE (Menu Field) III: 28.41
TITLE (Window Property) III: 28.33
(T@1 TO T@2) (Editor Command) II: 16.42
(T@1 TO) (Editor Command) II: 16.42; 16.44
TO FORM (I.S. Operator) II: 9.14; 9.15
TO (in event specification) II: 13.7
TO SET (Masterscope Path Option) II: 19.16
TOO MANY ARGUMENTS (Error Message) II: 10.3;
II: 14.31
TOO MANY FILES OPEN (Error Message) II: 14.28
TOO MANY USER INTERRUPT CHARACTERS (Error Message) II: 14.30
TOP (as argument to ADVISE) II: 15.11
**TOP** (in backtrace) II: 14.9
Top margin III: 27.11
TOTOPFN (Window Property) III: 28.20
(TOTOPFWINDOW NOCALLTOTOPFNFLG) III: 28.20

(TRACE X) II: 15.5; 14.5; 17.5; 15.1,7
TRACEREGION (Variable) II: 14.16
TRACEWINDOW (Variable) II: 14.16
Tracing functions II: 15.1
Transcript files III: 30.12
Translations in CLISP II: 21.17

INDEX
INDEX

TRANSMIT.ETHERPACKET ND8 PACKET) III: 31.40

TREAT AS CLISP? (Printed by DWIM) II: 21.15

TREATASCLISPFLG (Variable) II: 21.16

TREATED AS CLISP (Printed by DWIM) II: 21.16

(TRUE X₁ ... Xₙ) I: 10.18

TRUSTING (DWIM mode) II: 20.4; 20.2; 21.4,6,16

TRY NEXT PLST ENDFORM VAL) I: 11.21

TTY process III: 28.30

(TTY.PROCESS PROC) II: 23.12

(TTY.PROCSP PROC) II: 23.12

TTY: (Editor Command) II: 16.51; 15.6; 16.49,52,61

TTY: (Printed by Editor) II: 16.52

(TTYDISPLAYSTREAM DISPLAYSTREAM) III: 28.29

TTYENTRYFN (Process Property) II: 23.13; 23.3

TTYEXITFN (Process Property) II: 23.13; 23.3

(TTYIN PROMPT SPLST HELP OPTIONS ECHOTFILE
  TABS UNREADBUF RDTBL) III: 26.22; 26.29

(TTYIN.PrintARGS FN ARGS ACTUALS ARGTYPE)
  III: 26.34

(TTYIN.READ? = ARGS) III: 26.34

(TTYIN.SCRATCHFILE) III: 26.33

TTYIN? = FN (Variable) III: 26.34

TTYINAUTOCLOSEFLG (Variable) III: 26.33

TTYINBSFLG (Variable) III: 26.36

TTYINCOMMENTCHAR (Variable) III: 26.37; 26.24

TTYINCOMPLETFLG (Variable) III: 26.37

(TTYINEDIT EXPRS WINDOW PRINT FN PROMPT)
  III: 26.32

TTYINEDITPROMPT (Variable) III: 26.29; 26.33

TTYINEDITWINDOW (Variable) III: 26.33

TTYINERRORSETFLG (Variable) III: 26.37

TTYINPRINTFN (Variable) III: 26.33

TTYINREAD (Function) III: 26.28

TTYINREADMACROS (Variable) III: 26.35

TTYINRESPONSES (Variable) III: 26.37; 26.38

TTYJUSTLENGTH (Variable) III: 26.27

TV (Prog. Asst. Command) III: 26.29

TYPE (File Attribute) III: 24.18

Type names of data types I: 8.20

TYPE-AHEAD (Prog. Asst. Command) II: 13.18

TYPE? (Variable) II: 20.12

TYPE? (in record declarations) I: 8.14

TYPE? (Record Operator) I: 8.5; 8.8

TYPE? NOT IMPLEMENTED FOR THIS RECORD (Error
  Message) I: 8.5

TYPEAHEADFLG (Variable) III: 26.36; 26.32

(TYPENAME DATUM) II: 8.20

(TYPEMAPP DATUM TYPE) II: 8.21

TYPEPERCORD (Record Type) I: 8.7

Types in Masterscope II: 19.13

(TYPESOF NAME POSSIBLETYPES IMPOSSIBLETYPES
  SOURCE) II: 17.27

U

(U-CASE X) I: 2.10; II: 16.52

(U-CASEP FN) I: 2.10

(UALPHORDER A B) I: 3.18

UB (Break Command) II: 14.6

UCASELST (Variable) III: 26.46

(UGLYVARS VAR₁ ... VARₙ) (File Package
  Command) II: 17.36; III: 25.18

UNABLE TO DWIMIFY (Error Message) II: 18.12

(UNADVISE X) II: 15.12; 15.11,13

UNADVISED (Printed by System) II: 15.9

UNARYOP (Property Name) II: 21.28

UNBLOCK (Editor Command) II: 16.65

UNBOUND ATOM (Error Message) I: 2.2-3; II: 14.31

Unboxing numbers I: 7.1

(UNBREAK X) II: 15.7; 15.5,8; 22.9

(UNBREAK0 FN —) II: 15.7; 15.8

(FN UNBREAKABLE) (value of BREAKIN) II: 15.6

(UNBREAKIN FN) II: 15.8; 15.7

UNBROKEN (Printed by ADVISE) II: 15.11

UNBROKEN (printed by compiler) II: 18.13

UNBROKEN (Printed by System) II: 15.9

UNDEFINED CAR OF FORM (Error Message) II:
  14.31

UNDEFINED FUNCTION (Error Message) II: 14.31;
  20.2

UNDEFINED OR ILLEGAL GO (Error Message) I: 9.8;
  II: 14.28

UNDEFINED TAG (Error Message) I: 10.28; II: 18.23

UNDEFINED TAG, ASSEMBLE (Error Message) II:
  18.23

UNDEFINED TAG, LAP (Error Message) II: 18.23

Undo (DéEdit Command) II: 16.8

(UNDO EventSpec) (Editor Command) II: 16.66

UNDO (Editor Command) II: 16.64; 13.43

UNDO EventSpec : X₁ ... Xₙ (Prog. Asst. Command)
  II: 13.14

UNDO EventSpec (Prog. Asst. Command) II: 13.13;
  13.7,28,33,42-43; 20.3

Undoing II: 13.26; 13.44

Undoing DWIM corrections II: 13.14; 21.20

Undoing in the editor II: 16.64; 13.44; 16.29

Undoing out of order II: 13.27; 13.13

(UNDOLISPX LINE) II: 13.42

(UNDOLISPX1 EVENT FLG —) II: 13.42
INDEX

VALUE OUT OF RANGE EXPT (Error Message) I: 7.13

VALUECOMANDFN (Window Property) III: 26.8
(VALUEOF LINE) II: 13.19; 13.34

Variable bindings I: 11.1; 10.19; II: 17.54
Variable bindings in stack frames I: 11.6
(VARIABLES POS) I: 11.7; II: 14.10
(VARS VAR ... VAR_N) (File Package Command) II: 17.35

VARS (File Package Type) II: 17.24
VARTYPE (Property Name) II: 17.22; 17.18
VAXMACRO (Property Name) I: 10.21

VERSION (File name field) III: 24.6
Version information I: 12.11
Version recognition of files III: 24.11
VertScrollCursor (Variable) III: 30.15
VertThumbCursor (Variable) III: 30.15
Video display screens I: 12.4; III: 30.22
Video taping from the screen III: 30.23

(VIDEOCOLOR BLACKFLG) III: 30.23
(VIDEORATE TYPE) III: 30.23
(VIRGINFN FN FLG) II: 15.8

Virtual memory I: 12.6
Virtual memory file I: 12.6; III: 24.21,23
(VMEM.PURE.STATE X) I: 12.10
(VMEMSIZE) I: 12.11

(VOLUMES) III: 24.23
(VOLUMESIZE VOLUMENAME —) III: 24.23

W

(WAIT.FOR.TTY MSEC NEEDWINDOW) II: 23.12
WAITBEFORESCROLLTIME (Variable) III: 28.24
WAITBETWEENSCROLLTIME (Variable) III: 28.24
(WAITFORINPUT FILE) III: 25.6
WAITINGCURSOR (Variable) III: 30.15
(WAKE.PROCESS PROC STATUS) II: 23.5
WBorder (Variable) III: 28.14,32-33
(WBREAK ONFLG) II: 14.15
WEIGHT (Font property) III: 27.27
(WFROMDS DISPLAYSTREAM DONTCREATE) III: 27.25
(WFROMMENU MENU) III: 28.42
WHEN FORM (I.S. Operator) I: 9.15
WHENCHANGED (File Package Type Property) II: 17.31
(WHENCLOSE FILE PROP_1 VAL_1 ... PROP_N VAL_N) III: 24.20
(WHENCOPIEDFN IMAGEOBJ TARGETWINDOWSTREAM SOURCEHOSTSTREAM TARGETHOSTSTREAM) (IMAGEFNS Method) III: 27.39

(WHENDELETEDFN IMAGEOBJ TARGETWINDOWSTREAM) (IMAGEFNS Method) III: 27.39
WHENFILED (File Package Type Property) II: 17.32
WHENHELDFN (Menu Field) III: 28.40

(WHENINSERTEDFN IMAGEOBJ TARGETWINDOWSTREAM SOURCEHOSTSTREAM TARGETHOSTSTREAM) (IMAGEFNS Method) III: 27.39

(WHENMOVEDFN IMAGEOBJ TARGETWINDOWSTREAM SOURCEHOSTSTREAM TARGETHOSTSTREAM) (IMAGEFNS Method) III: 27.38

(WHENOPERATEDONFN IMAGEOBJ WINDOWSTREAM HOWOPERATEDON SELECTION HOSTSTREAM) (IMAGEFNS Method) III: 27.39

WHENSELECTEDFN (Menu Field) III: 28.40
WHENUNFILED (File Package Type Property) II: 17.32
WHENUNHELDFN (Menu Field) III: 28.40
WHERE (I.S. Operator) I: 9.22
WHEREATTACHED (Window Property) III: 28.54
WHEREIS NAME TYPE FILES FN) II: 17.14
(WICHW X Y) III: 28.32
WHILE FORM (I.S. Operator) I: 9.16
WHILE (use with REDO) II: 13.8
WHITESHADE (Variable) III: 27.7
&WHOLE (DEFINE macro keyword) I: 10.27
WHOLEDISPLAY (Variable) III: 30.22; 27.2
(WIDEPAPER FLG) III: 26.48
WIDTH (Window Property) III: 28.34
(WIDTHIFWINDOW INTERIORWIDTH BORDER) III: 28.32

WINDOW (Process Property) II: 23.3
Window command menu III: 28.3
Window has no REPAINT FN. Can't redisplay. (printed in prompt window) III: 28.16
Window menu III: 28.3
Window properties III: 28.13
Window system III: 28.2; 28.1

(WINDOWADDPROP WINDOW PROP ITEMTOADD FIRSTFLG) III: 28.13

WINDOWBACKGROUNDSHADE (Variable) III: 30.23

(WINDOWDELPROP WINDOW PROP ITEMTODELETE) III: 28.13
Your virtual memory backing file is almost full.
(Error Message) I: 12.11

YSIZE (IMAGEBOX Field) I: 27.37

Z
(ZERO X₁ ... Xₙ) I: 10.18
(ZEROP X) I: 7.4

[ ] inserted by PRETTYPRINT I: 26.47

\ LITATOM (Editor Command) I: 16.28
\ (Editor Command) I: 16.28; 16.33
\ (in event address) I: 13.6
\ functions I: 10.10
\ADD.PACKET.FILTER FILTER III: 31.40
\ALLOCATE.ETHERPACKET III: 31.39
\BeginDST (Variable) I: 12.16
\CHECKSUM BASE NWORDS INITSUM III: 31.40
\DELETE.PACKET.FILTER FILTER III: 31.40
\DEQUEUE Q III: 31.41
\EndDST (Variable) I: 12.16
\ENQUEUE Q ITEM III: 31.41
\ETHERTIMEOUT (Variable) III: 31.38; 31.30
\FILEOUTCHARFN (Function) I: 27.48
\FTPAVAILABLE (Variable) III: 24.36
\LASTVMEMFILEPAGE (Variable) I: 12.11
\LOCALNDBS (Variable) III: 31.39
\ONQUEUE ITEM Q III: 31.41
\P (Editor Command) I: 16.28; 16.49
\QUEUELENGTH Q III: 31.41
\RELEASE.ETHERPACKET EPK T III: 31.39
\TimeZoneComp (Variable) I: 12.16
\UNQUEUE Q ITEM NOERRORFLG III: 31.41

]]

] (use in input) I: 13.36

↑
↑ (Break Command) I: 14.6; 14.17
↑ (Break Window Command) I: 14.3
↑ (CLISP Operator) I: 21.7
↑ (Editor Command) I: 16.16
↑ (use in comments) III: 26.46

←
← (CLISP Operator) I: 21.9
INDEX

(← PATTERN) (Editor Command) II: 16.25
← (Editor Command) II: 16.25; 16.27
← (in event address) II: 13.6
← (in pattern matching) I: 12.28
← (in record declarations) I: 8.14
← (Printed by System) II: 14.2
←← (Editor Command) II: 16.28

' (backquote) (Read Macro) III: 25.42

| (change character) II: 16.30; III: 26.49
| (Read Macro) I: 7.4; III: 25.43

- (CLISP Operator) II: 21.11
- (in pattern matching) I: 12.27

! (in Masterscope template) II: 19.20
! (in PA commands) II: 13.9
! (in pattern matching) I: 12.27-28
! (use with <,> in CLISP) II: 21.10
!! (use with <,> in CLISP) II: 21.10
! (Editor Command) II: 16.15
!E (Editor Command) II: 16.55; 13.43
!EVAL (Break Command) II: 14.6
!EVAL (Break Window Command) II: 14.3
!F (Editor Command) II: 16.55; 13.43
!GO (Break Command) II: 14.6
!IN (Editor Command) II: 16.55; 13.43
!NX (Editor Command) II: 16.16; 16.17
!OK (Break Command) II: 14.6
!Undo (DEdit Command) II: 16.8
!UNDO (Editor Command) II: 16.64
!VALUE (Variable) II: 14.5; 14.16; 15.9-10

" (string delimiter) I: 4.1; III: 25.3-4
"" (use in ASKUSER) III: 26.20
"<c.r.>" (in history commands) II: 13.32

#
#N (N a number) (in pattern matching) I: 12.29
# FORM (PRINTOUT command) III: 25.30
(## COM1 COM2 ... COMn) II: 16.59; 16.24
### (in INSERT, REPLACE, and CHANGE commands) II: 16.34

## (Printed by System) III: 30.10
#CAREFULCOLUMNS (Variable) III: 26.47
#RPARS (Variable) III: 26.47
#SPELLINGS1 (Variable) II: 20.18
#SPELLINGS2 (Variable) II: 20.18
#SPELLINGS3 (Variable) II: 20.18
#UNDOHIVES (Variable) II: 13.41; 13.30
#USERWORDS (Variable) II: 20.18

$ $ FOR Y IN EventSpec (Prog. Asst. Command) II: 13.11
$ Y -> X IN EventSpec (Prog. Asst. Command) II: 13.11
$ Y TO X IN EventSpec (Prog. Asst. Command) II: 13.11
$ Y = X IN EventSpec (Prog. Asst. Command) II: 13.11
$ Y IN EventSpec (Prog. Asst. Command) II: 13.11
$ (dollar) (in pattern matching) I: 12.27
$ (escape) (CLISP) II: 21.10-11
$ (escape) (in Edit Pattern) II: 16.18
$ (escape) (in Editor) II: 16.45-46
$ (escape) (in spelling correction) II: 20.15; 20.22
$ (escape) (Prog. Asst. Command) II: 13.11
$ (escape) (use in ASKUSER) III: 26.19
$$ (escape, escape) (use in ASKUSER) III: 26.20
$$ (escape, escape) (use in ASKUSER) III: 26.19
$$EXTREME (Variable) I: 9.12
$$VAL (Variable) I: 9.12; 9.19
$1 (in pattern matching) I: 12.26
$GO (escape-GO) (TYPE-AHEAD command) II: 13.18
$Q (escape-Q) (TYPE-AHEAD command) II: 13.18
$STOP (escape-STOP) (TYPE-AHEAD command) II: 13.18

% % I: 2.1; 4.1; III: 25.3; 25.4; 38; 30.11
% (use in comments) III: 26.46
%% (use in comments) III: 26.46

& & (in Edit Pattern) II: 16.18
& (in MBD command) II: 16.36-37
& (in pattern matching) I: 12.26
& (Printed by System) III: 25.12
& (use in ASKUSER) III: 26.19

INDEX.44
&ALLOW-OTHER-KEYS (DEFMACRO keyword) II: 10.26
&AUX (DEFMACRO keyword) II: 10.26
&BODY (DEFMACRO keyword) II: 10.25
&KEY (DEFMACRO keyword) II: 10.25
&OPTIONAL (DEFMACRO keyword) II: 10.25
&REST (DEFMACRO keyword) II: 10.25
&Undo (DEDit Command) II: 16.8
&WHOLE (DEFMACRO keyword) II: 10.27

( (in DEdit Command) II: 16.7
  (out DEdit Command) II: 16.8
  () I: 3.3
  () (DEDit Command) II: 16.7
  () out (DEDit Command) II: 16.7
)

) in (DEDit Command) II: 16.7
) out (DEDit Command) II: 16.8

* (CLISP Operator) II: 21.11
* (in DWIM) II: 20.8
* (in pattern matching) I: 12.26
*LIST (Masterscope Set Specification) II: 19.11
*ATOM (Masterscope Set Specification) II: 19.10
* (Read macro) I: 10.12; III: 25.42

**DEALLOC** (data type name) II: 8.21; II: 22.4
**EDITOR** (in backtrace) II: 14.9
**TOP** (in backtrace) II: 14.9
*ANY* (in edit pattern) II: 16.18
*ARCHIVE* (History list property) II: 13.33; 13.16
*ARGN* (Stack blip) I: 11.15
*ARGVAL* (stack blip) I: 11.16
*CONTEXT* (history list property) II: 13.33
*ERROR* (history list property) II: 13.33
*FN* (stack blip) I: 11.16
*FORM* (stack blip) I: 11.16
*GROUP* (history list property) II: 13.33
*HISTORY* (history list property) II: 13.33
*LISPXPRINT* (history list property) II: 13.33
*PRINT* (history list property) II: 13.33
*TAIL* (stack blip) I: 11.16

+ (CLISP Operator) II: 21.7

, (PRINTOUT command) III: 25.26
" (PRINTOUT command) III: 25.26
... (PRINTOUT command) III: 25.26

- (CLISP Operator) II: 21.7
-- (in Edit Pattern) II: 16.19
-- (in pattern matching) I: 12.27
-- (Printed by System) III: 25.12
-> EXP (Break Command) II: 14.11
-> (in pattern matching) I: 12.30
-> (printed by DWIM) II: 20.4; 20.2-3.6
-> (printed by editor) II: 16.46

. (CLISP Operator) II: 21.9
. (in a floating point number) I: 7.11
. (in a list) I: 3.3
. (in Masterscope) II: 19.2
. (in pattern matching) I: 12.28
. (printed by Masterscope) II: 19.2
PATTERN .. @ (Editor Command) II: 16.27

... (in Edit Pattern) II: 16.19
... TEMPLATE (in Masterscope template) II: 19.20
... (in Edit Pattern) II: 16.19-20
... (printed by DWIM) II: 20.3,5
... (Printed by Editor) II: 16.14
... (printed during input) II: 13.37; 13.5
... VARS (Prog. Asst. Command) II: 13.10; 13.33
...ARGS (history list property) II: 13.33
.BASE (PRINTOUT command) III: 25.27
.CENTER POS EXPR (PRINTOUT command) III: 25.29
.CENTER2 POS EXPR (PRINTOUT command) III:
  25.29
.FFORMAT NUMBER (PRINTOUT command) III:
  25.30
.FONT FONTSPEC (PRINTOUT command) III: 25.27
.FR POS EXPR (PRINTOUT command) III: 25.29
.FR2 POS EXPR (PRINTOUT command) III: 25.29
.IFORMAT NUMBER (PRINTOUT command) III:
  25.30
.IN FORMAT NUMBER (PRINTOUT command) III:
  25.30
.P2 THING (PRINTOUT command) III: 25.28
.PAGE (PRINTOUT command) III: 25.26
.PARA LMARG RMARG LIST (PRINTOUT command)
  III: 25.28
.PARA2 LMARG RMARG LIST (PRINTOUT command)
  III: 25.28
.PPF THING (PRINTOUT command) III: 25.28
.PPFCTL THING (PRINTOUT command) III: 25.28
.PPV THING (PRINTOUT command) III: 25.28
.PPVCTL THING (PRINTOUT command) III: 25.28
.SKIP LINES (PRINTOUT command) III: 25.26
.SP DISTANCE (PRINTOUT command) III: 25.26
.SUB (PRINTOUT command) III: 25.27
.SUP (PRINTOUT command) III: 25.27
.TAB POS (PRINTOUT command) III: 25.25
.TAB0 POS (PRINTOUT command) III: 25.26

/ (CLISP Operator) II: 21.7
/ (use with @break command) II: 14.7
/ functions II: 13.26; 13.27,41
/FNS (Variable) II: 13.26
/MAPCON (Function) II: 21.13
/MAPCONC (Function) II: 21.13
/NCONC (Function) II: 21.13
/NCONC1 (Function) II: 21.13
/REPLACE (Record Operator) I: 8.3
/RPLACA (Function) II: 21.13
/RPLACD (Function) II: 21.13
/RPLNODE (Function) II: 13.40
/RPLNODE2 (Function) II: 13.40

0
0 (Editor Command) II: 16.15

0 (instead of right parenthesis) II: 20.5; 20.1,8,10

1
10MACRO (Property Name) I: 10.21

2
(2ND . @) (Editor Command) II: 16.24

3
32MBADDRESSABLE (Function) II: 22.5
(3ND . @) (Editor Command) II: 16.25

7
7 (instead of ') II: 20.9

8
8 (instead of left parenthesis) II: 16.67
8044 (Printer type) III: 29.5

9
9 (instead of left parenthesis) II: 20.5; 20.1,8,10-11

; (CLISP Operator) II: 21.9
(: E1 . . EM) (Editor Command) II: 16.32
(;) (Editor Command) II: 16.32
:: (Printed by System) II: 14.1
::: (CLISP Operator) II: 21.9

; FORM (Prog. Asst. Command) II: 13.18

<
< (CLISP Operator) II: 21.10
<,> (use in CLISP) II: 21.10

= FORM (Break Command) II: 14.10
= (CLISP Operator) II: 21.8
= (in event address) II: 13.6
= (in pattern matching) I: 12.26
= (printed by DWIM) II: 20.5
= (use with @break command) II: 14.7
= (in Edit Pattern) II: 16.19
= (in pattern matching) I: 12.26
> (in pattern matching) I: 12.30
E (Printed by Editor) II: 16.67

> (CLISP Operator) II: 21.10
? (Editor Command) II: 16.48
? (Litatom) I: 3.11
? (printed by DWIM) II: 20.4-5
? (printed by Masterscope) II: 19.18
? (Read Macro) II: 14.8; III: 25.43
? (Break Command) II: 14.7
? (Break Window Command) II: 14.3
? (Editor Command) II: 16.48
? = (in TTYIN) III: 26.33
?? EventSpec (Prog. Asst. Command) II: '13.13;
   13.33
?ACTIVATEFLG (Variable) III: 26.36; 26.23
?Undo (DEdit Command) II: 16.8

@ (Break Command) II: 14.6; 14.12
@ (in event specification) II: 13.39
(@ EXPRFORM TEMPLATEFORM) (in Masterscope template) II: 19.21
@ (in pattern matching) I: 12.26,28
@ (location specification in editor) II: 16.24
@ PREDICATE (Masterscope Set Specification) II:
   19.11
@ (use with @ break command) II: 14.7
@@ (in event specification) II: 13.8; 13.16,39
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