1993

Structure editors and attribute grammar programming.

Farook A. Wadia

University of Windsor

Follow this and additional works at: https://scholar.uwindsor.ca/etd

Recommended Citation


This online database contains the full-text of PhD dissertations and Masters' theses of University of Windsor students from 1954 forward. These documents are made available for personal study and research purposes only, in accordance with the Canadian Copyright Act and the Creative Commons license—CC BY-NC-ND (Attribution, Non-Commercial, No Derivative Works). Under this license, works must always be attributed to the copyright holder (original author), cannot be used for any commercial purposes, and may not be altered. Any other use would require the permission of the copyright holder. Students may inquire about withdrawing their dissertation and/or thesis from this database. For additional inquiries, please contact the repository administrator via email (scholarship@uwindsor.ca) or by telephone at 519-253-3000ext. 3208.
NOTICE

The quality of this microform is heavily dependent upon the quality of the original thesis submitted for microfilming. Every effort has been made to ensure the highest quality of reproduction possible.

If pages are missing, contact the university which granted the degree.

Some pages may have indistinct print especially if the original pages were typed with a poor typewriter ribbon or if the university sent us an inferior photocopy.

Reproduction in full or in part of this microform is governed by the Canadian Copyright Act, R.S.C. 1970, c. C-30, and subsequent amendments.

Canada
Structure Editors and Attribute Grammar Programming

by

Wadia Farook A.

A Thesis
Submitted to the Faculty of Graduate Studies and Research through the School of Computer Science in Partial Fulfillment of the Requirements for the Degree of Master of Science at the University of Windsor
Windsor, Ontario, Canada
1993
The author has granted an irrevocable non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of his/her thesis by any means and in any form or format, making this thesis available to interested persons.

The author retains ownership of the copyright in his/her thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without his/her permission.

L'auteur a accordé une licence irrévocable et non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de sa thèse de quelque manière et sous quelque forme que ce soit pour mettre des exemplaires de cette thèse à la disposition des personnes intéressées.

L'auteur conserve la propriété du droit d'auteur qui protège sa thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

ISBN 0-315-87381-7
### The Humanities and Social Sciences

<table>
<thead>
<tr>
<th>Subject Category</th>
<th>Subject Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communications and the Arts</td>
<td>0529</td>
</tr>
<tr>
<td>Art History</td>
<td>0517</td>
</tr>
<tr>
<td>Drama</td>
<td>0518</td>
</tr>
<tr>
<td>Fine Arts</td>
<td>0515</td>
</tr>
<tr>
<td>Information Science</td>
<td>0523</td>
</tr>
<tr>
<td>Library Science</td>
<td>0524</td>
</tr>
<tr>
<td>Mass Communications</td>
<td>0522</td>
</tr>
<tr>
<td>Music</td>
<td>0527</td>
</tr>
<tr>
<td>Speech Communication</td>
<td>0528</td>
</tr>
<tr>
<td>Theater</td>
<td>0529</td>
</tr>
</tbody>
</table>

### Education

<table>
<thead>
<tr>
<th>Subject Category</th>
<th>Subject Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td>0515</td>
</tr>
<tr>
<td>Administration</td>
<td>0514</td>
</tr>
<tr>
<td>Adult and Continuing Education</td>
<td>0516</td>
</tr>
<tr>
<td>Agricultural Education</td>
<td>0517</td>
</tr>
<tr>
<td>Art Education</td>
<td>0520</td>
</tr>
<tr>
<td>Bilingual and Multicultural Education</td>
<td>0519</td>
</tr>
<tr>
<td>Business Education</td>
<td>0580</td>
</tr>
<tr>
<td>Community College Education</td>
<td>0525</td>
</tr>
<tr>
<td>Curriculum and Instruction</td>
<td>0526</td>
</tr>
<tr>
<td>Early Childhood Education</td>
<td>0527</td>
</tr>
<tr>
<td>Elementary Education</td>
<td>0528</td>
</tr>
<tr>
<td>Finance</td>
<td>0529</td>
</tr>
<tr>
<td>Guidance and Counseling</td>
<td>0519</td>
</tr>
<tr>
<td>Health Education</td>
<td>0540</td>
</tr>
<tr>
<td>Higher Education</td>
<td>0541</td>
</tr>
<tr>
<td>History of Education</td>
<td>0542</td>
</tr>
<tr>
<td>Home Economics Education</td>
<td>0526</td>
</tr>
<tr>
<td>Industrial Education</td>
<td>0521</td>
</tr>
<tr>
<td>Language and Literature Education</td>
<td>0529</td>
</tr>
<tr>
<td>Mathematics Education</td>
<td>0520</td>
</tr>
<tr>
<td>Music Education</td>
<td>0522</td>
</tr>
<tr>
<td>Philosophy of Education</td>
<td>0548</td>
</tr>
<tr>
<td>Physical Education</td>
<td>0523</td>
</tr>
</tbody>
</table>

### Language, Literature, and Linguistics

<table>
<thead>
<tr>
<th>Subject Category</th>
<th>Subject Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Language General</td>
<td>0679</td>
</tr>
<tr>
<td>General</td>
<td>0679</td>
</tr>
<tr>
<td>Ancient</td>
<td>0289</td>
</tr>
<tr>
<td>Linguistics</td>
<td>0590</td>
</tr>
<tr>
<td>Modern</td>
<td>0290</td>
</tr>
<tr>
<td>Literature</td>
<td>0291</td>
</tr>
<tr>
<td>General</td>
<td>0292</td>
</tr>
<tr>
<td>Comparative</td>
<td>0293</td>
</tr>
<tr>
<td>Medieval</td>
<td>0294</td>
</tr>
<tr>
<td>Modern</td>
<td>0295</td>
</tr>
<tr>
<td>African</td>
<td>0316</td>
</tr>
<tr>
<td>American</td>
<td>0317</td>
</tr>
<tr>
<td>Asian</td>
<td>0318</td>
</tr>
<tr>
<td>Canadian (English)</td>
<td>0319</td>
</tr>
<tr>
<td>Canadian (French)</td>
<td>0320</td>
</tr>
<tr>
<td>Chinese</td>
<td>0321</td>
</tr>
<tr>
<td>Germanic</td>
<td>0322</td>
</tr>
<tr>
<td>Latin American</td>
<td>0312</td>
</tr>
<tr>
<td>Middle Eastern</td>
<td>0313</td>
</tr>
<tr>
<td>Romance</td>
<td>0314</td>
</tr>
<tr>
<td>Slavic and East European</td>
<td>0315</td>
</tr>
</tbody>
</table>

### Philosophy, Religion and Theology

<table>
<thead>
<tr>
<th>Subject Category</th>
<th>Subject Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Philosophy General</td>
<td>0422</td>
</tr>
<tr>
<td>Theological Studies</td>
<td>0423</td>
</tr>
<tr>
<td>Clergy</td>
<td>0321</td>
</tr>
<tr>
<td>History of Philosophy</td>
<td>0322</td>
</tr>
<tr>
<td>Theology</td>
<td>0469</td>
</tr>
</tbody>
</table>

### Social Sciences

<table>
<thead>
<tr>
<th>Subject Category</th>
<th>Subject Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anthropology General</td>
<td>0323</td>
</tr>
<tr>
<td>Archaeology</td>
<td>0324</td>
</tr>
<tr>
<td>Cultural</td>
<td>0325</td>
</tr>
<tr>
<td>Physical</td>
<td>0326</td>
</tr>
<tr>
<td>Business Administration General</td>
<td>0327</td>
</tr>
<tr>
<td>Accounting</td>
<td>0328</td>
</tr>
<tr>
<td>Banking</td>
<td>0329</td>
</tr>
<tr>
<td>Management</td>
<td>0330</td>
</tr>
<tr>
<td>Marketing</td>
<td>0331</td>
</tr>
<tr>
<td>Canadian Studies</td>
<td>0332</td>
</tr>
<tr>
<td>Economics General</td>
<td>0333</td>
</tr>
<tr>
<td>Agricultural Economics</td>
<td>0351</td>
</tr>
<tr>
<td>Commerce</td>
<td>0334</td>
</tr>
<tr>
<td>Economics</td>
<td>0335</td>
</tr>
<tr>
<td>Finance</td>
<td>0336</td>
</tr>
<tr>
<td>History</td>
<td>0337</td>
</tr>
<tr>
<td>Human Development</td>
<td>0338</td>
</tr>
<tr>
<td>International Relations</td>
<td>0339</td>
</tr>
<tr>
<td>Population</td>
<td>0340</td>
</tr>
<tr>
<td>Social</td>
<td>0341</td>
</tr>
<tr>
<td>Social Structure and Development</td>
<td>0342</td>
</tr>
<tr>
<td>Urban</td>
<td>0343</td>
</tr>
<tr>
<td>Women's Studies</td>
<td>0453</td>
</tr>
</tbody>
</table>

### The Sciences and Engineering

### Biological Sciences

<table>
<thead>
<tr>
<th>Subject Category</th>
<th>Subject Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture General</td>
<td>0423</td>
</tr>
<tr>
<td>Agronomy</td>
<td>0285</td>
</tr>
<tr>
<td>Animal Culture and Nutrition</td>
<td>0475</td>
</tr>
<tr>
<td>Animal Pathology</td>
<td>0476</td>
</tr>
<tr>
<td>Forestry and Wildlife</td>
<td>0478</td>
</tr>
<tr>
<td>Plant Pathology</td>
<td>0480</td>
</tr>
<tr>
<td>Plant Physiology</td>
<td>0477</td>
</tr>
<tr>
<td>Wood Technology</td>
<td>0746</td>
</tr>
<tr>
<td>Biology General</td>
<td>0306</td>
</tr>
<tr>
<td>Anatomy</td>
<td>0287</td>
</tr>
<tr>
<td>Biostatistics</td>
<td>0308</td>
</tr>
<tr>
<td>Botany</td>
<td>0309</td>
</tr>
<tr>
<td>Cell</td>
<td>0319</td>
</tr>
<tr>
<td>Ecology</td>
<td>0320</td>
</tr>
<tr>
<td>Entomology</td>
<td>0333</td>
</tr>
<tr>
<td>Genetics</td>
<td>0339</td>
</tr>
<tr>
<td>Limnology</td>
<td>0993</td>
</tr>
<tr>
<td>Microbiology</td>
<td>0610</td>
</tr>
<tr>
<td>Molecular Biology</td>
<td>0859</td>
</tr>
<tr>
<td>Neurochemistry</td>
<td>0817</td>
</tr>
<tr>
<td>Oceanography</td>
<td>0416</td>
</tr>
<tr>
<td>Physiology</td>
<td>0433</td>
</tr>
<tr>
<td>Radiobiology</td>
<td>0621</td>
</tr>
<tr>
<td>Zoology</td>
<td>0472</td>
</tr>
<tr>
<td>Biophysics General</td>
<td>0786</td>
</tr>
<tr>
<td>Medical Biophysics</td>
<td>0786</td>
</tr>
</tbody>
</table>

### Earth Sciences

<table>
<thead>
<tr>
<th>Subject Category</th>
<th>Subject Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biogeography</td>
<td>0425</td>
</tr>
<tr>
<td>Geochronology</td>
<td>0996</td>
</tr>
</tbody>
</table>
ABSTRACT

Attribute grammars provide a formal and yet intuitive way of specifying the static semantics of programming languages, but their use is not limited to compiler generation systems. Attribute grammars have been successfully used to provide solutions to problems from areas such as natural language processing, SQL processors, and circuit design transformers within a VLSI package [25]. One of the major advantage of using attribute grammar as a programming paradigm is the modular and declarative structure that results. Also, programs written as executable specification of attribute grammars are easy to debug because they mirror the structure of the input data.

W/AGE is an attribute grammar programming environment. It supports the attribute grammar programming paradigm where programs are constructed as executable specifications of attribute grammars. It consists of several functions that extend the standard environment of the pure lazy functional programming language Miranda.

Programs written in W/AGE have to obey many syntax and layout rules; also, in general, as the size of the program and the number of attributes used increases it may be difficult to keep track of the synthesized and inherited attributes used in the program. Compiling a W/AGE program containing syntax errors and missing attribute definitions can lead to errors which are at times very difficult to debug.
and at times can be very much frustrating.

The purpose of this thesis is to build a structure editor for W/AGE and evaluate its usefulness in developing attribute grammar specifications.
This work is dedicated to my parents, aunt Suraiya and Waheeda, without their inspiration and support I would not have been what I am today.
Acknowledgments

I owe the successful completion of my thesis work to many people who in some way or the other have helped me reach my goal.

First of all, I am indebted to my parents who have always prayed for my continued success and well-being.

I cannot miss this opportunity to express my sincere gratitude and thanks to Dr. Richard Frost, my supervisor. Working with him was a wonderful experience, his support and guidance made my stay in Canada very comfortable.

Dr. Subir Bandyopadhyay, my co-supervisor, I guess if it would not have been for him I would have left back for India the very next day I landed in Canada. His critical comments and advice regarding my thesis work and otherwise, have proven to be very useful and helped me make important decisions.

I extend my gratitude to Dr Gold, my external examiner, for being on my committee and providing valuable comments.

And last but not the least, I would like to thank all my peers in the graduate lab, Steve Karamatos, Walid Nyamneh, our wonderful secretaries Mary and Margaret and Dr. Morrissey for all your help. Thanks for being there.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td></td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>vii</td>
</tr>
<tr>
<td>1 INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>1.1 Motivation for the Thesis</td>
<td>1</td>
</tr>
<tr>
<td>1.2 Thesis Statement</td>
<td>3</td>
</tr>
<tr>
<td>1.3 Why is the thesis important?</td>
<td>4</td>
</tr>
<tr>
<td>1.4 Work Done</td>
<td>5</td>
</tr>
<tr>
<td>2 STRUCTURE EDITORS</td>
<td>6</td>
</tr>
<tr>
<td>2.1 What is a Structure Editor?</td>
<td>6</td>
</tr>
<tr>
<td>2.2 Benefits of Structure Editing</td>
<td>7</td>
</tr>
<tr>
<td>2.3 Survey on Structure Editors</td>
<td>8</td>
</tr>
<tr>
<td>2.4 The Cornell Synthesizer Generator</td>
<td>9</td>
</tr>
<tr>
<td>3 ATTRIBUTE GRAMMAR PROGRAMMING</td>
<td>11</td>
</tr>
<tr>
<td>3.1 What is an attribute grammar?</td>
<td>11</td>
</tr>
<tr>
<td>3.2 Attribute Grammar Programming</td>
<td>12</td>
</tr>
<tr>
<td>4 W/AGE — Windsor Attribute Grammar Environment</td>
<td>16</td>
</tr>
<tr>
<td>4.1 Structure of a W/AGE Program</td>
<td>16</td>
</tr>
<tr>
<td>4.2 Components of W/AGE</td>
<td>18</td>
</tr>
<tr>
<td>4.3 Support for Left-Recursive Interpreter Definitions in W/AGE</td>
<td>18</td>
</tr>
<tr>
<td>4.4 An example of attribute grammar specification in W/AGE</td>
<td>19</td>
</tr>
<tr>
<td>5 WAGE-ed — A STRUCTURE EDITOR FOR W/AGE</td>
<td>22</td>
</tr>
<tr>
<td>5.1 Introduction to WAGE-ed</td>
<td>22</td>
</tr>
<tr>
<td>5.2 Features of WAGE-ed</td>
<td>27</td>
</tr>
<tr>
<td>5.3 Versions of WAGE-ed</td>
<td>28</td>
</tr>
<tr>
<td>5.4 Limitations of WAGE-ed</td>
<td>29</td>
</tr>
<tr>
<td>5.5 Support for Left-Recursive Interpreter Definitions in WAGE-ed</td>
<td>33</td>
</tr>
<tr>
<td>5.6 Implementation of WAGE-ed</td>
<td>33</td>
</tr>
<tr>
<td>6 Conclusion</td>
<td>39</td>
</tr>
<tr>
<td>6.1 Assessing the value of WAGE-ed</td>
<td>39</td>
</tr>
<tr>
<td>6.2 Prospects for Future Work</td>
<td>44</td>
</tr>
<tr>
<td>BIBLIOGRAPHY</td>
<td>48</td>
</tr>
<tr>
<td>APPENDIX 1 An Example Session with a Structure Editor</td>
<td>53</td>
</tr>
<tr>
<td>APPENDIX 2 An Example Session with WAGE-ed</td>
<td>71</td>
</tr>
<tr>
<td>APPENDIX 3 W/AGE Manual</td>
<td>96</td>
</tr>
<tr>
<td>3.1 Notations Used</td>
<td>96</td>
</tr>
<tr>
<td>3.2 Components of W/AGE</td>
<td>96</td>
</tr>
<tr>
<td>3.2.1 Type of Interpreters</td>
<td>97</td>
</tr>
<tr>
<td>3.2.2 Type of Terminals</td>
<td>98</td>
</tr>
</tbody>
</table>
§ 1.1 Motivation for the Thesis

Attribute grammars provide a formal and yet intuitive way of specifying the static semantics of programming languages and as such have been used extensively in applications such as compiler generators, language-based editor generating tools and so on. Attribute grammars have been successfully used to provide solutions to problems from areas such as natural language processing, database query processors, and circuit design transformers [24]. One of the major advantages of using attribute grammars as a programming paradigm is the modular and declarative structure that results. Also, programs written as executable specification of attribute grammars are easy to reason about because they mirror the structure of the input data.

Many systems supporting the attribute grammar programming paradigm have been built [25]. In most of these systems, non-executable specifications of attribute grammars are compiled into code in some conventional host programming language. The pre-processing and translation of code into the host programming language results in increased indirection in the programming environment which may be tolerated less in problem domains where the use, and the advantages, of the attribute grammar formalism are not so obvious [23]. Extending the environment of conventional programming languages to support attribute grammar
Structure Editors and Attribute Grammar Programming

constructs is a non-trivial task. Also, since most of the conventional programming languages use strict (non-lazy) evaluation strategy, a good deal of unnecessary computation of attributes is required. Also, in order to support fully general attribute dependencies either substantial transformation or multi-pass evaluation is required.

W/AGE [25] is an attribute grammar programming environment. It supports the attribute grammar programming paradigm allowing programs to be constructed as executable specifications of attribute grammars. It consists of several functions that extend the standard environment of the pure, lazy functional programming language Miranda™. The problems which are encountered in supporting the attribute grammar paradigm in a conventional programming language do not arise in lazy functional programming language. Attribute grammar constructs can be easily added by using higher-order functions [23] and also because of lazy evaluation no unnecessary computation of an attribute value is required until it is deemed necessary. In addition, neither transformation nor multiple evaluations are required to support general attribute dependencies.

The resulting combination of attribute grammar and functional programming paradigm facilitates software development in several ways:

- Reasoning about programs for the purpose of verification, complexity analysis, transformations, etc., becomes easy, because the programs are extremely
declarative, modular and variable free.

- The combined paradigm lends itself well to the technique of deriving program from proofs.

- Programs are easy to debug, modify and maintain, because the structure of the program closely resembles the structure of the input data.

But the advantages derived from the combined paradigm are sometimes offset by the fact that programs written in W/AGE have to obey complex syntax and layout rules. Also, in general, as the size of the program and the number of attributes used increases, it may be difficult to keep track of the synthesized and inherited attribute definitions in the program. Compiling a W/AGE program containing syntax errors and missing attribute definitions can lead to errors which can be extremely difficult to debug and could intimidate a novice programmer.

A software tool, such as a structure editor, for W/AGE can alleviate the problem of syntax errors and missing attribute definitions by checking for them as the program is being developed. As a result, after compiling the program, the programmer can spend less time debugging syntax errors and missing attribute definitions, and can concentrate more on the design and development of the program.

§ 1.2 Thesis Statement

The purpose of the thesis work is to support my argument in the previous
section that a structure editor for W/AGE would be a useful software tool to
develop executable specification of attribute grammars and to show that structure
editors are relatively easy to build and to use.

Therefore, I propose the following thesis:

<table>
<thead>
<tr>
<th>It is possible, within the time constraints of Master’s thesis work, to build a structure editor for W/AGE which:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• detects all syntax errors, errors in the use of attributes, facilitates in the development of executable specification of attribute grammars, and</td>
</tr>
<tr>
<td>• can be mastered by programmers, with only one or two years of programming experience in less than a week.</td>
</tr>
</tbody>
</table>

§ 1.3 Why is the thesis important?

There is a growing interest amongst software developers in interactive pro-
gram development tools which would facilitate the development and management of software. Structure editors for different phases of a software development cycle have been built and are a part of some commercially available software development environments. However, there is very little specific information available that indicates the difficulty of building and using structure editors. The establishment of the thesis will provide such information and will be of value to organizations who are considering the use of structure editors in their operations.
§ 1.4 Work Done

In order to support and test the thesis, the following work was carried out:

- A survey of structure editors was carried out. The survey covered amongst other things, structure editors and structure editor generators that were built for research and pedagogical purpose, and together with ones that are commercially available.

- A pure, lazy functional programming language Miranda; the attribute grammar programming paradigm; and W/AGE — an attribute grammar programming environment (built by extending the standard environment of Miranda™) were studied.

- A structure editor generating tool, the Cornell Synthesizer Generator, was studied.

- A structure editor, WAGE-ed, for W/AGE was built using the Cornell Synthesizer Generator.

- Users of WAGE-ed were surveyed and the results analysed.
Chapter 2 STRUCTURE EDITORS

§ 2.1 What is a Structure Editor?

The need to manage the development of large software systems is one of the most pressing problems faced by computer programmers. An important aspect of this problem is the design of new tools to aid interactive program development.

Recently, research on structure editing has developed promising ways to enhance the power of tools used by programmers.

Structure editors are specialized editors which have the knowledge of the syntax and semantics of the underlying language. Meyrowitz and van Dam [15] define structure editing as manipulation of general structures such as trees and graphs instead of raw text. They further define syntax-directed editing or language-based editing as a subset of structure editing where the general structures represent particular syntactic structures of the language being edited.

A language-based editor makes use of the context-free syntax of the programming language to ensure that the program being developed is syntactically correct and well-formed at all times. It reinforces the view that a program is a hierarchical composition of computational structures. Programs are composed of templates, which provide predefined, formatted patterns for each of the language constructs. Programs are created top-down by inserting new templates at placeholders in the
skeleton of previously entered templates. A program being developed using a language-based editor is represented by its derivation tree. On the other hand, a text-oriented editor has no knowledge about the syntax and semantics of the underlying language they edit.

Language-based editors naturally support interaction. Data development and incremental computation can be performed at edit time. Text editors support only data development, whereas language-based editors support both data development and program execution and can therefore be considered as complete interactive programs rather than just an editors.

Also, a language-based editor alleviates some of the conceptual misunderstandings that occur between the user and the system. Using a text editor the programmer may write some program text with one meaning in mind, whereas the system may interpret it differently. The dangling else problem is a good example. If language-based editors are used to develop programs, fewer misunderstandings occur.

§ 2.2 Benefits of Structure Editing

Apart from its main purpose of facilitating interactive program development, there are other benefits which derive from structural editing. A structure editor,

• Ensures that the program is structurally well-formed at all times,
Structure Editors and Attribute Grammar Programming

- Prohibits the user from making inappropriate insertions by restricting the choices offered to the insertions that are legal in the context of the current selection,

- Guarantees the syntactic integrity of the program at every step by enforcing the removal and insertion of entire, well-formed, program fragments,

- Provides a mechanism for making controlled changes in a single step through transformation operations,

  - Allows a program to be displayed according to its hierarchical structure,
  - Performs automatic indentation of programs,
  - Prohibits typographical errors in structural units because the templates are predefined and immutable,

  - Allows programs to be developed at a higher-level of abstraction, because templates that correspond to abstract computational units are inserted and removed as units,

  - Can also allow text editing to be integrated, but at the same time preclude the creation of syntactically incorrect programs.

§ 2.3 Survey on Structure Editors

Work on structure editors was inspired by research work carried out in the 1970's on program analysis, transformations and translation facilities for a language-based editor for a programming language of the Algol family and also on
LISP environments which have long exploited the ability to manipulate programs as data objects.

The Mentor [16] project, which was initiated in 1974, created a collection of special-purpose tools for processing PASCAL abstract syntax trees using a general purpose tree-manipulation language. Around 1979, three systems, viz., Gandalf, Lispedit and the Cornell Program Synthesizer delved into ways of unifying language-based program editing with execution and debugging.

To date, a great deal of research work has been done in this field and a large collection of published work is available. The result of a survey work carried out in this field is described in [56], it lists and describes various (research and commercial) structure editors that have been built, their features, structure editor generating tools (research and commercial), structure editor generating technologies, etc.

§ 2.4 The Cornell Synthesizer Generator

The Cornell Synthesizer Generator [48] is a tool for creating language-based editors. Just as a parser generator may be used to create a parser from a grammar that specifies the language’s concrete syntax, the Cornell Synthesizer Generator can be used to create a language-based editor given a specification of the language’s abstract syntax, context-sensitive relationship, display format, concrete input syntax, and transformation rules for restructuring programs. From
Structure Editors and Attribute Grammar Programming

despite these specifications, the Synthesizer Generator creates a language-based editor for manipulating objects according to these rules.

The editor specifications are written in SSL (Synthesizer Specification Language), which is itself built around the concept of attribute grammars and a type definition facility.

The Synthesizer Generator is written in C and runs under Berkeley UNIX. It can generate editors for the X Window System, SunView and video display terminals.
Chapter 3 ATTRIBUTE GRAMMAR PROGRAMMING

§ 3.1 What is an attribute grammar?

Definition

An attribute grammar is a generalization of a context-free grammar.

Attribute grammars were first proposed by Knuth in 1968 as a notation for specifying the static semantics of programming languages. An attribute grammar is a syntax-directed definition where each grammar symbol\(^1\) (nonterminals) has an associated set of attributes. These attributes are partitioned into two disjoint sets: synthesized attributes and inherited attributes.

The value of an attribute associated with a grammar symbol at a parse-tree node is defined by semantic rules associated with the production used at that node. The value of a synthesized attribute at a node in the parse-tree is a function of the value of the attributes at that node and/or at the children of that node. The value of an inherited attribute at a node in the parse-tree is a function of the value of the attributes at the parent and/or the sibling nodes.

---

\(^1\) In an attribute grammar definition, terminals are assumed to have synthesized attributes only and the root nonterminal cannot have inherited attributes.
§ 3.2 Attribute Grammar Programming

In an attribute grammar definition, each production in the grammar of the form $A \rightarrow \beta$ has associated with it a set of semantic rules. Each semantic rule is of the form $a = f(a_1, a_2, \ldots, a_k)$ where $f$ is a function, and either

- $a$ is a synthesized attribute of $A$ and $a_1, a_2, \ldots, a_k$ are attributes associated with grammar symbols appearing on the right side of the production and/or $A$, or
- $a$ is an inherited attribute of one or more grammar symbols appearing on the right side of the production and $a_1, a_2, \ldots, a_k$ are attributes associated with $A$ or grammar symbols appearing on the right side of the production.

Example

Consider writing an attribute grammar specification which accepts two parameters, one a number (say $n$) and second a list of numbers (say $ls$). The problem is to identify how many occurrences of the number $n$ are present in the list $ls$. An attribute grammar specification involving synthesized and inherited attributes is shown on Figure 3.1.

It should be noted that this is not the only attribute grammar solution to this problem but has been chosen for explanatory purposes.
In Figure 3.1 above:

- The text in boldface is a context-free grammar which specifies the structure of the input string. The notation used is a variant of BNF, where terminal symbols appear in quotes,

- The symbol \(^\ast\) signifies that the attribute is synthesized. For example, \(\text{NUM_OCCUR} ^\ast \text{list_of_numbers}\) should be read as ‘the \(\text{NUM_OCCUR}\) attribute that is passed up/synthesized for the nonterminal \(\text{list_of_numbers}\)’,

- The symbol \(\land\) signifies that the attribute is inherited. For example, \(\text{NUM_VAL} \land \text{list_of_numbers}\) should be read as ‘the \(\text{NUM_VAL}\) attribute passed down/inherited to/by the nonterminal \(\text{list_of_numbers}\)’,

- The text which appear in italics are semantic rules. The semantic rules indicate how the value of a synthesized or inherited attribute is obtained. For example, in the semantic rule \("\text{NUM_OCCUR} ^\ast \text{lhs} = \text{init_num_occur}[\text{VAL} ^\ast \text{number, NUM_VAL} \land \text{lhs}]\)\), the attribute \(\text{NUM_OCCUR}\) passed up \(\text{lhs}\) (\text{list_of_numbers})
Structure Editors and Attribute Grammar Programming

is obtained by applying the function init_num_occur to the VAL attribute passed up number and the attribute NUM_VAL passed down to lhs.

The advantage of using attribute grammars as a programming paradigm is the modular structure that results [23]. Modular design is one of the most desired feature of a software system. It allows parts of a system to be easily extended and/or reused. For example, the attribute grammar specification in the Figure 3.1 could be easily extended to process a list of strings. The extended specification is shown in Figure 3.2.

```
input ::= number "::" "[" list_of_numbers "]"
    NUM_VAL v list_of_numbers = VAL " number
    NUM_OCCUR " lhs = NUM_OCCUR " list_of_numbers
| string "::" "[" list_of_strings "]"
    STR_VAL v list_of_strings = VAL " string
    NUM_OCCUR " lhs = NUM_OCCUR " list_of_strings

list_of_numbers ::= number "," list_of_numbers
    NUM_VAL v list_of_numbers = NUM_VAL v lhs
    NUM_OCCUR " lhs = add_num_occur[
        VAL " number,
        NUM_OCCUR " list_of_numbers,
        NUM_VAL v lhs]
| number
    NUM_OCCUR " lhs = init_num_occur[VAL " number,
        NUM_VAL v lhs]

list_of_strings ::= string "," list_of_strings
    STR_VAL v list_of_strings = STR_VAL v lhs
    NUM_OCCUR " lhs = add_str_num_occur[
        VAL " string,
        NUM_OCCUR " list_of_strings,
        STR_VAL v lhs]
| string
    NUM_OCCUR " lhs = init_str_num_occur[VAL " string,
        STR_VAL v lhs]
```

Figure 3.2
As shown by the above example, it is very easy to extend existing specifications. Another advantage inherent in this programming paradigm is that there is a clean separation between syntax and semantics, and the computation of attributes is well-structured. The programmer could first specify the overall structure of a passage without having to worry about the associated semantic actions. This leads to modular design of programs and which are easy to debug and test because they reflect the structure of the input data.
Chapter 4  W/AGE — Windsor Attribute Grammar Environment

W/AGE supports the attribute grammar programming paradigm by extending the environment of a pure, lazy functional programming language Miranda\textsuperscript{2} [25]. Attribute grammar specifications written in W/AGE are declarative, modular and variable free.

§ 4.1 Structure of a W/AGE Program

An attribute grammar specification written in W/AGE consists of various sections:

File inclusion section

This section specifies the files which are to be included when the W/AGE program is compiled. If the full pathname is included between angle brackets then the file is searched in the Miranda directory. If the pathname is specified between double quotes then the file should reside in the current working directory. The following file must be included, using \texttt{\%insert}, in all W/AGE programs:

\texttt{\%insert <local/header_for_WAGE_VERSION_2_RELEASE_0.m>}

\textsuperscript{2} Miranda is a trademark of Research Software Ltd.
Attribute definition section

This section is used to declare the name and type of attributes that are used in the program.

Special symbol declaration section

All single character symbols, other than alphabets and digits, that are used in the program must be declared within single quotes in this section.

Reserved word declaration section

All words that are to be treated as reserved words in the program, e.g. language keywords, must be defined within double quotes in this section.

Interpreter definition section

This section contains definition of interpreters (nonterminals) that are used in the program. An interpreter could be defined as one of the following types: literal, interpreted, uninterpreted, recognised, or structure.

Each production of an interpreter of type structure may have optional semantic rules. In W/AGE, there are three types of semantic rules, as explained later, in section 4.3.6.2.

If any Miranda functions are used in a W/AGE program\(^3\), then they may be defined in the same file which contains the W/AGE program or they may be

\(^3\) Note that the Miranda functions are not a part of W/AGE.
defined in a separate file in which case the name of the file must be specified in the program using the %insert command. All files that are specified in the W/AGE program using the %insert command are included during compilation.

§ 4.2 Components of W/AGE

W/AGE consists of the following components:

- A function for applying interpreters: apply_interpreter,
- A lexical scanning function: tokenize,
- A set of functions for building basic interpreters: literal, interpreted, and uninterpreted,
- A set of interpreter combinators: $orelse, $excl_orelse, $enables, and structure.

For more information on W/AGE refer to Appendix 3.

§ 4.3 Support for Left-Recursive Interpreter Definitions in W/AGE

According to a widely held belief, it is not possible to construct executable specifications of language processors that use a top-down parsing strategy and which have structures that directly reflect the structure of grammars containing left-recursive productions. It has been shown in [24] that top-down parsing and left-recursive productions can co-exist. The technique involves the use of non-
left-recursive recognizers, known as guards, to avoid non-termination of top-down left-recursive language processors. The description below is summarised from [24].

W/AGE provides a function enables to support left-recursive interpreter definitions. Each left-recursive interpreter definition, \( f = e \), where \( f \) is of the form \( f \rightarrow f \ast \) is replaced by a guarded-left-recursive definition \( f = r \text{ enables } e' \), where \( r \) is a non-left-recursive recognizer and \( r \) and \( e \) recognize the same language. And \( e' \) is obtained from \( e \) by replacing each left-recursive alternative \( \rho \) in \( e \) by \( p \text{ enables } \rho \), where \( p \) is a non-left-recursive recognizer, recognizing the same language as \( \rho \).

The current version of W/AGE supports left-recursive interpreter definitions. For more information, the interested reader is referred to [24].

§ 4.4 An example of attribute grammar specification in W/AGE

The W/AGE program for the attribute grammar specification listed in Figure 3.2 is given below:

```
----
%insert <local/header_for_WAGE_VERSION_2_RELEASE_0.m>
|| ATTRIBUTE DECLARATION

Figure 4.1 (Continued ...)
```

19
Structure Editors and Attribute Grammar Programming

```
attribute
  "LITERAL_VAL terminal
| NUM_VAL num
| STR_VAL [char]
| NUM_OCCUR num
|| SPECIAL SYMBOLS DECLARATION
special_symbols
= [',', ':', '[:', ']]'
|| RESERVED WORD DECLARATION
reserved_words
= []
|| INTERPRETER DEFINITIONS
any_number
= literal INT_TERM
any_string
= literal IDENTIFIER_TERM
colon
  uninterpreted (SPECIAL_SYMBOL_TERM "::")
comma
  uninterpreted (SPECIAL_SYMBOL_TERM ",")
open_br
  uninterpreted (SPECIAL_SYMBOL_TERM "[")
close_br
  uninterpreted (SPECIAL_SYMBOL_TERM "]")

input
  structure (s1 any_number ++ s2 colon ++ s3 open_br ++ s4 list_of_numbers ++ s5 close_br)
  [a_rule 1.1 (NUM_VAL $d s4) EQ conv_2 NUM_VAL[LITERAL_VAL $u s1],
   c_rule 1.2 (NUM_OCCUR $u lhs) EQ (NUM_OCCUR $u s4)]
  $excl_orelse
  structure (s1 any_string ++ s2 colon ++ s3 open_br ++ s4 list_of_strings ++ s5 close_br)
  [a_rule 1.3 (STR_VAL $d s4) EQ conv_2 STR_VAL[LITERAL_VAL $u s1],
   c_rule 1.4 (NUM_OCCUR $u lhs) EQ (NUM_OCCUR $u s4)]
  list_of_numbers
  = structure (s1 any_number ++ s2 comma ++
   s3 list_of_numbers)
  [c_rule 2.1 (NUM_VAL $d s3) EQ (NUM_VAL $d lhs),
   a_rule 2.2 (NUM_OCCUR $u lhs) EQ
   add_NUM_OCCUR[LITERAL_VAL $u s1,
     NUM_OCCUR $u s3,
     NUM_VAL $d lhs]]
  $excl_orelse
```

Figure 4.1 (Continued ...)

20
structure (s1 any_number)
[a_rule 2.3 (NUM_OCCUR $u$ lhs) EQ
  init_NUM_OCCUR[LITERAL_VAL $u$ s1,
                  NUM_VAL $d$ lhs]]

list_of_strings
structure (s1 any_string ++ s2 comma ++
           s3 list_of_strings)
[c_rule 2.1 (STR_VAL $d$ s3) EQ (STR_VAL $d$ lhs),
 a_rule 2.2 (NUM_OCCUR $u$ lhs) EQ
   add_STR_NUM_OCCUR[LITERAL_VAL $u$ s1,
                      NUM_OCCUR $u$ s3,
                      STR_VAL $d$ lhs]]

$excl_or else
structure (s1 any_string)
[a_rule 2.3 (NUM_OCCUR $u$ lhs) EQ
  init_STR_NUM_OCCUR[LITERAL_VAL $u$ s1,
                      STR_VAL $d$ lhs]]

| | MIRANDA FUNCTIONS
add_STR_NUM_OCCUR[LITERAL_VAL (IDENTIFIER_TERM a),
                  NUM_OCCUR b,
                  STR_VAL c]
= NUM_OCCUR (1 + b) , a = c
define $b$
= NUM_OCCUR b , otherwise

add_NUM_OCCUR[LITERAL_VAL (INT_TERM a),NUM_OCCUR b,
               NUM_VAL c]
= NUM_OCCUR (1 + b) , (numval a) = c
define $b$
= NUM_OCCUR b , otherwise

init_STR_NUM_OCCUR[LITERAL_VAL (IDENTIFIER_TERM a),
                   STR_VAL b]
= NUM_OCCUR 1 , a = b
define $b$
= NUM_OCCUR 0 , otherwise

init_NUM_OCCUR[LITERAL_VAL (INT_TERM a),NUM_VAL b]
= NUM_OCCUR 1 , (numval a) = b
define $b$
= NUM_OCCUR 0 , otherwise

conv 2 NUM_VAL[LITERAL_VAL (INT_TERM a)]
= NUM_VAL (numval a)
define $a$
conv 2 STR_VAL[LITERAL_VAL (IDENTIFIER_TERM a)]
= STR_VAL a

-------------------------------------------------------------

Figure 4.1
Chapter 5  WAGE-ed — A STRUCTURE EDITOR FOR W/AGE

§ 5.1 Introduction to WAGE-ed

WAGE-ed is an interactive program development tool which facilitates in the development of executable specification of attribute grammars. It was constructed in entirety by the author as part of the thesis work. A program being developed using WAGE-ed is continuously checked for syntax errors and missing attribute definitions. If any syntax errors and/or missing attribute definitions are detected they are immediately displayed on the terminal screen to provide feedback to the programmer as the program is developed and modified.

The knowledge, about W/AGE, incorporated in WAGE-ed prohibits the user from developing syntactically incorrect specifications, notifies the user of missing attribute definitions, performs transformation, pretty-printing and analysis of the object being edited. The editor checks the objects being edited for inconsistencies, prompts the user of the editor with legal alternative and/or imposes constraints on how the user can proceed.

WAGE-ed reinforces the view that a program is a hierarchical composition of computational structures. The editor provides templates which are predefined, formatted patterns for each construct in W/AGE, e.g., it provides templates for entering interpreter definitions, attribute declarations and so on. The attribute
grammar specification is created top-down by inserting new templates at placeholders in the skeleton of previously entered templates. For example, in the figure shown below,

![Diagram of main function with placeholders for reserved_words and special_symbols]

Figure 5.1

*<interpreter>* is a placeholder that identifies a location where additional insertions can be made.
When a program is being edited, it is read into a distinct buffer. Each window shows the contents of a distinct buffer; the same buffer can be displayed in more than one window. The window may be scrolled up or down to view different regions of the buffer.

The program contained in a buffer is a term, i.e., derivation tree with respect to the underlying abstract syntax of W/A GE. The nodes of a term are instances of operators and the subtrees of a node are the operator’s arguments, which are themselves terms. Each term has a two-dimensional, textual display representation. The view of a term displayed in a window is a rectangular section of this textual representation.

The program being edited in a buffer has a current selection (i.e., insertion point). The selection can only be moved from one template to another, or from one template to its constituents, not from character to character nor from one line of text to another. The selections in W/A GE-ed are indicated on the display screen by highlighting the selected region. There are two ways for making an object the current selection viz.,

• by selecting different tree-walking commands from the menu such as forward-sibling-with-optionals, backward-sibling-with-optionals, etc., which allow navigation according to the structure of the term. These commands are also bound to a sequence of return keys,
• by using a mouse or cursor keys of an ASCII terminal. Clicking the mouse on a character causes the selection to change to the subterm associated with that character.

The net effect of each editing operation is the replacement of a selected subterm with another. The editing operations are carried out by using transformations or text editing.

Additional templates can be inserted into the program by choosing an item from a list of legal items displayed in the help pane. For example, as shown in Figure 5.1, if the current selection is <interpreter>, it can be transformed into a template for interpreted interpreter by selecting interpreted from the list of choices displayed. After making the selection, the <interpreter> template shown in Figure 5.1 above is transformed into one shown below:
Notice that the placeholder `<interpreter_defn>` has been automatically indented according to the layout rules of Miranda.

**WAGE-ed** forbids the user from making inappropriate choices by offering only those choices which are legal in the context of current selection.

**WAGE-ed** allows changes to a program to be made by insertion and removal of entire, well-formed, program fragments. This ensures the syntactical integrity
of the program. Construct-to-construct transformation mechanism provided by WAGE-ed allows the user to construct the program at a higher-level of abstraction.

§ 5.2 Features of WAGE-ed

WAGE-ed eliminates much of the mundane task of program development and lets the programmer focus on the intellectually challenging aspect of programming. Its features include the following:

- Minimal text insertion: the user will need text only to enter interpreter names, attribute names, reserved words, special symbols, function names, and file names. WAGE-ed performs checking of lexical syntax, inserts all punctuation symbols, W/AGE keywords, etc.

- Automatic indentation: WAGE-ed indents the program according to the layout rules of Miranda. Because of automatic indentations certain type error messages are eliminated during compilation.

- Checking for missing attribute definitions: WAGE-ed continuously checks the program for attributes used but not declared in attribute declaration section, using synthesized/inherited attributes, in function calls, that have not been passed up/down the associated interpreter, multiple attribute declarations, etc.

Compiling an attribute grammar specification, which has been developed using WAGE-ed and has no warning messages, will compile without signalling any syntax errors or missing attribute definitions.
§ 5.3 Versions of WAGE-ed

There are two versions of WAGE-ed, namely:

- Guarded editors: a family of editors which support left-recursive interpreter definitions.

- Unguarded editors: a family of editors which do not support left-recursive interpreter definitions.

In each version, there are five editors which are classified according to their functionality. The following are the five editors, in each version, with their functionality:

- ed_syntax_only: attribute grammar specifications developed using this editor are guaranteed to be syntactically correct and conforms to the layout rules of Miranda. This editor does not check for any other kinds of errors.

- ed_no_synh_inh: attribute grammar specifications developed using this editor are guaranteed to be syntactically correct. In addition, this editor also checks for various other errors e.g. multiple attribute declarations in attribute declaration section.

This editor does not check for the use of inherited and/or synthesized attribute values which are not evaluated or missing attribute equations for synthesized and/or inherited attributes in semantic rules.
• ed_synh: this editor is similar in functionality to ed_no_synh_inh, except that in addition it keeps a check on the use of synthesized attribute values which are not evaluated or missing synthesized attribute definitions in semantic rules.

• ed_inh: this editor is similar in functionality to ed_no_synh_inh, except that in addition it keeps a check on the use of inherited attribute values which are not evaluated or missing inherited attribute definitions in semantic rules.

• wage_editor: this is a fully-fledged editor for W/AGE. Attribute grammar specifications developed using this editor are guaranteed to be syntactically correct, are checked for a number of different types of errors including the use of missing inherited and/or synthesized attribute values or missing inherited and/or synthesized attribute equations for synthesized and/or inherited attributes in semantic rules.

§ 5.4 Limitations of WAGE-ed

No Type Checking

Attribute grammar specifications developed using WAGE-ed are not checked for type errors. For example, if the following specification, which contains a type error, is entered using WAGE-ed the type error will not be reported by WAGE-ed.
%insert <local/header_for_WAGE_VERSION_2_RELEASE_0.m>

attribute
   \ LITERAL VAL terminal
   | HOLD_SUM num
   | TOTAL_SUM num

special_symbols
   [',']

reserved_words
   []

comma
   uninterpreted (SPECIAL_SYMBOL_TERM ",")

a_number
   literal INT_TERM

list_of_numbers
   structure (s1 a_number ++ s2 comma ++ s3 list_of_numbers)
   [a_rule 1.1 (HOLD_SUM $d s1) EQ add_numbers[LITERAL VAL $u s1,
      HOLD_SUM $d 1hs],
     c_rule 1.2 (TOTAL_SUM $u 1hs) EQ (TOTAL_SUM $u 53)]

$except{else
   structure (s1 a_number)
   [a_rule 1.3 (TOTAL_SUM $u 1hs) EQ add_last_num[LITERAL VAL $u sl
      HOLD_SUM $d 1hs]]

input
   structure (s1 list_of_numbers)
   [i_rule 2.1 (HOLD_SUM $d s1) EQ (HOLD_SUM 'o'), \| ERROR
    c_rule 2.2 (TOTAL_SUM $u 1hs) EQ (TOTAL_SUM $u s1)]

Figure 5.3

In the above specification, the attribute HOLD_SUM should have been
initialized to 0 in the initialization rule 2.1 and not to the character 'o'. Such kind
of type errors will not be reported by WAGE-ed, but if a specification containing a
type error is compiled, the line number of the right hand side interpreter definition
whose associated semantic rule contains the type error will be reported by the
Miranda compiler.

30
No Mutually Recursive Definitions

**WAGE-ed** requires that interpreter names used in the right hand side interpreter definition be previously defined. An implication of this constraint is that mutually recursive definitions have to be treated in a special way. If a **WAGE** specification containing mutually recursive definition (either direct or indirect) is entered using **WAGE-ed**, then interpreter definitions involved in mutual recursion will not be annotated with appropriate warning messages. The example specification listed below, which contains mutual recursion, will help to illustrate this limitation.

```
%insert <local/header_for_WAGE_VERSION_2_RELEASE_0.m>

attribute
  LITERAL_VAL terminal
    | VAL num
    | ADD_CONST num

reserved_words
  []

special_symbols
  ['+','(',' ',',')']

a_number
  literal INT_TERM

plus
  uninterpreted (SPECIAL_SYMBOL_TERM "+")

open_bracket
  uninterpreted (SPECIAL_SYMBOL_TERM "(")

close_bracket
  uninterpreted (SPECIAL_SYMBOL_TERM ")")

factor

Figure 5.4 (Continued ...)
```
The attribute grammar specification listed above was developed using WAGEd and saved as a text file. As one can observe, the interpreter definitions for factor and term are mutually-recursive. Because of mutual recursion, even though interpreter term has been defined, it is annotated with the warning message {UNDEFINED} in the definition of interpreter factor. Second, in the semantic rule 1.1, the attribute VAL is annotated with the warning message {ERROR} even though it is being passed up s2, i.e., interpreter term in the semantic rules 2.3 and 2.5. And finally, the interpreter name term appearing on the right hand side in the first interpreter definition option for factor, should have been annotated with the warning message {MISSING INH. ATTR. DEFN.} because in the associated semantic rule we have not defined a semantic rule to pass down the inherited
attribute ADD_CONST to s2, i.e., interpreter term, which is required.

§ 5.5 Support for Left-Recursive Interpreter Definitions in WAGE-ed

The guarded version of WAGE-ed supports left-recursive interpreter definitions. The behavior and working of guarded editors are exactly similar to unguarded editors, except that guarded editors have two additional types of interpreters, viz.:

- recognised: this interpreter type is similar to structured interpreter type, except that the productions do not have semantic rules associated with them. Also, interpreters defined as recognised should be non-left-recursive. These interpreters are used as guards to recognize left-recursive interpreter definitions,

- guarded: these interpreters can have left-recursive interpreter productions with associated semantic rules. Interpreters defined as guarded interpreters are also similar to structured interpreters, except that they have guards (interpreters which must be defined as recognised interpreters and they must be defined before their use) which enables left-recursive interpreter definitions if and only if the application of the recognised interpreter, used as a guard, to an input string terminates.

§ 5.6 Implementation of WAGE-ed

WAGE-ed has been implemented using the Synthesizer Generator [48], which
Structure Editors and Attribute Grammar Programming

is itself based on the concept of attribute grammar programming. This programming paradigm provides a powerful mechanism for specifying how widely separated parts of a tree are constrained in the context provided by the rest of the tree.

The reader should note that this section is concerned only with the implementation of WAGE-ed and not its use. The fact that WAGE-ed is implemented in an attribute grammar programming language may be a little confusing at first and the reader should be careful not to confuse what is discussed in this section with the use of WAGE-ed as a tool to support attribute grammar programming.

One of the components of the specification for WAGE-ed are the attribute equations that express context-sensitive constraints. As an object is edited with WAGE-ed, it is represented as a derivation tree that is consistently attributed in accordance with the grammar's attribute equation. A tree is consistently attributed when the value of each attribute instance in the tree is equal to the value of the appropriate attribute definition function applied to the value of the neighboring attribute instances in the tree. For example, when a tree is modified by, say, some editing operations then some of the attributes may no longer have consistent values. Incremental analysis is performed by updating attribute values throughout the tree in response to the modification. The dependency relationship between attributes defined in the specification for WAGE-ed is used to reestablish consistent values.
In **WAGE-ed**, various constraints are expressed by having certain attributes in the specification indicate whether the constraint is satisfied. In addition to the attribute grammar component, the specification for **WAGE-ed** consists of *unparsing* rules that determines how objects are displayed on the screen. Attributes used in the unparsing specification cause the screen to be annotated with values of attribute instances. Basically, the attribute that indicate satisfaction or violation of the specified constraints are used to annotate the display to indicate the presence or absence of errors. If an editing operation modifies an object in such a way that formerly satisfied constraints are now violated or vice-versa, the attribute that indicate satisfaction of constraints will receive new values. The changed values of the attributes are used to provide feedback to the user about new errors introduced and/or old errors corrected.

The specification for **WAGE-ed** is specified using **SSL** (Synthesizer Specification Language), the language in which editors are specified. Each SSL specification consists of various *declarations*.

**Abstract Syntax Declarations**

The main component of the specification for **WAGE-ed** is the definition of **W/AGE**’s abstract syntax, given as a set of grammar rules. The grammar rules are productions of a context-free grammar. The effect of each editing modification
Structure Editors and Attribute Grammar Programming

is to change the underlying abstract syntax tree. The abstract syntax of W/AGE consists of a collection of productions of the form.

\[ x_0: \text{op}(x_1 \ x_2 \ldots \ x_k) \]

where \text{op} is an operator name and each \( x_i \) is a nonterminal of the grammar.

Attribute and Attribute Equations Declarations

The specification for WAGE-ed also consists of attribute declarations that associate attributes with nonterminals and productions. The attribute equations are used to define the value of attributes in terms of other attributes that occur in the production. If the value of an attribute is a function of other attributes that occur in the production, then these functions appear in function declarations. When the program is being edited, the underlying derivation tree is fully and consistently attributed, all attributes of all nonterminals and productions are given values. Attribute values are updated automatically as objects are modified.

The attribute equations make use of synthesized and inherited attributes to make static inferences about the objects being edited. The warning messages that annotate the program as it is edited arise from static inferences about whether the program violates various constraints.

Unparsing Declarations

The display representation of the derivation trees derived from nonterminals of the grammar is defined by unparsing declarations. These declarations determine
how various objects in WAGE-ed are displayed on the screen. The display representation, in some cases, is influenced by the value of attributes. Therefore, after each editing operation, attribute values are reevaluated and only then the objects are displayed on the screen.

Concrete Input Syntax Declarations

In WAGE-ed objects are modified by three kinds of editing operations viz. text editing, transformation operations and system commands. System commands are same in all editors generated with the Synthesizer Generator, but text editing and transformation operations are defined in the specification of WAGE-ed.

Whenever a placeholder is refined by text, it is parsed and translated to an abstract form which is determined by an input syntax. In WAGE-ed, parsing declarations define the productions of a grammar to be used for parsing the text. Attribute equations associated with the productions of the input syntax define the translation of text to abstract syntax.

The entry declarations defined in the specification of WAGE-ed are used to establish a correspondence between the abstract syntax of objects editable as text and the subsets of the input syntax, because at any given moment only a subset of the input syntax is recognized. Each well-formed text in a given context determines a parse tree with respect to the input syntax. This parse tree is translated into an abstract syntax tree with attribution.
Structure Editors and Attribute
Grammar Programming

Transformation Declarations

The transformation declarations defined in the specification for WAGE-ed specify how to restructure a selected object, when the component located at the selection matches a given structural pattern.

A transformation determines a replacement value for the selected subterm as a function of its current value. At any given moment during editing, a transformation is either enabled or disabled depending on whether or not its pattern matches the value of the selection. Transformations which are enabled are listed in the help pane, they can be invoked either by clicking on them in the help pane or selecting them from the menu. Transformations maintain the syntactical integrity of the program, because their definitions are type checked during compilation.

The complete code for WAGE-ed is listed in Appendix 2.
Chapter 6 Conclusion

In this section I recapitulate the result of my thesis and give directions for future research work.

§ 6.1 Assessing the value of WAGE-ed

The driving force behind the construction of the editor is that it should facilitate in the construction of syntactically correct W/AGE program, allow programs to be constructed at a higher level of abstraction, perform automatic indentation of the program, insert punctuation symbols automatically, and provide the user with feedback about missing attribute equations.

In order to support my thesis, I have:

- Built a structure editor, WAGE-ed, for W/AGE — an environment for constructing executable specification of attribute grammars,

- Surveyed users of WAGE-ed and summarized their experience with it.

The main conclusions which I draw after implementing the editor are:

- WAGE-ed prohibits all errors which emanate as a result of misspelled W/AGE keywords, missing punctuation symbols, incorrect indentation of the program, undefined interpreters, etc. Users of WAGE-ed are relieved of the frustration and time wasted in debugging these kind of errors, because the editor simply prohibits them.
Structure Editors and Attribute Grammar Programming

- **WAGE-ed** facilitates in the construction of executable specification of attribute grammars at a higher-level of abstraction, without having to bother about the fine implementation details.

- **WAGE-ed** signals, with appropriate warning message, the use of undeclared attributes, and reference to synthesized or inherited attribute values whose associated attribute equations are undefined.

- **WAGE-ed** is easy to use and learn.

- **WAGE-ed**, to some extent, helps users learn the concept of attribute grammar programming.

The last two points are the analysis of the survey which I conducted after implementing the editor. The main idea of surveying the users of WAGE-ed was to obtain answers for the following questions:

- Are there any disadvantages, such as the time to learn how to use the editor, of using a specialized editor which might offset the facilities provided by it?

- Does it help the user in learning attribute grammar programming?

The users of WAGE-ed, who were surveyed, were undergraduate students (a mix of second and third year students) who took the 60-214 Compiler course offered by the School of Computer Science. The students used WAGE-ed for their assignments and project.

- A total of 43 students (1 Master's, 20 Third Year, and 22 Second Year
students) were surveyed.

- All of the students had experience with more than one programming language, viz., C and Turing.

- None of them had any prior experience using a structure editor.

The graph shown below illustrates the time taken by students to learn using WAGE-ed without any assistance, i.e., without any help from the GA or the course instructor, except for reference to the user manual. Out of a total of 43 students, 37 responded.
ANALYSIS OF SURVEY

As seen in the graph above, most of the students took less than a week to
learn to use WAGE-ed, the average being around 4 days.

Almost 65% of the students surveyed responded that WAGE-ed helped them learn the attribute grammar programming paradigm.

The results of the survey and feedback from users of WAGE-ed has confirmed my belief that a structure editor is useful to novice users who are unfamiliar with a particular programming paradigm or language and also to experienced programmers who are switching from one programming language to another. Because it helps them to become familiar to the new environment in a relatively short period of time and acts like a guide overlooking their shoulder for various kinds of errors. As a result, a beginner is not intimidated by unfriendly error messages issued by the compiler because they are taken care of during the editing phase itself and at the same time learns to write programs in the new language relatively fast.

In our case, I believe that WAGE-ed will:

- Help users unfamiliar with attribute grammar programming paradigm, learn it through the various warning messages issued by WAGE-ed due to incorrect use of synthesized and/or inherited attributes.

- Considerably reduce the time taken to develop a W/AGE program, free of syntax errors and errors in the use of attributes, by saving time in learning the syntax and layout rules of W/AGE and time spent debugging errors.
Structure Editors and Attribute Grammar Programming

- Help users unfamiliar with W/AGE become familiar with it. Because WAGE-ed: automatically handles insertion of various keywords, punctuation symbols, layout of the program; provides predefined templates for various types of interpreter definitions, reserved words, special symbols, etc., it can be used as a manual to learn W/AGE.

From the facilities supported by WAGE-ed in the construction of executable specification of attribute grammars and the results of the survey, I conclude that WAGE-ed is of value in the construction of executable specification of attribute grammars and at the same time is easy to use and learn.

§ 6.2 Prospects for Future Work

Interactive Programming Environment for W/AGE

WAGE-ed currently facilitates the construction of syntactically correct attribute grammar specifications and checks for missing attribute declarations and attribute equations.

WAGE-ed does not support structure editing facility for the programming language Miranda. It would have been possible to create a structure editor for Miranda that would check for syntax, semantic and type errors, using the Synthesizer Generator if more time had been available. It would be challenging to develop an interactive programming environment for W/AGE, which facilitates
the development of attribute grammar specifications, checks Miranda functions for syntax and semantic violations and performs type checking.

Another important feature to be included would be interactive testing and debugging of attribute grammar specifications. It would be desirable to initiate the execution of the program at any stage of execution, with no delay for compilation. It would be interesting to investigate whether or not it is possible to produce and maintain an executable code in Miranda as attribute grammar specifications are developed using WAGE-ed.

Developing Benchmarks for Interactive Program Development Environments

There has been absolutely no work done in developing benchmarks for interactive programming environments supporting structure editing facility. A programming environment for W/AGE with the above mentioned features could be used as a testbed to develop benchmarks for interactive program development environments. These benchmarks could be used to test the versatility and features of current and future interactive program development environments and check their effectiveness in increasing the productivity of the programmer.

Handling Mutually Recursive Definitions

WAGE-ed at present does not have any facility for entering mutually recursive definitions. It would be interesting to investigate whether or not it is possible to extend WAGE-ed to support mutually recursive definitions.
Writing Concrete Input Syntax for the Entire W/AGE Language

If a W/AGE program developed using W/AGE-ed is saved as a text file then it is not possible to read that file back into W/AGE-ed for further editing.

It is possible to do this by extending the W/AGE-ed specification to include concrete input syntax (refer to section 5.7) for the entire W/AGE language.

Evaluating Various Aspects of W/AGE-ed

Due to unavailability of time, it was not possible to perform experiments to evaluate various aspects of W/AGE-ed, namely:

- Ease with which programs being developed using W/AGE-ed could be modified, viz., inserting and deleting placeholders and text by making appropriate selections from the pop-up menu.

- Ease of performing cut and paste operations. These operations might be prohibited, by W/AGE-ed, at some locations in the program which the user might feel is inappropriate. But as I have mentioned no rigorous experiments were conducted to check for all possible locations where these operations would prove to be necessary and useful. If all such probable locations are found, it is just a matter of modifying unparsing properties of appropriate nodes in the abstract syntax tree.
• Suitability of refining certain placeholders by entering text from the keyboard, rather than transforming them by making selections from choices listed in the help pane.
BIBLIOGRAPHY


APPENDIX 1
An Example Session with a Structure Editor

This section illustrates an editing session with a structure editor for a subset of Pascal-like programming language.

The language supports four kinds of statements, viz., an assignment statement, an if-then-else statement, a while statement, and compound statement, i.e., a sequence of statements enclosed between the keywords begin and end. The body of the while and if-then-else statements can have only one statement (if a sequence of statements is required then they should be enclosed between the keywords begin and end). The language supports two kinds of data types, viz., integer and boolean. The language requires that all variables be declared before their use and the language is strongly typed, i.e., an integer value cannot be used at a place which requires a boolean and vice-versa.

The editor used for the demonstration illustrates the kind of structure editor that can be built using the Cornell Synthesizer Generator [48] and the features that can be incorporated into it.

When the editor is initially loaded, it appears as shown in Figure 1.1.
The screen, as shown in Figure 1.1, is divided into four regions:

- The topmost highlighted region, the *title bar*, containing the identifier main, indicates the name of the buffer whose contents are being currently edited. By default, this buffer is named *main*. 
• The next region following the title bar displays system error messages. The editor will not allow any further edits before the error displayed in this region is corrected.

• The next region is the place where one enters the program, the object pane. It consists of text enclosed within angle brackets, known as placeholders, these are the locations which need to be refined or locations where additional text can be inserted. In order to insert text at a particular placeholder, one has to select the placeholder by placing the mouse arrow on the placeholder to be refined and clicking the leftmost mouse button. On doing so the placeholder is selected and appears in reverse video. If there are any transformations associated with the placeholder they will be listed in the lowermost region of the window, the help pane. In such a case, the user can select one of the choices listed by placing the mouse arrow on one of them and clicking the leftmost mouse button. If there are no transformations listed, that means the user can enter text from the keyboard to refine the selected placeholder. Text not enclosed within angle brackets are language keywords and are immutable.

• The lowermost region of the window, the help pane, displays the node or phylum in the abstract syntax tree which is the current selection and the legal transformations associated with it, if any.

The arrows which appear on the right hand side and lower half region of the
screen can be used to move the program text vertically and horizontally.

As seen in Figure 1.1, initially, the entire program template is selected. At this point one can choose to refine any placeholder in the template by selecting it. Suppose we choose to refine the statement placeholder, on doing so the screen appears as shown in Figure 1.2.

As we can see in Figure 1.2, the statement placeholder is now our current selection. Also, the legal transformations associated with the statement placeholder are listed in the help pane. In order to refine the statement placeholder we can select any one of the choices. Suppose we select assign. On doing so, the statement placeholder is transformed into one shown below:
As seen in Figure 1.3, the statement placeholder has been transformed into an assignment statement consisting of an identifier placeholder and an expression placeholder. The identifier placeholder is our current selection, since there are no transformations associated with it we can enter any legal identifier (consisting
of alphanumeric characters, starting with an alphabet and can have embedded underscores).

Suppose, we key in an illegal identifier and then try to select the expression placeholder. But the system will not allow us to select the expression placeholder because we have entered an illegal identifier and a system error message will be displayed. We have to rectify our error in order to perform further edits. The sequence of performing above action is shown in Figure 1.4.
Figure 1.3

We can use the delete key to erase the illegal identifier and then retype a legal identifier. Next we select the expression placeholder, as seen in Figure 1.5.
The system, before making any placeholder a current selection, makes sure whether or not the previous placeholder was transformed into a legal sentence. In the above figure, we entered an undefined legal identifier, the system responded with a warning message and made the expression placeholder the current selection.
A warning message need not be rectified as soon as it is introduced, but it serves to inform the user that an appropriate action must be taken in order for the program to compile correctly.

Next, we refine the expression placeholder by entering the text \texttt{value + 1} and hit the return key. After entering the return key, the system parses the previously entered text and takes appropriate action.

As exemplified by Figure 1.6 with the automatic insertion of the parentheses and semi-colon, a structure editor can be crafted to perform desired pretty-printing, indentation, display appropriate warning messages, \textit{etc}. Now, let us define the type for the identifier \texttt{value}. In order to do so, we select the identifier placeholder present in the variable declaration section. First, we key in the identifier name then we select the type placeholder and choose \texttt{boolean} type for it and finally hit return. The system takes the actions as seen in Figure 1.7.
As seen in Figure 1.7, the editor has attributed the assignment statement with appropriate warning messages, because we have used a boolean variable in an expression which requires an integer. Also, the editor has introduced another
template for variable declaration. Next we introduce\textsuperscript{4} a while statement as seen in Figure 1.8.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.6}
\caption{Figure 1.6}
\end{figure}

\textsuperscript{4} The procedures to introduce placeholders, perform copy-paste-cut operations, walk through the abstract syntax tree etc. are explained in detail in Appendix C.
As we can see in the figure above, the body of the while statement has been appropriately indented. We enter, $(\text{value} \leftarrow 100)$ and $\text{value} := \text{value} + 1$, for expression and statement placeholder respectively and hit return. When each of these texts is entered it is parsed to check whether it is syntactically and semantically correct. After performing the above actions, the screen appears as seen in Figure 1.9.
As seen in Figure 1.9, the next statement placeholder is outside the scope of the while statement. Suppose we want to define multiple statements for the while statement, we can do this by selecting only the body of the while statement (this can be done by placing the mouse arrow on := symbol and clicking the left
mouse button) as seen in Figure 1.10.

As we can see in Figure 1.10, there is one transformation associated with the highlighted statement, namely \texttt{(begin}. If we click on this choice the entire body
of the \textbf{while} statement will be enclosed within the keywords \texttt{begin} — \texttt{end} and then we can define multiple statements. See Figure 1.11.
We can revert to Figure 1.10 by clicking on \texttt{)begin}. As we can see our program has some warning messages, we can remove them by declaring the variable \texttt{value} to have type \texttt{integer}. We can do this by first selecting \texttt{boolean}, then deleting it and then choosing \texttt{integer} from the menu which appears at the bottom of the screen. As soon as we perform the above actions all the warning messages disappear as seen in Figure 1.12.
If we enter a name for the program at the remaining identifier placeholder and compile this program, we can be sure that our program will compile without coming up with any syntax or semantic error messages.

The above editing session with a structure editor illustrates some of the
features provided by a structure editor. The structure editor used in this example performs type checking, pretty-printing, transformations, checked for undeclared variables. It is possible to create sophisticated structure editors to perform incremental code generation, couple testing and debugging with editing etc.

If we have a powerful structure editor, one that performs syntax checking, semantic checking, type checking, incrementally generates code, and allows testing during editing, it is highly plausible that the time required for program development can be significantly reduced, because the programmer can focus on the intellectually challenging aspects of programming rather than waste time in debugging syntax and semantic errors.
APPENDIX 2
An Example Session with WAGE-ed

This section demonstrates the behavior of WAGE-ed. Specifically, it illustrates in detail how an attribute grammar specification is developed using WAGE-ed, the various warning messages issued by WAGE-ed, how to introduce regular and optional templates and placeholders and enter text.

The attribute grammar specification of Figure 3.2 will be implemented in W/AGE using WAGE-ed. The editor used to enter the specification is unguarded wage_editor and can be invoked on the School of Computer Science network by typing xwageedit at the system prompt.

When the editing session is initiated, the screen containing a template for the W/AGE program appears as seen in Figure 2.1.
Figure 2.1

In Figure 2.1, the text which appears in bold font are W/AGE keywords and are immutable, italic text which appears in angle brackets are placeholders — locations which need to be refined. A placeholder should be first selected, in

72
order to refine it. It can be selected by placing the mouse arrow on it and clicking
the left mouse button. As seen in Figure 2.1 above, initially the entire program
template is selected.

The placeholders in WAGE-ed can be refined in an arbitrary order. In
this example, initially the <path> placeholder is selected. Since the <path>
placeholder has no transformations listed for it in the help pane, it can be re-
efined by entering characters from the keyboard. In WAGE-ed, each com-
ponent of the path name must be entered by introducing a new <path> place-
holder, either by entering a sequence of returns or using the system com-
mand\textsuperscript{5} \texttt{forward-sibling-with-optionals}. To include the W/AGE header file, lo-
cal/header_for_WAGE_VERSION_2_RELEASE_0.m, two <path> placeholders are required. Note that the / symbol is inserted automatically, if we enter the
full path name it will not be accepted by the system. After entering the header file
name, we select the special symbols declaration section to enter special symbols
\textit{viz.} :, [, ], and ,, see Figure 2.2 below.

\footnote{For more explanation, refer to Appendix 3.}
In order to transform the above selection to a template which contains a placeholder to enter special symbols, we click on `insert_spec_symbols` listed in the help pane. This introduces a `<spec_symbols>` placeholder between the opening and closing square bracket. A `<spec_symbols>` placeholder can be refined...
by any single character, except alphanumeric characters. Placeholders for entering
additional special symbols, after entering the first symbol, can be introduced by
entering a sequence of return keys or using \textit{forward-sibling-with-optionals}. The
result of entering $:, [1,],$, and selecting \texttt{<interpreter> for refinement is seen in
Figure 2.3.}
Attribute
::=
  <attribute_name> <attribute_type>

reserved_words
=
  []

special_symbols
=
  [":"','['',']','\',',']
interpreter, by clicking on structured in the help pane, as seen in Figure 2.4 below.

```
main

attribute ::= <attribute_name> <attribute_type>

reserved_words = []

special_symbols = ['::', ',', '[', ']', '(', ')', '

<interprtr_name> = <interprtr_defn>

Positioned at interprtr_name
```

The template for entering structured interpreter definition consists of `<interprtr_name>` and `<interprtr_defn>` placeholders. As seen in the figure above the `<interprtr_defn>` placeholder has been automatically indented according to the...
layout rule of Miranda. Since no transformations are associated with the <interprtr\_name> placeholder, we can refine it by entering text from the keyboard. Placeholders for entering right hand side interpreter names and associated semantic rule can be introduced by selecting the <interprtr\_defn> placeholder and then clicking on show listed in the help pane. The result of refining the <interprtr\_name> placeholder and transforming the <interprtr\_defn> placeholder is seen in Figure 2.5.
Figure 2.5

As seen in the figure above, the template for entering right hand side interpreter definition consists of two templates for entering right hand side production definition separated by the placeholder <separator>. Each template consists of <interprrt_name> placeholder, additional placeholders can be obtained by first
refining the already selected <interprtr_name> placeholder and then entering a sequence of return keys or using forward-sibling-with-optionals. In Figure 2.5 above, we refine the first right hand side structure definition option by entering the interpreter names: number, colon, op_bracket, list_of_numbers, and finally cl_bracket and then select the <separator> placeholder. The result of the previous operation is seen in Figure 2.6.
WAGE-ed requires that all right hand side interpreter names be declared before their use. In our case, since we have not declared the right hand side interpreter names, the interpreter names are juxtaposed with the message {UNDEFINED}. WAGE-ed does not constraint the user to take care of the warning
messages immediately. Now, we refine the \(<\text{separator}>\) placeholder by choosing $\text{sexcl\_orelse}$ from the help pane. Next, we refine the second structure template by entering the interpreter names: \textit{string}, \textit{colon}, \textit{op\_bracket}, \textit{list\_of\_strings}, and finally \textit{cl\_bracket}. The result of previous operations is seen in figure below.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure27.png}
\caption{Figure 2.7}
\end{figure}
Next we declare all undefined interpreters. To declare an interpreter we need an `<interpreter>` placeholder to begin with. This can be done by selecting the entire definition of the interpreter input, by clicking on the equal sign, and then using the system command `backward-sibling-with-optionals`, which will introduce an `<interpreter>` placeholder before the definition of the interpreter input. If we use `forward-sibling-with-optionals`, an `<interpreter>` placeholder will be introduced after the definition of the interpreter input. Since we need to define interpreters before their use, we use `backward-sibling-with-optionals`.

The interpreters number, list_of_numbers, string, list_of_strings, colon, op_bracket, and cl_bracket have been defined as literal, structured, literal, structured, uninterpreted, uninterpreted, and uninterpreted interpreters respectively, as shown in Figure 2.8.
Note in the figure above all the undefined messages have disappeared. Next
we refine the two `<interprtr_defn>` placeholders in the figure above and define the comma as an uninterpreted interpreter. The resulting structure is seen in Figure 2.9.
Up to this stage, our program is syntactically correct. The readers must
have noticed, at each stage the program was well-formed, WAGE-ed prohibited any syntax errors, insertion of all punctuation symbols, keywords and layout was done by WAGE-ed as a result very minimal typing is required on part of the programmer and at the same time syntactical integrity of the program was maintained.

Semantic rules associated with a production can be inserted by first selecting the production, this is done by clicking on the keyword structure. In the previous figure we selected the first right hand side production of the interpreter list_of_numbers. Placeholder for entering a semantic rule, <semantic_rule>, is inserted by clicking on sem_rules displayed in the help pane. After following a sequence of transformation, <semantic_rule> can be transformed into a template for defining an attribute equation for synthesized or inherited attribute. Templates for entering additional attribute equations can be obtained in a similar fashion by first introducing the <semantic_rule> placeholder, this can be done by first selecting a previously entered attribute equation and then entering a sequence of return keys or using the system commands forward-sibling-with-optionals or backward-sibling-with-optionals. Figure 2.10 shows the result of entering the semantic rules associated with the first production for the interpreter list_of_numbers.
list_of_numbers =
structure ( s1 number ++ s2 comma ++ s3 list_of_numbers )
[c_rule 1.1 (UNDEFINED)NUM_VAL $d s3) EQ (UNDEFINED)NUM_VAL $d lhs],
a_rule 1.2 (UNDEFINED)NUM_OCCUR $u 1hs) EQ add_num_occurs[UNDEFINED]LITERAL_VAL $u s1, UNDEFINED]NUM_OCCUR $u s3, UNDEFINED]NUM_VAL $d 1hs]
*excl_or_else
structure ( s1 number )
[]{INCOMP, SYNTH, ATTR.}

list_of_strings =
structure ( s1 string ++ s2 comma ++ s3 list_of_strings )
[]
*excl_or_else
structure ( s1 string )
[]

input =
structure ( s1 number ++ s2 colon ++ s3 op_bracket ++ s4 list_of_numbers{MISSING INH, ATTR, EQN.} ++ s5 cl_bracket )
[]
*excl_or_else
structure ( s1 string ++ s2 colon ++ s3 op_bracket

Positioned at mandatory_defn
As seen in the figure above, the program has been annotated with various warning messages. The attributes names are juxtaposed with the message {UN-
DEFINED} because we have not defined them as yet in the attribute declaration section, the second production for interpreter list_of_numbers is annotated with the message {INCOMP. SYNTH. ATTR.} because the production does not have a semantic rule for the synthesized attribute NUM_OCCUR, and finally the message {MISSING INH. ATTR. EQN.} appears because we have not defined an attribute equation for the inherited attribute NUM_VAL to be passed down the interpreter list_of_numbers i.e. s4 in definition for interpreter input whereas it is used in semantic rule 1.1.

In order to remove these messages, we:

- Declare the attributes: LITERAL_VAL, NUM_VAL, NUM_OCCUR, and STR_VAL in the attribute declaration section,

- Define an attribute equation for the synthesized attribute NUM_OCCUR, and

- Define an attribute equation for the inherited attribute NUM_VAL.

The result of performing the previous operation and entering semantic rules for interpreter list_of_strings is seen in Figure 2.11.
main

[c_rule 1.1 (NUM_VAL $d s3) EQ (NUM_VAL $d lhs)]
[a_rule 1.2 (NUM_OCCUR $u lhs) EQ add_num_occur[LITERAL VAL $u s1, NUM_OCCUR $u s3, NUM_VAL $d lhs]]
$excl_or else
structure ( s1 number )
[a_rule 1.3 (NUM_OCCUR $u lhs) EQ init_num_occur[LITERAL VAL $u s1, NUM_VAL $d lhs] ]

list_of_strings
=
structure ( s1 string ++ s2 comma ++ s3 list_of_strings )
[c_rule 2.1 (STR_VAL $d s3) EQ (STRVAL $d lhs) ]
[a_rule 2.2 (NUM_OCCUR $u lhs) EQ add_str_num_occur[LITERAL VAL $u s1, NUM_OCCUR $u s3, STRVAL $d lhs] ]
$excl_or else
structure ( s1 string )
[a_rule 2.3 (NUM_OCCUR $u lhs) EQ init_str_num_occur[LITERAL VAL $u s1, STRVAL $d lhs] ]

input
=
structure ( s1 number ++ s2 colon ++ s3 op_bracket ++ s4 list_of_numbers[MISSING INH. ATTR. EQN.3 ++ s5 cl_bracket ]
[]
$excl_or else
structure ( s1 string ++ s2 colon ++ s3 op_bracket ++ s4 list_of_strings[MISSING INH. ATTR. EQN.3 ++ s5 cl_bracket ]
[]

Positioned at attr_type

Figure 2.11
As seen in the figure above, all the warning messages have disappeared, except for one. Next we introduce placeholders for entering semantic rules for each right hand side production of the interpreter input by clicking on the keyword structure associated with each production. Due to limitation of space, the entire program is shown in Figures 2.12, 2.13, and 2.14.
main

%insert <local/header_for_WAGE_VERSION_2_RELEASE_0.m>

attribute
::= LITERAL_VAL terminal
| NUM_OCCUR num
| NUM_VAL num
| STR_VAL num

reserved_words
=
[
]

special_symbols
=
[',',[],',',']

cl_bracket
=
uninterpreted (SPECIAL_SYMBOL_TERM "[")

op_bracket
=
uninterpreted (SPECIAL_SYMBOL_TERM "]")

Positioned at decl_of_interpreters

Figure 2.12

92
main

colon
    =
        uninterpreted (SPECIAL_SYMBOL_TERM "::")

string
    =
        literal IDENTIFIER TERM

number
    =
        literal INT TERM

comma
    =
        uninterpreted (SPECIAL_SYMBOL TERM ",")

list_of_numbers
    =
        structure ( s1 number ++ s2 comma ++ s3 list_of_numbers )
        [c_rule 1.1 (NUM VAL $d s3) EQ (NUM VAL $d lhs),
         a_rule 1.2 (NUM OCCUR $u lhs) EQ add_num_occursLITER
         AL_VAL $u s1,NUM OCCUR $u s3,NUM VAL $d lhs] ]
        $excl_or_else
        structure ( s1 number )
        [a_rule 1.3 (NUM OCCUR $u lhs) EQ init_num_occursLIT
         ERAL_VAL $u s1,NUM VAL $d lhs] ]

Positioned at decl_of_interpreters

Figure 2.13
list_of_strings

structure ( s1 string ++ s2 comma ++ s3 list_of_strings )
[c_rule 2.1 (STR_VAL $d s3) EQ (STR_VAL $d lhs),
 a_rule 2.2 (NUM_OCCUR $u lhs) EQ add_str_num_occurs[LITERAL_VAL $u s1,NUM_OCCUR $u s3,STR_VAL $d lhs] ]
*excl_orelse
structure ( s1 string )
a_rule 2.3 (NUM_OCCUR $u lhs) EQ init_str_num_occurs[LITERAL_VAL $u s1,STR_VAL $d lhs] ]

input

structure ( s1 number ++ s2 colon ++ s3 op_bracket ++ s4 list_of_numbers ++ s5 cl_bracket )
[ a_rule 3.1 (NUM_VAL $d s4) EQ conv_to_num_val[LITERAL_AL_VAL $u s1],
 c_rule 3.2 (NUM_OCCUR $u lhs) EQ (NUM_OCCUR $u s4) ]
*excl_orelse
structure ( s1 string ++ s2 colon ++ s3 op_bracket ++ s4 list_of_strings ++ s5 cl_bracket )
[ a_rule 3.3 (STR_VAL $d s4) EQ conv_to_str_val[LITERAL_AL_VAL $u s1],
 c_rule 3.4 (NUM_OCCUR $u lhs) EQ (NUM_OCCUR $u s4) ]

Positioned at decl_of_interpreters

Figure 2.14
If this program is compiled, the only error messages signalled will be the undefined function names: \texttt{add\_str\_num\_occur}, \texttt{init\_str\_num\_occur}, \texttt{add\_num\_occur}, \texttt{init\_num\_occur}, \texttt{conv\_to\_num\_val}, and \texttt{conv\_to\_str\_val}, because \texttt{WAGE-ed} does not support any editing facility for entering of Miranda functions.
§ 3.1 Notations Used

The notations used in this appendix are Miranda notations whose meanings are explained below:

- $x == y$, introduces $x$ as an acronym for the type name $y$.
- $x :: y$, declares $x$ to be of type $y$,

where type is defined inductively as follows:

num, char, bool $\in$ type.

If $t \in$ type, then so is [$t$] i.e. list type whose elements are of type $t$.

If $t_1, \ldots, t_n \in$ type, then so is $(t_1, \ldots, t_n)$ i.e. tuple type with elements of type $t_1$ to $t_n$.

if $t_1, t_2 \in$ type, then so is $t_1 \rightarrow t_2$ i.e. a function that accepts input argument of type $t_1$ and output result of type $t_2$.

If $y, z \in$ type then so is $x$, where $x ::= C_1 y \mid \ldots \mid C_n z$, and $C_1$ to $C_n$ are user-defined constructors.

§ 3.2 Components of W/AGE

W/AGE consists of the following components:

- A function for applying interpreters: apply_interpreter,
• A lexical scanning function: *tokenise*.

• A set of functions for building basic interpreters: *literal*, *interpreted*, and *uninterpreted*.

• A set of interpreter combinators: $sorelse$, $sexcl orelse$, $senables$, and *structure*.

### 3.2.1 Type of Interpreters

In W/AGE the type *interpreter* is defined as:

\[
\text{interpreter} \equiv \{([\text{attribute}], [\text{terminal}], [\text{terminal}]) \rightarrow ([\text{attribute}], [\text{terminal}], [\text{terminal}])\}
\]

The above definition means that an interpreter is a function that maps a list of triples of type $\{(\text{attribute}, \text{terminal}, \text{terminal})\}$ to a list of triples of the same type, such that:

• Each triple $(as, ts_1, ts_2)$ in the list that is input to an interpreter is such that the list of attributes as may be regarded as a context in which the list of terminals $ts_2$ is to be interpreted,

• Each triple $(as', ts^1, ts^2)$ in the list that is output by an interpreter is associated to exactly on pair $(as, ts_1, ts_2)$ in the input list such that: (i) $as'$ is a subset of the union of as and some initial segment of $ts_2$, (ii) $ts^2$ is the list of remaining uninterpreted terminals in $ts_2$, and (iii) $ts^1$ is the list of terminals that have been consumed,
• Interpreters return lists of triples because each pair in the input may have more than one interpretation.

3.2.2 Type of Terminals

W/AGE classifies terminals into the following categories:

• **INT_TERM**: includes all integer numbers.

• **REAL_TERM**: includes all real numbers.

• **IDENTIFIER_TERM**: includes all legal identifiers — alphanumeric characters, starting with an alphabet, may have embedded underscores and no blanks.

• **SPECIAL_SYMBOL_TERM**: includes all single character symbols, except alphabet and digits.

• **RESERVED_WORD_TERM**: includes strings which are declared in the reserved declaration section.

• **ANY_TERM**: could be any of the above mentioned types.

• **UNCATEGORISED_TERM**: any term which does not fall into any of the categories mentioned above.

3.2.2.1 terminal

The type of *terminal* is defined in W/AGE as:
terminal ::= INT_TERM [char] 
| REAL TERM [char] 
| IDENTIFIER TERM [char] 
| SPECIAL_SYMBOL TERM [char] 
| RESERVED WORD TERM [char] 
| ANY TERM [char] 
| UNCATEGORISED TERM [char]

3.2.3 Type of Functions for Top-level Application of Interpreters

The apply_interpreter function in W/AGE is defined as follows:

```plaintext
apply_interpreter :: interpreter -> string_to_be_interpreted 
                      -> [([attribute], [terminal])]
```

The above definition means that the apply_interpreter function takes as input an interpreter (of type mentioned above) and the string to be interpreted (of type [char]) and returns a list of pairs of type ([attribute], [terminals]). According to the symbols used in the definition of interpreter, ([attribute], [terminals]) would be (as', ts²) respectively.

Usage

```
apply_interpreter interpreter_name "string_to_be_interpreted"
```

Example

```
apply_interpreter input "1:[1,2,1,3,1]"
```

3.2.4 Type of Lexical Scanning Function

W/AGE provides a function, tokenise, for classifying terminals according to their type.
Type

tokenise :: string_to_be_processed -> [terminal]
    where string_to_be_processed == [char]

Usage

tokenise "string_to_be_processed"

Example

(server.uwindsor.ca
version 2.018 last revised 19 April 1991

Copyright Research Software Ltd, 1990

(300000 cells)
compiling test3892.m
checking types in test3892.m
for help type /help
Miranda tokenise "123 hello 1.2 7*"
[INT_TERM "123",IDENTIFIER_TERM "hello",REAL_TERM "1.2"
",UNCATEGORISED_TERM "7*" ]
Miranda []

Figure 3.1

3.2.5 Type of Functions for Building Basic Interpreters

In W/AGE there are three functions that may be used to build interpreters
for single terminals, namely,

- literal
• uninterpreted
• interpreted

3.2.5.1 literal

The interpreter constructor literal accepts a string and a terminal and returns an interpreter. If an interpreter is defined as a literal interpreter then it has automatically associated with it only one synthesized attribute LITERAL_VAL of type terminal, which is as defined in section 4.3.2. It cannot have any inherited attributes, nor can it have any other synthesized attributes.

Type

[char] -> terminal -> interpreter

Usage

interpreter_name = literal term_declaration

where term_declaration, could be any one of:
• INT_TERM : matches any integer number,
• REAL_TERM : matches any real number,
• RESERVED_WORD_TERM : matches any word which has been declared as a reserved word,
• SPECIAL_SYMBOL_TERM : matches any single character symbols, except alphabet and digit, and which have been declared as special symbols,
• **IDENTIFIER_TERM**: matches any identifier (can be composed of any alphanumeric characters with embedded underscores and no blanks).

• **ANY_TERM**: matches any thing which belongs to any of the categories mentioned above,

• **UNCATEGORISED_TERM**: matches any thing which does not belong to any of the term types mentioned above.

**Example**

```plaintext
$\text{insert } \langle \text{local/header_for_WAGE_VERSION_2_RELEASE_0.m} \rangle$
attribute
::= LITERAL_VAL terminal
special_symbols
== ['+', '-']
reserved_words
== ['begin', 'end']
type_of_terminals
literal SPECIAL_SYMBOL_TERM
$\text{excl_orelse}
literal RESERVED_WORD_TERM
$\text{excl_orelse}
literal IDENTIFIER_TERM
$\text{excl_orelse}
literal INT_TERM
$\text{excl_orelse}
literal REAL_TERM
```

**Figure 3.2**

After compiling the above program, if we apply the function `apply_interpreter` to the interpreter `type_of_terminals` with an argument, then the synthesized
attribute LITERAL_VAL associated with type_of_terminals (it is defined as a literal interpreter) will contain the value of the argument. See Figure 4.3.

3.2.5.2 uninterpreted

The interpreter constructor uninterpreted accepts a terminal and returns an interpreter. If an interpreter is defined as an uninterpreted interpreter, then it has no attributes associated with it. An interpreter is defined as uninterpreted if we only want to match a terminal (string) in the input but do not need its value in processing the input. Terminals such as keywords (begin, end, while etc.), punctuation symbols are usually defined as uninterpreted.
Type

\[
\text{terminal} \rightarrow \text{interpreter}
\]

Usage

\[
\text{interpreter}_\text{name} = \text{uninterpreted} \ (\text{term}_\text{declaration})
\]

where \text{term}_\text{declaration} could be any one of the following:

- \text{RESERVED\_WORD\_TERM} "reserved_word": reserved_word is declared in Reserved word declaration section,

- \text{SPECIAL\_SYMBOL\_TERM} "special_symbol": special_symbol is declared in Special symbol declaration section,

- \text{INT\_TERM} "any_integer"

- \text{INT\_TERM} any

- \text{REAL\_TERM} "any_real"

- \text{REAL\_TERM} any

- \text{IDENTIFIER\_TERM} "any_identifier"

- \text{IDENTIFIER\_TERM} any

- \text{ANY\_TERM} "any_terminal"

- \text{ANY\_TERM} any
The keyword any acts as a wild-card, meaning that it will match any terminal in the input if it is of type similar to the constructor with which the corresponding any is associated.

Example

```plaintext
%insert <local/header_for_WAGE_VERSION_2_RELEASE_0.m>
attribute
::= LITERAL_VAL terminal
special_symbols
= ['+', '-']
reserved_words
= ['begin', 'end']
type_of_terminals
= uninterpreted SPECIAL_SYMBOL_TERM "+"
$excl_orelse
uninterpreted RESERVEDWORD_TERM "begin"
$excl_orelse
uninterpreted IDENTIFIER TERM any
$excl_orelse
uninterpreted INT TERM "123"
$excl_orelse
uninterpreted REAL TERM any
```

Figure 3.4

105
In Figure 4.5 above,

- `[['[[]],[]]]` denotes that the terminal (string) has been accepted,

- `[]` denotes that the terminal (string) was not accepted.

The terminal 456 was not accepted, because we have defined our interpreter `type_of_terminals` to match only that integer whose value is 123. In the other case, the interpreter successfully accepted identifiers `hi` and `Hello`, because we have defined it to match any legal identifier.

### 3.2.5.3 interpreted

The interpreter constructor `interpreted` accepts the pair `(terminal, attribute)` and returns an interpreter. If an interpreter is defined as an `interpreted` interpreter
then the interpreter has associated with it a set of synthesized attributes values.

Type

\[(\text{terminal, [attribute]})) \rightarrow \text{interpreter}\]

Usage

\[\text{interpreter_name} = \text{interpreted} (\text{term_declaration}, [\text{list_of_attribute_values}])\]

where \text{term_declaration} could be any one of those defined above. The \text{list_of_attribute_values} could be zero or more attribute values of the form:

\[\text{attribute_name} \text{ attribute_value}\]

The type of \text{attribute_value} should be the same as that defined for \text{attribute_name} in the attribute definition section which appears at the beginning of the program. Whenever a terminal in the input string matches an \text{interpreted} definition then the attribute values associated with it become the synthesized attributes of the \text{interpreter_name}. Interpreters defined as \text{interpreted} do not have any inherited attributes, though they may have zero or more synthesized attributes.

\[6\] Inherited attributes cannot be defined for \text{interpreted} interpreters.
Example

```plaintext
\%insert <local/header_for_WAGE_VERSION_2_RELEASE_0.m>
attribute
::= LITERAL VAL terminal
    | VAL num
special_symbols
= []
reserved_words
[ "one", "two", "three" ]
type_of_terminals
= interpreted (RESERVED_WORD_TERM "one", [VAL 1])
  $excl_orelse
interpreted (RESERVED_WORD_TERM "two", [VAL 2])
  $excl_orelse
interpreted (RESERVED_WORD_TERM "three", [VAL 3])
```

Figure 3.6

server.uwindsor.ca

Copyright Research Software Ltd, 1990

(300000 cells)
test3892.m
for help type /help
Miranda apply_interpreter type_of_terminals "one"
  [[[VAL 1],[[]]]]
Miranda apply_interpreter type_of_terminals "two"
  [[[VAL 2],[[]]]]
Miranda apply_interpreter type_of_terminals "three"
  [[[VAL 3],[[]]]]
Miranda

Figure 3.7

108
In the first case, in Figure 4.7 above, since the first interpreter definition option matched input terminal one, type_of_terminals has a synthesized attribute VAL of type num whose value is 1. Similar description applies for the second and third case.

3.2.6 Type of Interpreter Combinators

In W/AGE there are four combinators (functions) that may be used to define new interpreters in terms of other interpreters, namely, $excl_or else, $or else, and structure, also refer to section 4.4.

3.2.6.1 $excl_or else and $or else

These two combinators can be used to define new interpreters, they have the following type:

\[
\text{interpreter} \to \text{interpreter} \to \text{interpreter}
\]

The above type definition means that these two combinators take two interpreters as arguments and return a new interpreter. As an example of their use, consider the following context-free grammar:

\[
\text{integer_or_identifier ::= integer_number} \\
\text{        | identifier}
\]

The above context-free grammar would be coded\(^7\) in W/AGE as:

\(^7\) There are other ways to specify this in W/AGE.
integer_or_identifier =
  literal INT_TERM
  $excl_orelse
  literal IDENTIFIER_TERM

OR

integer_or_identifier =
  literal INT_TERM
  $orelse
  literal IDENTIFIER_TERM

Even though, $excl_orelse and $orelse have similar type and serve a common purpose there exists a subtle difference. Consider the following context-free grammar:

```
plus_expression ::= number
                  | number + plus_expression
```

where number is, say, any integer number. The following is a complete⁸ W/AGE specification for the above grammar:

---

⁸ No semantic actions are specified.
\%insert <local/header_for_WAGE_VERSION_2_RELEASE_0.m>
attribute ::= LITERAL_VAL terminal
special_symbols
= ['\+
] reserved_words
= ()
int_number
= literal INT_TERM
plus_sign
= uninterpreted (SPECIAL_SYMBOL_TERM "+")
plus_expression
= structure (s1 int_number)
[]
sexcl_orelse
structure (s1 int_number ++ s2 plus_sign ++
 s3 plus_expression)
[]

Figure 3.8

After compiling the above program, the result of applying the function

apply_interpreter to plus_expression with 2 as an argument is as shown below:
As shown in Figure 3.9 above, the terminal 2 was successfully accepted, denoted by $\text{[\{\},\{\}]}$. The result of applying the function `apply_interpreter` to `plus_expression` with 4 + 5 as arguments is shown below:
As shown in Figure 4.9 above, the terminals + and 5 failed to parse, but 4 was accepted. The reason for this failure is the way the interpreter combinator $excl_orelse$ works. Consider the following:

```
interpreter_name
  definition_1
  $excl_orelse
  definition_2
  $excl_orelse
  ...
  $excl_orelse
  definition_n
```

If an interpreter definition has the above structure, then definition_1 is first applied to the input string. If it succeeds, then interpreter_name succeeds; no matter if there are still input symbols to be consumed. If definition_1 fails, only
then \texttt{definition.2} is applied to the input string. This process goes on until at least one definition succeeds, in which case the application of \texttt{interpreter_name} succeeds, or all of them fail, in which case the application of \texttt{interpreter_name} fails.

In our example case, the interpreter \texttt{int.number} is first applied to the input string $4 + 5$. This interpreter successfully consumes the first terminal, 4, and succeeds, and as a result the application of the interpreter \texttt{plus_expression} succeeds even though there are remaining input symbols to be processed. The listing shown below is one way to get around this problem.

\begin{verbatim}
$insert <local/header_for_WAGE_VERSION_2_RELEASE_0.m>
$attribute
  LITERAL_VAL terminal
special_symbols
  ['+']
reserved_words
[]
int_number
  literal INT_TERM
plus_sign
  uninterpreted (SPECIAL_SYMBOL_TERM "+")
plus_expression
  structure (s1 int_number ++ s2 plus_sign ++ s3 plus_expression)
[]
$exclusive_or
  structure (s1 int_number)
[]
\end{verbatim}

Figure 3.11

The listing above is similar to the previous one, except that the position of the two right hand side interpreter definition for \texttt{plus_expression} is interchanged.
In this case, the first right hand side interpreter definition for `plus_expression` is applied to `4 + 5`. The interpreters `int_number` and `plus_sign` successfully consume the terminals 4 and +, respectively. The interpreter `plus_expression` is then recursively applied to the remaining terminal, namely, 5. Now, as it is self-explanatory, the application of the first right hand side interpreter definition for `plus_expression` to 5 will fail and as a result the second right hand side interpreter definition is applied, which succeeds. As a result, the recursive call made to `plus_expression` succeeds, which results in the success of the initial application of `plus_expression` to the input string `4 + 5`.

The other way to get around the problem is to use the other interpreter combinator, *viz.*, `$orelse`. The only difference between `$exc_orelse` and `$orelse` is that the latter parses the input string to be processed in *all* possible ways. The above example could be rewritten using `$orelse` as shown below:
The result of applying the function `apply_interpreter` to `plus_expression` and the input string `4 + 5` is shown below:
As shown in the figure above, the string was parsed in two different ways. The application of the first right hand side interpreter definition for plus_expression to the input string failed, while the application of the second right hand side interpreter definition succeeded.

The combinator $\text{sexcl_orelse}$ is used to improve efficiency but care should be taken in the order in which alternatives are listed in a production so that correct parses are not missed.

### 3.2.6.2 structure

This function (interpreter combinator) takes in a list of interpreters and a list
of semantic rules\(^9\) and creates a new interpreter.

---

\(^9\) The list of semantic may be empty.
Type

structure :: list_of_numbered_interpreters -->
  list_of_attribute_rules -->
  interpreters

where,
list_of_numbered_interpreters == [{(num, interpreter)}]
list_of_attribute_rules == [{(num, att_id, att_function
  , [att_id])}]

where,
att_id == {(num, att_direction), att_type}
att_function == [attribute] --> attribute
att_type == [char]
att_direction ::= 'UP' | 'DOWN'

Usage

    interpreter_name = structure (s1 interpreter_name1 ++ ... ++ s_n
    interpreter_name_n)

[ list_of_semantic_rules ]

where each semantic rule in the list_of_semantic_rules specifies the depen-
dency of the value of a synthesized or inherited attribute as a function of the value
of other synthesized or inherited attributes.

In W/AEG, there are three types of semantic rules:

* i_rule: this is an initialization rule and is used when the value of an attribute
  needs to be initialized.
• **e_rule:** this is a copy rule, and is used when the value of an attribute is to be simply copied to another attribute; the name and type of the two attributes should be the same.

• **a_rule:** this is an application rule and is used when the value of an attribute is a function of one or more than one attributes.

**Example**

Figure 3.12 illustrates the use of the interpreter combinator, *structure*. 
§ 4.1 Basics

4.1.1 Generating WAGE-ed

As mentioned in section 5.3, there are two versions of WAGE-ed, viz., guarded and unguarded editors. Guarded editors support left recursive interpreter definitions, whereas unguarded editors do not support left recursive interpreter definitions. Each version has five editors, the editors are distinguished from one another depending upon their level of versatility.

In order to generate an editor from an editor specification, type

```
sgen -o output_file -kernel ATO input_file
```

where `output_file` is an executable editor and `input_file` is the file containing the editor specification.

Note that the specification for WAGE-ed has been compiled using the ATO kernel. It will not compile using the ORDERED kernel, which is the default kernel used for compiling SSL specification, and works only for the ordered subclass of attribute grammars. Attribute grammar specification for WAGE-ed is unordered, therefore the specification will not compile with the new version of the Synthesizer Generator viz. version 4.0 because it supports only ORDERED kernel. However, the ATO kernel will be included in future versions of the Synthesizer Generator.
The editor for W/AGE available on our system is an unguarded wage_editor and was generated using the command,

sgen -o xwageedit -kernel ATO wage_editor.ssl

4.1.2 Invoking WAGE-ed

In order to invoke WAGE-ed on our system, type:

xwageedit[filename]

where the optional filename is the name of a file previously saved as structured or attribute form using WAGE-ed. If filename does not exist, then the program to be currently edited will be held in the buffer named filename.

xwageedit does not support left-recursive interpreter definitions, prohibits development of syntactically incorrect programs and performs various checking on attributes values and attribute definitions.

4.1.3 Exiting out of WAGE-ed

To exit from WAGE-ed, select exit from the Edit option or use 'C.

4.1.4 Saving Buffers

In order to save a program, select write-named-file from the File option. If the program is to be edited later, then it must be saved either in structure or attributed form. If the program is to be saved as text for compilation, then choose text form.
Note that a program saved as text cannot be re-edited using WAGE-ed later. Therefore, it is advisable to save a program in text and structure/attributed form.

§ 4.2 Using WAGE-ed

4.2.1 File Inclusion Section

In order to enter the header file, select <path>. Since no transformations are listed for <path>, text can be entered. In general, text can be entered from the keyboard if no transformations, listed in the help pane, are associated with a placeholder. The <path> placeholder can only be refined with alphanumeric characters, starting with an alphabet and may contain embedded underscores. The last pathname component may have a .m extension. Each component of the pathname must be entered one at a time. For example, in order to enter local/header_for_WAGE_VERSION_2_RELEASE_0.m after selecting <path> and keying in local, to enter header_for_WAGE_VERSION_2_RELEASE_0.m we have to get another <path> placeholder. To get one, select forward-sibling-with-optionals from the Cursor menu option or hit return key twice. If additional files are to be included, the template for entering pathname can be introduced by highlighting %insert which selects the entire declaration and then entering a sequence of return keys until a %insert template is obtained or by selecting forward-sibling-with-optionals from the Cursor menu option.
In order to delete any path component, highlight it and then choose delete-selection from the Edit menu option.

4.2.2 Attribute Declaration Section

Attribute names and their type can be declared by selecting <attribute_name> and <attribute_type> placeholders respectively. The <attribute_name> placeholder has no associated transformations, and it can only be refined by entering capital alphabetic characters, starting with an alphabet and may contain embedded underscores. In order to delete an attribute name, highlight it and then choose delete-selection from the Edit menu option.

The <attribute_type> placeholder has transformations associated with it. In order to refine it, select one of the choices from the help pane. User defined types can be entered by selecting User_DEFINED_Type from the help pane. In order to delete an attribute type, highlight it and then choose delete-selection from the Edit menu option.

Additional templates for declaring attribute names and their types can be obtained in one of the following ways:

- by clicking the left mouse button between the space separating the name and the type, this selects the entire declaration and then using forward-sibling-with-optionals or backward-sibling-with-optionals from the Cursor menu option,
- by clicking the left mouse button between the space separating the name and the type, this selects the entire declaration and then entering a sequence of return keys until a template for entering attribute name and type appears, or
- by highlighting the attribute type and then using `forward-sibling-with-optionals` from the Cursor menu option.

In order to delete an entire single attribute declaration i.e. an attribute name and its type, click the left mouse button between the space separating the name and the type, this selects the entire declaration and then use `delete-selection` from the Edit menu option.

4.2.3 Reserved Word Declaration Section

In order to declare reserved words, click the left mouse button on the keyword `reserved_words`, this selects the entire reserved word declaration section. Now select `insert_reserved_words` from the help pane, this introduces the `<reserved_word>` placeholder to enter a reserved word. A reserved word can be any word consisting of alphanumeric characters, starting with an alphabet and may contain underscores.

Additional placeholders for entering reserved words can be obtained in one of the following ways:

- if there is only a single declaration, then select the entire declaration by clicking the left mouse button on the keyword `reserved_words` and then choose
*forward-with-optionals* from the **Cursor** menu option.

- if there is more than one declaration, then select a declaration, and then choose *forward-with-optionals* from the **Cursor** menu option,

- if there is more than one declaration, except the first one, and then choose *backward-with-optionals* from the **Cursor** menu option,

- by clicking the left mouse button on a declaration this selects the declaration and then entering a sequence of return keys until a `<reserved_word>` placeholder appears.

In order to delete a reserved word declaration, highlight it and then choose *delete-selection* from the **Edit** menu option.

4.2.4 Special Symbol Declaration Section

In order to declare reserved words, click the left mouse button on the keyword *special_symbols*, this selects the entire special symbols declaration section. Now select *insert_spec_symbols* from the help pane, this introduces the `<spec_symbols>` placeholder to enter a special symbol. A special symbol can be any character, other than alphanumeric characters.

Additional placeholders for entering special symbols can be obtained in one of the following ways:

- if there is only a single declaration, then select the entire declaration by clicking the left mouse button on the keyword *special_symbols* and then choose
\textit{forward-with-optionals} from the \texttt{Cursor} menu option,

- if there is more than one declaration, then select a declaration, and then choose \textit{forward-with-optionals} from the \texttt{Cursor} menu option,

- if there is more than one declaration, except the first one, and then choose \textit{backward-with-optionals} from the \texttt{Cursor} menu option,

- by clicking the left mouse button on a declaration this selects the declaration and then entering a sequence of return keys until a \texttt{<spec_symbols>} placeholder appears.

In order to delete a special symbol declaration, highlight it and then choose \textit{delete-selection} from the \texttt{Edit} menu option.

4.2.5 Interpreter Definition Section

An interpreter in \texttt{W/AGE} may be one of \texttt{interpreted}, \texttt{uninterpreted}, \texttt{literal}, \texttt{recognised}, \texttt{guarded}, or \texttt{structured} type. A template for defining interpreter can be obtained by selecting \texttt{<interpreter>} placeholder and then transforming it into one of the above mentioned types by making a selection from the help pane.

In order to delete an entire interpreter definition select the entire definition by clicking on the equal sign and then using \textit{delete-selection} from the \texttt{Edit} option. Templates for defining additional interpreters can be obtained, by selecting a previously entered interpreter definition (click on the equal sign) and then using
forward-sibling-with-optionals or backward-sibling-with-optionals, this action will introduce an <interpreter> placeholder.

An interpreter defined as literal interpreter, has automatically associated with it a synthesized attribute LITERAL VAL of user-defined type terminal.

An interpreter defined as an interpreted interpreter, may have one or more than one synthesized attributes associated with it.

An interpreter defined as an uninterpreted interpreter, has no attributes associated with it.

An interpreter defined as a recognised interpreter, has no semantic rules associated with it. The interpreter definition should be non-left-recursive.

An interpreter defined as a guarded interpreter is similar to a structured interpreter except that it has a guard (a recognised interpreter) and it can have left-recursive productions. The guard is applied to the input data, if it terminates only then the left-recursive definitions following the guard are applied to the input data.

An interpreter defined as a structured interpreter, may have one or more synthesized or inherited attributes associated with it. Semantic rules for productions can be entered by clicking on the keyword structure associated with the production, this introduces the <semantic_rule> placeholder. The <semantic_rule> placeholder can be transformed, by making a sequence of selections from the
help pane, into a template for entering an attribute equation for a synthesized or inherited attribute.

An attribute equation can be deleted by clicking on the rule number, this selects it, and then using *delete-selection*. Templates for entering additional attribute equations can be introduced by first introducing the `<semantic_rule>` placeholder. To introduce the `<semantic_rule>` placeholder select a previously entered semantic rule and then use `forward-sibling-with-optionals` or `backward-sibling-with-optionals`.

The attribute equations for inherited attributes must come before the attribute equations for synthesized attributes in the set of semantic rules associated with a production.

When an `<inteptr_defn>` placeholder is refined by clicking on show listed in the help pane, it gets transformed as shown below
If the right hand side of an interpreter consists of only one production, then in order to get rid of the \(<separator>\) placeholder and the second structure template click on the \(<separator>\) placeholder which will select it and then click back on the immediately preceding structure definition. The following two figures illustrate this operation.
special_symbols = []

<interptr_name>
= structure ( s1 <interptr_name> )
[]    <separator>
structure ( s1 <interptr_name> )
[]
Suppose, we need additional structure templates: select the keyword **structure** and then use *forward-sibling-with-optionals* or *backward-sibling-with-optionals* or enter a series of returns. In order to delete a right hand side production and its associated semantic rules select it by clicking on the associated **structure** keyword and then use **delete-selection**.

The *<separator>* placeholder can be refined by making a selection from the help pane. A refined *<separator>* placeholder can be deleted, by selecting it and
then using *delete-selection*.

§ 4.3 Editor Commands

4.3.1 Executing Commands

In WAGE-ed, commands can be executed in the following four ways:

- A command may be bound to a sequence of keystrokes.
- A command may be selected from the pop-up menu.
- A command name may be typed on the command line of a window.

In order to enter a command name on the command line, the *execute-command*, bound to TAB, must be invoked. Certain commands may need some extra parameters. The parameters are entered using a *parameter form* which appears as soon as the command is executed. After the parameters have been entered they are passed to the command by executing *start-command*. A command may be canceled at any time while entering its parameter by executing *cancel-command*. The following table contains a summary for executing commands through command line.
<table>
<thead>
<tr>
<th>Command</th>
<th>Control Keys</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>execute-command <em>name</em></td>
<td>TAB <em>name</em></td>
<td>execute the command <em>name</em></td>
</tr>
<tr>
<td>illegal-operation</td>
<td>ESC-¨G, ¨G, ¨X¨G</td>
<td>cancel any incomplete command key-binding or partial entry on the command line</td>
</tr>
<tr>
<td>start-command</td>
<td>ESC-s</td>
<td>initiates execution of a command with parameters contained in the parameter form</td>
</tr>
<tr>
<td>cancel-command</td>
<td>ESC-c</td>
<td>cancel execution of a command awaiting completion of its parameter form</td>
</tr>
<tr>
<td>execute-monitor-command</td>
<td>¨X!</td>
<td><em>command-line</em> is passed to UNIX to be executed as a command.</td>
</tr>
<tr>
<td>repeat-command</td>
<td>ESC-r</td>
<td>repeat the most recently initiated command. If the command had parameters then use the same parameters</td>
</tr>
<tr>
<td>return-to-monitor</td>
<td></td>
<td>call the UNIX shell</td>
</tr>
</tbody>
</table>
4.3.2 Transforms

If the current selection has any transformation(s) associated with it, then selection of this option will bring down a pull-down menu which will list all the legal transformations. These transformations are also listed at the bottom of the screen. The user has the choice of selecting a transformation either from the pull-down menu or making a selection\textsuperscript{10} from the bottom of the screen.

If the current selection does not have any transformation(s) associated with it, then no pull-down menu will appear. In this case, WAGE-ed expects the user to key in text from the keyboard in order to refine the current selection.

\textsuperscript{10} All selections in WAGE-ed are made by placing the mouse arrow on the text to be selected and then clicking the left mouse button.
### 4.3.3 Edit Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Control Keys</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>apropos keyword</code></td>
<td>ESC-?</td>
<td>lists all commands containing the keyword as a syllable or as a prefix of a syllable</td>
</tr>
<tr>
<td>text-capture</td>
<td></td>
<td>captures the text of the current selection into a text buffer. It fails if the current selection prohibits text entry</td>
</tr>
<tr>
<td>undo</td>
<td>^X^U</td>
<td>deletes the contents of a text buffer</td>
</tr>
<tr>
<td>cut-to-clipped</td>
<td>^W</td>
<td>moves the current selection to the buffer CLIPPED</td>
</tr>
<tr>
<td>copy-to-clipped</td>
<td>ESC-^W</td>
<td>copies the current selection to the buffer CLIPPED</td>
</tr>
<tr>
<td>paste-from-clipped</td>
<td>^Y</td>
<td>moves the contents of the CLIPPED buffer to the current selection, which must be a placeholder</td>
</tr>
<tr>
<td>copy-from-clipped</td>
<td>ESC-^Y</td>
<td>copies the contents of the CLIPPED buffer to the current selection ,which must be a placeholder</td>
</tr>
<tr>
<td>Command</td>
<td>Control Keys</td>
<td>Description</td>
</tr>
<tr>
<td>-------------------------</td>
<td>--------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>copy-text-from-clipped</td>
<td>ESC-&quot;T</td>
<td>copies the contents of the CLIPPED buffer, as text, into a text buffer at the current selection immediately preceding the character selection</td>
</tr>
<tr>
<td>delete-selection</td>
<td>^K</td>
<td>moves the contents of the current selection to the buffer DELETED</td>
</tr>
</tbody>
</table>

4.3.4 Cursor Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Control Keys</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ascend-to-parent</td>
<td>ESC-\</td>
<td>changes the selection to the closest enclosing resting place</td>
</tr>
<tr>
<td>forward-preorder</td>
<td>^N</td>
<td>changes the selection to the next resting place in forward preorder traversal of the abstract syntax tree, does not stop at optional placeholders</td>
</tr>
<tr>
<td>forward-with-optionals</td>
<td>^M</td>
<td>changes the selection to the next resting place in forward preorder traversal of the abstract syntax tree, stops at optional placeholder</td>
</tr>
<tr>
<td><strong>forward-sibling</strong></td>
<td>ESC-(^N)</td>
<td>bypasses all resting place, without stopping at optional placeholders, contained within the current selection and advance to the next sibling in forward preorder traversal of the abstract syntax tree. If there is no next sibling, ascend to the enclosing resting place and advance to its next sibling</td>
</tr>
<tr>
<td><strong>forward-sibling-with-optionals</strong></td>
<td>ESC-(^M)</td>
<td>similar to forward-sibling, but stops at optional placeholders</td>
</tr>
<tr>
<td><strong>backward-preorder</strong></td>
<td>(^P)</td>
<td>changes the selection to the previous resting place in forward preorder traversal of the abstract syntax tree, does not stop at optional placeholders</td>
</tr>
<tr>
<td><strong>backward-with-optionals</strong></td>
<td>(^H)</td>
<td>similar to backward-preorder, but stops at optional placeholders</td>
</tr>
<tr>
<td><strong>backward-sibling</strong></td>
<td>ESC-(^P)</td>
<td>bypasses all resting places, without stopping at optional placeholders, contained within the current selection and advances to the previous sibling in forward preorder traversal of the abstract syntax tree. If there is no next sibling, then ascend to the enclosing resting place and advance to its next sibling</td>
</tr>
<tr>
<td>Command</td>
<td>Control Keys</td>
<td>Description</td>
</tr>
<tr>
<td>--------------------------</td>
<td>--------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>read-file <em>filename</em></td>
<td>&quot;X&quot;F, &quot;X&quot;R</td>
<td>reads in a file previously saved in text, structured, or attributed form</td>
</tr>
<tr>
<td>visit-file <em>filename</em></td>
<td>&quot;X&quot;V</td>
<td>reads a named file into a buffer with the same name. If a buffer already exists with that name, then a new buffer is created with that name suffixed by some integer i</td>
</tr>
<tr>
<td>insert-file <em>filename</em></td>
<td>&quot;X&quot;I</td>
<td>replaces the current selection with the contents of <em>filename</em></td>
</tr>
<tr>
<td>Command</td>
<td>Control Keys</td>
<td>Description</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>--------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>write-current-file</td>
<td>^Xs</td>
<td>writes the contents/value of the current buffer in the format associated with the buffer to its associated file</td>
</tr>
<tr>
<td>write-named-file filename format</td>
<td>^X^W</td>
<td>writes the contents of the current buffer to filename in the format specified. The default is attributed, other formats are structure and text</td>
</tr>
<tr>
<td>write-selection-to-file filename format</td>
<td></td>
<td>writes the current selection to filename in the format specified</td>
</tr>
<tr>
<td>write-modified-files</td>
<td>^X^M</td>
<td>writes the contents of every modified buffer to its associated file in the current format associated with the buffer</td>
</tr>
<tr>
<td>write-file-exit</td>
<td>^Xf</td>
<td>exits the editor after performing an operation similar to write-modified-files</td>
</tr>
<tr>
<td>write-attribute attribute-name filename</td>
<td></td>
<td>writes attribute-name of the current selection to filename in textual format</td>
</tr>
</tbody>
</table>

### 4.3.6 Buffer Commands
<table>
<thead>
<tr>
<th>Command</th>
<th>Control Keys</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>list-buffers</td>
<td>&quot;X&quot;B</td>
<td>lists all buffers and their associated properties</td>
</tr>
<tr>
<td>switch-to-buffer</td>
<td>&quot;Xb&quot;</td>
<td>places the buffer-name in the current window. If no such buffer exist, then create a new buffer</td>
</tr>
<tr>
<td>buffer-name</td>
<td></td>
<td></td>
</tr>
<tr>
<td>new-buffer</td>
<td></td>
<td>creates a new buffer, in the current window, called as buffer-name and is initialized with the placeholder term of phylum. If buffer-name already exist, then the command is invalid</td>
</tr>
<tr>
<td>buffer-name phylum</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.3.7 Window Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Control Keys</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>split-current-window</td>
<td>&quot;X2&quot;</td>
<td>creates a new window and displays the same buffer in both the windows</td>
</tr>
<tr>
<td>delete-other-windows</td>
<td>&quot;X1&quot;</td>
<td>deletes all windows, except the current one</td>
</tr>
<tr>
<td>delete-window</td>
<td>&quot;Xd&quot;</td>
<td>deletes the current window</td>
</tr>
</tbody>
</table>

4.3.8 Search Command

<table>
<thead>
<tr>
<th>Command</th>
<th>Control Keys</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>search-forward text</td>
<td>ESC-^F</td>
<td>searches forward from the current selection for text in preorder traversal of the tree and wraps around to the root after reaching the end of the object</td>
</tr>
<tr>
<td>---------------------</td>
<td>--------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>search-backward text</td>
<td>ESC-^R</td>
<td>searches backward from the current selection for text in preorder traversal of the tree and wraps around to the rightmost leaf and continues searching after reaching the root of the object</td>
</tr>
</tbody>
</table>

### 4.3.9 Optional Commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Control Keys</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>set-parameters</td>
<td></td>
<td>allows the modification of global editor parameters</td>
</tr>
<tr>
<td>help-off</td>
<td></td>
<td>reduces the size of the help pane to zero</td>
</tr>
<tr>
<td>help-on</td>
<td></td>
<td>resets the size of the help pane to the default size</td>
</tr>
<tr>
<td>enlarge-help</td>
<td>ESC-^Xz</td>
<td>increases the size of the help pane of the current window by a line</td>
</tr>
<tr>
<td>Command</td>
<td>Key</td>
<td>Description</td>
</tr>
<tr>
<td>------------------</td>
<td>---------</td>
<td>-------------------------------------------------------</td>
</tr>
<tr>
<td>shrink-help</td>
<td>ESC-&quot;X&quot;Z</td>
<td>reduces the size of the help pane of the current window by a line</td>
</tr>
<tr>
<td>show-copyright</td>
<td></td>
<td>displays copyright information</td>
</tr>
</tbody>
</table>

§ 4.4 Error Messages

When an attribute grammar specification is developed using **WAGE-ed**, it might be annotated with various warning messages. These warning messages arise if the program being edited violates any constraints. The warning messages serve to notify the user that an error exists in the program and may result in compilation errors, although **WAGE-ed** does not constrain the user in correcting them as soon as they appear.

An explanation about the cause of each warning message is given below.

**Inconsistent Synthesized Attribute Definition**

When the left hand side nonterminal has associated with it more than one definition (productions), then semantic rules associated with each production must pass the same set of synthesized attributes up the left hand side nonterminal. If this constraint is violated, then the program is annotated with **{INCOMP. SYNTH. ATTR.}** warning message.
Undefined Attributes, Special Symbols and Reserved Words

If the attribute grammar specification being developed using \texttt{WAGE-ed} makes use of attributes, special symbols and reserved words which are not declared in attribute, special symbol, reserved word declaration section respectively, then \texttt{WAGE-ed} displays \{\texttt{UNDEFINED}\} warning message at locations in the program where the undeclared attribute, special symbol or reserved word is used.

Misuse of Reserved Word

If an interpreter is defined as an uninterpreted or interpreted interpreter to recognize a particular identifier in the input string, but if that identifier is predeclared as a reserved word then the interpreter definition is annotated with \{\texttt{RESERVED WORD TERM}\} message, notifying the user that the identifier is declared as a reserved word in the reserved word declaration section.

Multiple Attribute Definition

If an attribute is multiply defined in the attribute declaration section or if the semantic rules associated with a production contains more than one attribute equation synthesizing the same attribute up the left hand side nonterminal or inheriting the same attribute down to one of the right hand side nonterminal, then the program is annotated with the message \{\texttt{ATTR. MULTIPLY DEFN.}\}.
Left Recursive Definitions

If an unguarded WAGE-ed is used to develop an attribute grammar specification and if the definition for a structured interpreter contains left recursion, then the interpreter name (left hand side nonterminal) is juxtaposed with the message \{DEFN. CONTAINS LEFT RECURSION\}.

Multiple Interpreter Definition

If more than one interpreter definitions contain the same left hand side nonterminal name, then the interpreter name is juxtaposed with the message \{INTERPRETER ALREADY DEFINED\}.

Missing Inherited Attribute Equation

If a semantic rule associated with a production makes use of an inherited attribute value but if that attribute value is not available at the left hand side nonterminal, say \(x\), of a production, then every occurrence of the nonterminal \(x\) used in the right hand side definition of all structured interpreter definitions are juxtaposed with the message \{MISSING INH. ATTR. EQN\}.

This notifies the user that the semantic rules associated with the production containing the message require an attribute equation for an inherited attribute.

Note: This warning message might still be there even if the attribute equation passes down an inherited attribute to a nonterminal (interpreter) appearing on
the right hand side of a production. This happens if attribute equation(s) for synthesized attribute(s) are defined before the attribute equation(s) for inherited attribute(s) in the collection of semantic rules associated with the production. To get rid of this make sure that attribute equation(s) for inherited attribute(s) are defined before the attribute equation(s) for synthesized attribute(s) in the collection semantic rules.

Type Mismatch

If a semantic rule is either an initialization or copy rule, then the name of the attribute on the left hand side of the EQ symbol must be the same as name on the right hand side or vice-versa. If this constraint is violated, then the semantic rule which violates this constraint is annotated with the message {TYPE MISMATCH}.

Circular Synthesized Attribute Definition

If the value of an attribute being synthesized up the left hand side nonterminal is a function of itself, then such an erroneous semantic rule is annotated with the message {CIRC. ATTR. DEFN.}.

Use of Undefined Synthesized Attribute Value

Reference in a semantic rule to a synthesized attribute value which has not been synthesized up an interpreter causes WAGE-ed to annotate the semantic rule which contains the reference with the message {ERROR}.
Reference to Undefined Interpreters

If a reference is made to an interpreter name, in a semantic rule, which does not appear on the right hand side of an interpreter definition then the definition is annotated with the message {UNDEFINED INTR.}.

Use of Undefined Guards

If an interpreter is used as a guard in the definition of a guarded interpreter, but has not been defined as a non-left-recursive recognised interpreter, then the interpreter name is juxtaposed with the message {NOT RECOGNISED INTR.}. 
Due to space limitation, only the source code for unguarded wage_editor (fully-fledged editor for W/A GE) is included here. Source code for other editor specification can be obtained from the School of Computer Science.

```
/* Declaration of Lexemes */

NUMBER     < "num" >
CHARACTER  < "char" >
BOOLEAN    < "bool" >
ANY        < "any" >
EMPTY_TYPE < "()" >
START      < "{" >
END        < "}" >
SEPARATOR  < "semicolon" >
            < ";" >
RESWORDTERM < "RESERVEDWORDTERM" >
SPCSYMTERM  < "SPECIALSYMBOLTERM" >
INTTERM     < "INTTERM" >
REALTERM    < "REALTERM" >
ANYTERM     < "ANYTERM" >
IDENTTERM  < "IDENTIFIERTERM" >
INTEGER     < [0-9]+ >
FLOAT       < [0-9]+ \* [0-9]+ >
ATTRIBUTE   < [A-Z][A-Za-z]* [A-Z] >
SYMBOL      < [a-zA-Z-0-9]+ >
ALPHANUMERIC < [a-zA-Z][a-zA-Z-0-9]+ >
RESWORD     < [a-zA-Z][a-zA-Z-0-9]+ >
DIRNAME     < [a-zA-Z][a-zA-Z-0-9]+* >
FILENAME    < [a-zA-Z][a-zA-Z-0-9]+*.* >
TERM        < [\[] [a-zA-Z-0-9;\"\-'\%\&{\}_\+=|,<>./\:\/\-\" ]+ >
WHITESPACE  < [\t\n] >
```
list_of_attr_decl { synthesized ATTRIB_LIST attr_name_list;};
attr_decl_list { synthesized ATTRIB_LIST attr_name_list;};
attr_decl { synthesized ATTRIB attr;};
attr_name { synthesized ATTRIB attr;};
decl_of_res_words { synthesized RES_WORD_LIST res_word_table; };
list_of_res_words { inherited RES_WORD_LIST res_word_list;
synthesized RES_WORD_LIST res_word_table; };
res_word { synthesized STR resword; };
decl_of_spec_symbols { synthesized SPEC_SYMBOL_LIST spec_sym_table; };
list_of_spec_symbols { inherited SPEC_SYMBOL_LIST spec_sym_list;
synthesized SPEC_SYMBOL_LIST spec_sym_table; };
spec_sym { synthesized spec_sym spec_sym; };
decl_of_interpreters { inherited SYNTHETIC_ATTR_LIST synth_list;
inherited LIST_INTERPRETERS intprtr_list;
inherited INT Inh_int;
/* INH */
inherited INH_ATTR_LIST inh_sym_table; };
types_of_interprtr { inherited LIST_INTERPRETERS intprtr_list;
synthesized ALPHANUMERIC name_of_interprtr;
synthesized ATTRIB_LIST attr_list;
inherited INT int_Inh;
synthesized INT int_sym;
/* INH */
synthesized ATTRIB_LIST u_inh_attr_list; };
an_interprtr_defn { synthesized ATTRIB_LIST attr_list;
synthesized ALPHANUMERIC name_of_interprtr;
inherited LIST_INTERPRETERS intprtr_list; };
interpreter_defn { synthesized ATTRIB_LIST attr_list; };
definition { synthesized ATTRIB_LIST attr_list; };
res_key_word { synthesized STR key_word; };
spec_sym_key_word { synthesized STR key_word; };
int_key_word { synthesized STR key_word; };
real_key_word { synthesized STR key_word; };
ident_key_word { synthesized STR key_word; };
any_term_key_word { synthesized STR key_word; };
op_list_of_interpreter_defn { inherited ATTRIB_LIST attr_list; };
op_decl { synthesized ATTRIB_LIST attr_list; };
list_of_intr_attr_decl { synthesized ATTRIB_LIST attr_list; };
intr_attr_decl { synthesized ATTRIB attr; };
an_interpreter_defn { synthesized ALPHANUMERIC name_of_interprtr;
inherited LIST_INTERPRETERS intprtr_list; };
ident_str { synthesized STR resword; };
spec_ident_str { synthesized STR resword; };

150
literal_interpstr_def  { synthesized ALPHANUMERIC name_of_interpstr;
    synthesized ATTRIB LIST attr_list;
  inherited LIST_INTERPRTRS interpstr_list; }

literal_decl  { synthesized ATTRIB LIST attr_list; }

structured_defn  { inherited LIST_INTERPRTRRS interpstr_list;
    synthesized ALPHANUMERIC name_of_interpstr;
    synthesized ATTRIB LIST attr_list;
    inherited INT int_inh;
    synthesized INT int_synh;
    /* INH */
    synthesized ATTRIB LIST u_inh_attr_list; }

interpstr_name  { inherited LIST_INTERPRTRRS interpstr_list;
    synthesized ALPHANUMERIC name_of_interpstr; }

interpstr_defn  { inherited LIST_INTERPRTRRS interpstr_list;
    synthesized ATTRIB LIST attr_list;
    synthesized LR_INTERPRTRR NAMES lr_interpstr_names;
    inherited INT int_inh;
    inherited INT frac_inh;
    /* INH */
    synthesized ATTRIB LIST u_inh_attr_list; }

mandatory_defn  { synthesized ATTRIB LIST mand_attr_list;
    inherited LIST_INTERPRTRRS interpstr_list;
    synthesized ALPHANUMERIC name_of_interpstr;
    inherited INT int_inh;
    inherited INT frac_inh;
    synthesized INT frac_synh;
    /* INH */
    inherited ATTRIB LIST d_inh_attr_list;
    synthesized ATTRIB LIST u_inh_attr_list; }

list_of_rhs_interpstr_names  { inherited LIST_INTERPRTRRS interpstr_list;
    synthesized LOC_LIST_INTERPRTRRS loc_list_interpstrs;
    synthesized ALPHANUMERIC name_of interpstr;
    inherited INT num;
    /* INH */
    inherited LIST_ATTR_INT_PAIR laip; }

rhs_interpstr_name  { synthesized ALPHANUMERIC name_of_interpstr; }

list_of_semantic_rules  { inherited ATTRIB LIST inh_attr_list;
    synthesized ATTRIB LIST synh_attr_list;
    inherited LOC_LIST_INTERPRTRRS loc_list_interpstrs;
    inherited INT int_inh;
    inherited INT frac_inh;
    synthesized INT frac_synh;
    /* INH */
    inherited ATTRIB LIST d_inh_attr_list;
    synthesized ATTRIB LIST u_inh_attr_list;
    synthesized LIST_ATTR_INT_PAIR laip; }

semantic_rule  { synthesized ATTRIB attr;
    inherited LOC_LIST_INTERPRTRRS loc_list_interpstrs;
    inherited INT int_inh;
    inherited INT frac_inh;
    /* INH */
    inherited ATTRIB LIST d_inh_attr_list;
    synthesized ATTRIB LIST u_inh_attr_list;
    synthesized ATTRIB_PAIR alp; }

init_rule  { synthesized ATTRIB attr;
    inherited INT int_inh;
    inherited INT frac_inh;
    inherited LOC_LIST_INTERPRTRRS loc_list_interpstrs;
    /* INH */
    synthesized ATTRIB_PAIR alp; }

copy_rule  { synthesized ATTRIB attr;
inherited LOC_LIST_INTERPRETERS loc_list_interprtrs;
inherited INT int_inh;
inherited INT frac_inh;
  /* INH */
inherited ATTRIB_LIST d_inh_attr_list;
synthesized ATTRIB_LIST u_inh_attr_list;
synthesized ATTR_INT_PAIR alp; }

appl_rule { synthesized ATTRIB attr;
inherited LOC_LIST_INTERPRETERS loc_list_interprtrs;
inherited INT int_inh;
inherited INT frac_inh;
  /* INH */
inherited ATTRIB_LIST d_inh_attr_list;
synthesized ATTRIB_LIST u_inh_attr_list;
synthesized ATTR_INT_PAIR alp; }

list_of_rhs_attr_type { inherited LOC_LIST_INTERPRETERS loc_list_interprtrs;
synthesized ATTRIB_LIST circ_lhs_attr_list;
  /* INH */
inherited ATTRIB_LIST d_inh_attr_list;
synthesized ATTRIB_LIST u_inh_attr_list; 1;
}
synh_rhs_attr_type { inherited LOC_LIST_INTERPRETERS loc_list_interprtrs;
synthesized ATTRIB attr;
synthesized ATTR_INT_PAIR alp; }
synthesized ATTRIB circ_lhs_attr; }

synh_lhs_attr_type { synthesized ATTRIB attr; }
inh_lhs_attr_type { inherited LOC_LIST_INTERPRETERS loc_list_interprtrs;
  /* INH */
synthesized ATTR_INT_PAIR alp;
synthesized ATTRIB lhs_lhs_attr; 1;
}
inh_rhs_attr_type { synthesized ATTRIB lhs_rhs_attr;
  /* INH */
};
inlh_or_synh_type { synthesized ATTRIB attr;
inherited LOC_LIST_INTERPRETERS loc_list_interprtrs;
synthesized ATTRIB circ_lhs_attr;
  /* INH */
inherited ATTRIB_LIST d_inh_attr_list;
synthesized ATTRIB_LIST u_inh_attr_list;
synthesized ATTRIB lhs_rhs_attr; 1;
}

interprtr_number { synthesized INT num; 1; }

optional_list_of_defs { inherited ATTRIB_LIST inhopt_attr_list;
inherited LIST_INTERPRETERS interprtr_list;
synthesized LIST_INTERPRETH_NAMES lr_interprtr_names;
inherited INT int_inh;
inherited INT frac_inh;
  /* INH */
inherited ATTRIB_LIST d_inh_attr_list;
synthesized ATTRIB_LIST u_inh_attr_list; 1;
}
op_defn { synthesized ATTRIB_LIST attr_list;
inherited LIST_INTERPRETERS interprtr_list;
synthesized ALPHANUMERIC name_of_interprtr;
inherited INT int_inh;
inherited INT frac_inh;
synthesized INT frac_synh;
  /* INH */
inherited ATTRIB_LIST d_inh_attr_list;
synthesized ATTRIB_LIST u_inh_attr_list; 1;
}
```c
/* Abstract Syntax */

run: prog;
prog : Prog(header_files list_of_attr_decl decl_of_res_words decl_of_spec_symbols decl_of_interpreters);

/* SSL Specification for File Inclusion Section in W/AGE */

list header_files;
header_files : HeaderNil()
             | HeaderFiles(path header_files)
             ;

list path;
path : PathNil()
      | PathDecl(pathname path)
      ;

pathname : PathNameNil()
          | PathCapName(ATTRIBUTE)
          | PathAlphaNumName(ALPHANUMERIC)
          | PathResWordName(RESGRD)
          | PathFileName(FILENAME)

/* Semantic Rules */

prog : Prog(decl_of_interpreters.synh_list = synhAttrListNil;
           decl_of_interpreters.interprtr_list = ListInterprtsNil;
           local ATTRIB_LIST attr_defn_table;
           decl_of_interpreters.int_Inh = 1;
           local RES_WORD LIST res_word_table;
           local SPEC SYMB LIST spec_symb_table;
           decl_of_res_words.res_word_table = decl_of_res_words.res_word_table;
           decl_of_spec_symbols.spec_symb_table = decl_of_spec_symbols.spec_symb_table;
           /* INIT */
           decl_of_interpreters.inh_symb_table = InhAttrListNil;)

/* Unparsing Rules */

style Normal, Keyword, Placeholder, Error;

prog : Prog(" := " "keyword" " "keyword" " "keyword" " "keyword" ")

header_files : HeaderFiles[ @ := "$\{Keyword:\$insert\$\} <" "#> [\"#\"] @ ]

path : PathNil[@ := ]
      | PathDecl[@ := ["/"] @]

pathname : PathNameNil[@ := "$\{Placeholder:<path>\$\}"
                  | PathCapName[@ := ]
                  | PathAlphaNumName[@ := ]
                  | PathResWordName[@ := ]
                  | PathFileName[@ := ]
``
/* Entry Declarations */
Pathname ( synthesized pathname val; );
pathname = Pathname.val;

/* Parsing Rules */
Pathname ::= (ATTRIBUTE) [Pathname.val] PathCapName (ATTRIBUTE); |
| (ALPHANUMERIC) [Pathname.val] PathAlphaNumeric (ALPHANUMERIC); |
| (RESERVED) [Pathname.val] PathReserved (RESERVED); |
| (FILENAME) [Pathname.val] PathFileName (FILENAME); |
/**** SQL Specification for Attribute Definition Section in SQL-92 ****/

/* Abstract Syntax */

list_of_attr_decl : AttrDecl(list_attr_decl_list)
;

list_attr_decl_list;
attr_decl_list : AttrDeclNil()
| ListOfAttrDecl(attr_decl attr_decl_list)
;
attr_decl : AttrDeclPair(attr_name attr_type)
;
attr_name : AttrNameNil()
| AttrName(ATTRIB)
;
attr_type : AttrTypeNil()
| AttrTypeName(type_name)
| AttrTupleType(tuple_type)
| AttrListType(list_type)
| AttrAlphaNumType(user_defined_type)
| AttrFunctionType(func_type)
;
list_tuple_type;
tuple_type : TupleTypeNil()
| TupleTypeList(attr_type tuple_type)
;
list_list_type;
list_type : ListTypeNil()
| ListOfType(attr_type list_type)
;
func_type : FuncType(attr_type attr_type)
;
user_defined_type : UserDefinedTypeNil()
| UserDefinedType(ALPHANUMERIC)
;
type_name : NumType(number)
| CharType(character)
| BoolType(boolean)
| EmptyType(empty)
;
number : NumVal(NUMBER)
;
character : CharVal(CHARACTER)
;
boolean : BoolVal(BOOLEAN)
;
empty : EmptyVal(EMPTY_TYPE)
;

/* Semantic Rules */

list_of_attr_decl : AttrDecl(list_of_attr_decl$1.attr_name_list =
attr_decl_list.attr_name_list)
;

attr_decl_list : AttrDeclNil(attr_decl_list$1.attr_name_list = AttrDeclNil;
| ListOfAttrDecl(attr_decl_list$1.attr_name_list =
| TNameAttrName(attr Decl.attr,
| attr_decl_list$2.attr_name_list)
| local SYR error;
error = (ChAttrList(attr Decl.attr,
| attr_decl_list$2.attr_name_list))
;

155
attr_decl : AttrDeclPair(attr_decl, attr attr_name attr_name Nil)

attr_name : AttrNameNil[attr_nameNil.attr attribNil]
             | AttrName attr_nameNil.attr ATTRIB Nil

/* Definition of Functions in Semantic Rules */
ATTRIB_LIST InsertAttrName(ATTRIB n1, ATTRIB_LIST s1) {
    (n1 == AttrBNil) ? s1
        : with(s1) {
            AttrListNil : n1::s1,
            AttrList(ATTRIB, s1) : (n1 == ATTRIB) ? s1.
                | ATTRIB::InsertAttrName(n1, s1)
        }
}

BOOL ChkAttribList(ATTRIB n1, ATTRIB_LIST s1) {
    (n1 == AttrBNil) ? false
        : with(s1) {
            AttrListNil : false,
            AttrList(ATTRIB, s1) : (n1 == ATTRIB) ? true :
                ChkAttribList(n1, s1)
        }
};

/* Unparsing Rules */
list_of_attr_decl : AttrDecs[":: = \$(Keyword:attribute<$\n$>: attr attr\n$>\n$)"

    | ListOfAttrDecl[":: = error\"<\n$\n$>\n$]"

attr_decl : AttrDeclPair[":: = " attr]

attr_name : AttrNameNil[@ ::= "\$(Placeholder:attribute_name>$\n$)"
    | AttrName[@ ::= ""]

attr_type : AttrTypeNil[@ ::= "\$(Placeholder:attribute_type>$\n$)"
    | AttrTypeNil[@ ::= ""
    | AttrTupleType[@ ::= "(\n$\n$)"
    | AttrListType[@ ::= "[\n$\n$]"
    | AttrAlphaNumType[@ ::= ""
    | AttrFunctionType[@ ::= ""

tuple_type : TuploTypeNil[@ ::= ""
    | TuploTypeList[@ ::= ["",""

list_type : ListTypeNil[@ ::= ["",""
    | ListOfListType[@ ::= ["",""

func_type : FuncType[":: = " ["",""

user_defined_type : UserDefinedTypeNil[@ ::= "<user_defined_type>"
    | UserDefinedType[":: = "

typename : NumType[":: = "
    | CharType[":: = "
    | BoolType[":: = "
    | EmptyType[":: = "

number : NumVal[":: = "

character : CharVal[":: = "

156
/* Entry Declarations */
Attr_name  { synthesized attr_name val; };
  attr_name  = Attr_name.val;
Attr_type  { synthesized attrib_type val; };
  attr_type  = Attr_type.val;
List_type  { synthesized list_type val; };
  list_type  = List_type.val;
Tuple_type { synthesized tuple_type val; };
  tuple_type = Tuple_type.val;
Typename  { synthesized typename val; };
  typename  = Typename.val;
Number     { synthesized number val; };
  number    = Number.val;
Character  { synthesized character val; };
  character = Character.val;
Boolean    { synthesized boolean val; };
  boolean   = Boolean.val;
Empty      { synthesized empty val; };
  empty     = Empty.val;
User_defined_type { synthesized user_defined_type val; };
  user_defined_type = User_defined_type.val;

/* Parsing Declarations */
Attr_name ::= (ATTRIBUTE) {Attr_name.val =
   AttrName(AttribName(ATTRIBUTE));}
   attr_name;
Attr_type ::= (Typename) {Attr_type.val =
   AttrTypeName(Typename.val);
   Attr_type =
   TupleType(Tuple_type.val);
   Tuple_type =
   (Attr_type , Tuple_type) {Tuple_type.val =
   TupleTypeList(Attr_type.val,
   Tuple_type$2.val)};
   Tuple_type;
List_type ::= (Attr_type) {List_type.val =
   ListOfListType(Attr_type.val,
   List_type$1.val);
   List_type =
   (Attr_type , List_type) {List_type.val =
   ListOfListType(Attr_type.val,
   List_type$2.val)};
   List_type;
Typename ::= (Number) {Typename.val = NumType(Number.val);
   Typename =
   (Character) {Typename.val = CharType(Character.val);
   Character =
   (Boolean) {Typename.val = BoolType(Boolean.val);
   Boolean =
   (Empty) {Typename.val = EmptyType(Empty.val);
   Empty =
   (NUMBER) {Number.val = NumVal(NUMBER)};
   Number =
   (CHARACTER) {Character.val = CharVal(CHARACTER)};
   Character =
   (BOOLEAN) {Boolean.val = BoolVal(BOOLEAN)};
   Boolean =
   (EMPTY_TYPE) {Empty.val = EmptyVal(EMPTY_TYPE)};"}
/* Transformation Declarations */
transform attr_type on "num" <attr_type>:
    AttrType{NumType{{NumVal{"num"}}});
transform attr_type on "char" <attr_type>:
    AttrType{CharType{{CharVal{"char"}}});
transform attr_type on "bool" <attr_type>:
    AttrType{BoolType{{BoolVal{"bool"}}});
transform attr_type on "Empty_type" <attr_type>:
    AttrType{EmptyType{{EmptyVal{"Empty"}}}};
transform attr_type on "Tuple_type" <attr_type>:
    AttrType{TupleType{{TupleVal{}}}};
transform attr_type on "List_type" <attr_type>:
    AttrType{ListType{{ListVal{}}}};
transform attr_type on "Function_type" <attr_type>:
    AttrType{FunctionType{{FunctionVal{}}}};
transform attr_type on "UserDefinedType" <attr_type>:
    AttrType{UserDefinedType{{UserDefinedVal{}}}};
/* Abstract Syntax */
decl_of_res_words : ResWordList(list_of_res_words)

optional list list_of_res_words:
list_of_res_words : ResWordListNil()
| ResWordDecl(res_word list_of_res_words)
res_word : ResWordNil()
| ResWord(RESWORD)
| AlphaNum(ALPHANUMERIC)
| UpCase(ATRIBUTE)

/* Semantic Rules */
decl_of_res_words : ResWordList(list_of_res_words.res_word_list =
  ResWordListNull;
  decl_of_res_words$1.res_word_table =
  list_of_res_words.res_word_table;)

list_of_res_words : ResWordListNil(list_of_res_words$1.res_word_table
  = ResWordListNull;)
| ResWordDecl(list_of_res_words$2.res_word_list =
  InsertResWordList(res_word.resword,
  list_of_res_words$1.res_word_list);
  local STR error;
  error = (ChkResWordList(res_word.resword,
  list_of_res_words$1.res_word_list))
  "(MULTIPLE DEFN.)" : "";
  list_of_res_words$1.res_word_table =
  InsertResWordList(res_word.resword,
  list_of_res_words$2.res_word_table);
)
res_word : ResWordNil(res_word$1.resword = "\n";)
| ResWord(res_word$1.resword = RESWORD;)
| AlphaNum(res_word$1.resword = ALPHANUMERIC;)
| UpCase(res_word$1.resword = ATRIBUTE;)

/* Definition of Function in Semantic Rules */
RES_WORD_LIST InsertResWordList(STR nl, RES_WORD_LIST sl) {
  (nl == "$") ? sl
  : with(sl) {
  ResWordListNull : nl::sl,
  ResWordListPair(STR, tl) : (STR == nl) ? sl
  : STR::InsertResWordList(nl, tl)
  }
}

BOOL ChkResWordList(STR nl, RES_WORD_LIST sl) {
  (nl == "$") ? false
  : with(sl) {
  ResWordListNull : false,
  ResWordListPair(STR, tl) : (STR == nl) ? true
  : ChkResWordList(nl, tl)
  }
}

/* Unparsing Rules */
decl_of_res_words : ResWordList[@ := "$$(Keyword:reserved_words$$)"
\n\n"]
list_of_res_words : ResWordListNil[0 :: "$"]
    | ResWordDecl["\\"" $\\"" error "$", "$" ] ]
res_word : ResWordNil[0 :: "$S\"\" placeholder:reserved word\"$\"]
    | ResWord["", ]
    | AlphaNum["", ]
    | UpCase["", ]

/* Entry Declaration */
Res_word (synthesized res_word val:);
res_word - Res_word.val;

/* Parsing Declarations */
Res_word ::= (RESWORD)
    | (ALPHANUMERIC)
    | (ATTRIBUTE)
    | {Res_word.val - ResWord(RESWORD): ]
    | {Res_word.val - AlphaNum(ALPHANUMERIC): ]
    | {Res_word.val - UpCase(ATRIBUTE): ]

/* Transformation Rules */
transform decl_of_res_words on "insert reserved word"
    ResWordList([list_of_res_words]) - ResWordList(<list_of_res_words>)
/** Abstract Syntax */
dec_of_spec_symbols : SpecSymbol(list_of_spec_symbols)
    ;
optional list list_of_spec_symbols;
list_of_spec_symbols : SpecSymbolListNil()
    |
SpecSymbolDecl(spec_symb list_of_spec_symbols)
    ;
spec_symb : SpecSymbolNil()
    | SpecSymbol(SYMBOL)
    ;

/** Semantic Rules */
dec_of_spec_symbols : SpecSymbolList(list_of_spec_symbols.spec_symb_list =
    SpecSymbolListNil;
    dec_of_spec_symbols$1.spec_symb_table =
    list_of_spec_symbols.spec_symb_table;)
    ;
list_of_spec_symbols : SpecSymbolListNil(list_of_spec_symbols$1.spec_symb_table =
    SpecSymbolListNull;
    | SpecSymbolDecl(list_of_spec_symbols$2.spec_symb_list =
    InsertSpecSymbolList(spec_symb.spec_sym,spec_sym,
    list_of_spec_symbols$1.spec_symb_table);
    local stk.error;
    error = (ChkSpecSymbolList(spec_symb.spec_sym,
    list_of_spec_symbols$1.spec_symb_list) ?
    "[MULTIPLE DEFINE]": ";
    list_of_spec_symbols$1.spec_symb_table =
    InsertSpecSymbolList(spec_symb.spec_sym,
    list_of_spec_symbols$2.spec_symb_table);)
    ;
spec_symb : SpecSymbolNil(spec_symb$1.spec_symb = SpecSymbolNil; )
    |
SpecSymbol(spec_symb$1.spec_symb = SpecSymbol(SYMBOL); )
    ;

/** Definition of Function in Semantic Rules */
SPEC_SYM_LIST InsertSpecSymbolList(spec_symb n1, SPEC_SYM_LIST s1) {
    (n1 == SpecSymbolNil) ? s1
    : with(s1) {
        SpecSymbolListNil : n1::s1,
        SpecSymbolListPair(SYMBOL, t1) : (SYMBOL == n1) ? s1
        : SYMBOL::InsertSpecSymbolList(n1, t1)
    }
    ;
}

BOOL ChkSpecSymbolList(spec_symb n1, SPEC_SYM_LIST s1) {
    (n1 == SpecSymbolNil) ? false
    : with(s1) {
        SpecSymbolListNil : false,
        SpecSymbolListPair(SYMBOL, t1) : (SYMBOL == n1) ? true
        : ChkSpecSymbolList(n1, t1)
    }
    ;
}

/** Unparsing Rules */
dec_of_spec_symbols : SpecSymbolList($) := "$S(Keyword:special_symbols$S)"
    $n
    $n
    "$n$"}
list_of_spec_symbols : SpecSymbolListNil[@ : ; "#"]
| SpecSymbolDeci[":; ""error [",", ","]"]
spec_symb : SpecSymbolNil[@ : ; "IS {Placeholder: <spec_symbols> IS}"
| SpecSymbol["""]

/* Entry Declaration */
Spec_symb [ synthesized spec_symb Val; ];
spec_symb " Spec_symb.Val;

/* Parsing Declarations */
Spec_symb ::= (SYMBOL) [Spec_symb.Val SpecSym(SYMBOL)];

/* Transformation Rules */
transform decl of spec_symbols on "insert spec_symbols"
   SpecSymList([)List_of_spec_symbols]) :
   SpecSymList(<List of spec_symbols>)
Abstract Syntax /

list decl_of_interprters:
  :: DeclofInterprtersNil()
  | DeclofInterprters(types_of_interprtr
    decl_of_interprters)
;

types_of_interprtr
  :: NilInterprtr()
  | InterprtrredInterprtr(an_interprtr_defn)
  | UnInterprtrdInterprtr(un_interprtr_defn)
  | StructuredInterprtr(structured_defn)
  | LiteralInterprtr(literal_interprtr_defn)
;

decl_of_interprters:
  :: DeclofInterprters()
  |
  local SYNH_ATTR_LIST a
  |
  | a = InsertSynList(types_of_interprtr.name_of_interprtr,
    types_of_interprtr.atrr_list,
    decl_of_interprters$1.synh_list);
  |
  decl_of_interprters$1.synh_list =
    InsertSynList(types_of_interprtr.name_of_interprtr,
    types_of_interprtr.atrr_list,
    decl_of_interprters$1.synh_list);
  |
  types_of_interprtr.interprtr_list =
    decl_of_interprters$1.interprtr_list;
  |
  decl_of_interprters$2.interprtr_list =
    ChkInterprtrDef(types_of_interprtr.name_of_interprtr,
    decl_of_interprters$1.interprtr_list) ?
    decl_of_interprters$1.interprtr_list;
  |
  InsertListInterprtr(types_of_interprtr.name_of_interprtr,
    decl_of_interprters$1.interprtr_list);
  |
  types_of_interprtr.int_inh =
    decl_of_interprters$1.int_inh;
  |
  decl_of_interprters$2.int_inh =
    types_of_interprtr.int_synh + 1;
  |
  /* INH */
  |
  decl_of_interprters$2.int_synh =
    ChkInhAttrList(types_of_interprtr.name_of_interprtr,
    decl_of_interprters$2.int_synh)
    ?
    (types_of_interprtr.u_int_attr_list = AttrBlistNil)
    &
    (types_of_interprtr.u_int_simb_table)
    &
    (decl_of_interprters$2.int_inh_attr_list)
    ;
  |
  local INH_ATTR_LIST h;
  |
  h = (ChkInhAttrList(types_of_interprtr.name_of_interprtr,
    decl_of_interprters$1.int_synh)
    ?
    (types_of_interprtr.u_inh_attr_list = AttrBlistNil)
    &
    (decl_of_interprters$1.inh_simb_table)
    &
    (types_of_interprtr.u_inh_simb_table)
    ;
  |
  types_of_interprtr
    :: NilInterprtr(types_of_interprtr.atrr_list = AttrBlistNil;
    types_of_interprtr.name_of_interprtr = ""
    types_of_interprtr$1.int_synh = 0;
    /* INH */
    |
    types_of_interprtr$1.u_inh_attr_list = AttrBlistNil;
    | InterprtrredInterprtr(types_of_interprtr.atrr_list =
      an_interprtr_defn.atrr_list;
    types_of_interprtr.name_of_interprtr =
  */
an interpreter defn. name of interpreter:
types of interpolr$1.int synh 0;
an interpreter defn.interpr list
types of interpolr$1.interpr list;
/* INH */
types of interpolr$1.u inh attr list AttrObjNil;

| UninterpretedInterpreter(types of interpolr.attr list
| AttrObjNil;
| types of interpolr.name of interpreter
| an UninterpretedInterpreter name of interpreter
| types of interpolr$1.int synh 0;
an uninterpreted defn.interpr list
| types of interpolr$1.interpr list;

/* INH */
types of interpolr$1.u inh attr list AttrObjNil;

| StructuredInterpreter(structured defn.interpr list
| types of interpolr$1.interpr list;
types of interpolr$1.int synh 0;
| structured.defn.int synh
| types of interpolr$1.int synh 0;

/* INH */
types of interpolr$1.u inh attr list AttrObjNil;

| LiteralInterpreter(types of interpolr.attr list
| literal interp$1.attr list
| types of interpolr.name of interpreter
| LiteralInterpreter name of interpreter
| types of interpolr$1.int synh 0;
literal Interpreter defn.interpr list
| types of interpolr$1.interpr list;

/* INH */
types of interpolr$1.u inh attr list AttrObjNil;

/* Unparsing Rule */
dec of interpreters Dec of Interpreters Nil[0 :=]

| Dec of Interpreters[0 := 

| "Placeholder:Interpreter\n"

| types of interp
| NilInterpreter(" := "
| UninterpretedInterpreter(" := "
| StructuredInterpreter(" := "
| LiteralInterpreter(" := "

/* Transformation Rules */
transform types of interp
on "interpreted" <types of interp>:
  InterpretedInterpreter(can_interp defn),
on "uninterpreted" <types of interp>:
  UninterpretedInterpreter(can_uninterp defn),
on "structured" <types of interp>:
  StructuredInterpreter(structured defn),
on "literal" <types of interp>:
  LiteralInterpreter(literal interp defn)

164
/* Abstract Syntax */

an_interpreter_defn : interpreterDecl(interpreter_name interpreter_defn)

interpreter_defn : interpreterDefnNil()
| interpreterDefn(definition op_list_of_interpreter_defn)

definition : DefnDecl(term_decl list_of_intr_attr_decl)

optional list list_of_intr_attr_decl:
list_of_intr_attr_decl : ListOf[ IntrAttrDeclNil() ]
| ListOf[ IntrAttrDecl(intr_attr_decl list_of_intr_attr_decl) ]

intr_attr_decl : intrAttrDecl(attr_name any_thing)

optional list op_list_of_interpreter_defn:
op_list_of_interpreter_defn : OpDeclNil()
| DefnList(op_decl op_list_of_interpreter_defn)

op_decl : OpDecl(separator definition)

separator : SeparatorNil()
| SeparatorType(SEPARATOR)

term_decl : TermDeclNil()
| ResWordDecl(res_key_word res_word)
| SpecSymbDecl(spec_symb_key_word spec_symb)
| IntTermDecl(int_key_word int_str)
| RealTermDecl(real_key_word real_str)
| IdentTermDecl(ident_key_word ident_str)
| AnyTermDecl(any_term_key_word any_Str)

res_key_word : ResKeyWord(RESWORDETERM)

spec_symb_key_word : SpecSymbKeyWord(SPECSYMBTERM)

int_key_word : IntKeyWord(INTTERM)

int_attr : IntAttrNil()
| IntAttr(integer_val)
| AnyWildInt(any_wild_symb)

integer_val : IntegerValNil()
| IntegerVal(INTEGER)

real_key_word : RealKeyWord(REALTERM)

real_str : RealStrNil()
| RealStr(real_val)
| AnyWildReal(any_wild_symb)

real_val : RealValNil()
| RealVal(FLOAT)

ident_key_word : IdentKeyWord(IDENTTERM)

ident_str : IdentStrNil()
| AnyWildIdent(any_wild_symb)
| SpecIdent(spec_ident_str)
spec_ident_str : SpecIdentStr NIL() |
    ident (RESWORD) |
    identAlphaNum(ALPHANUMERIC) |
    identUpCase (ATTRIBUTE)
;
any_term_key_word : AnyTermKeyWord (ANYTERM)
;
any_str : AnyStr NIL() |
    AnyWildAnyStr (any_wild_sym) |
    SpecAnyStr (spec_any_str)
;
spec_any_str : AnySpecSym (SYMBOL) |
    AnyResWord (RESWORD) |
    AnyAlphaNum (ALPHANUMERIC) |
    AnyCap (ATTRIBUTE) |
    AnyInt (INTEGER) |
    AnyReal (FLOAT)
;
any_thing : AnyThingNIL() |
    AnyThingCap (ATTRIBUTE) |
    AnyThingAlphaNum (ALPHANUMERIC) |
    AnyThingResWord (RESWORD) |
    AnyThingInt (INTEGER) |
    AnyThingReal (FLOAT) |
    AnyThingEl (TERM)
;
any_wild_sym : AnyWildSym (ANY)
;

/* Semantic Rules */
an_interprtr_defn : InterpreterDecl (an_interprtr_defn$1.attr_list |
    Interpreter_defn.attr_list; |
    an_interprtr_defn$1.name_of_interprtr |
    Interprtr_name.name_of_interprtr |
    an_interprtr_defn$1.interprtr_list)
;
interpreter_defn : InterpreterDefnNIL (interpreter_defn$1.attr_list |
    AttrListNIL(); |
    InterpreterDefn (interpreter_defn$1.attr_list = |
    definition.attr_list; |
    op_list_of_interprtr_defn$1.attr_list = |
    definition.attr_list;)
;
op_list_of_interprtr_defn : DecListTop (op_list_of_interprtr_defn$2.attr_list |
    op_list_of_interprtr_defn$1.attr_list |
    local STR error; |
    error = (ChkMandOptListDecn (op_decl.attr_list, |
    op_list_of_interprtr_defn$1.attr_list)) |
    "**": "[INCOMP. SYM. ATTR.]"); |
op_decl : OpDecl (op_decl$1.attr_list = definition.attr_list |
    list_of_intr.attr_decl.attr_list)
;
definition : DefnDecl (definition$1.attr_list = list_of_intr.attr_decl.attr_list)
;
term_decl : ResWordDefn (local STR error; |
    error = {{(res_key_word.key_word == "RESERVED_WORD_TERM") & & |
    (res_word.rownword ! = "")}) |
    ChkResWordList (res_word.rownword, (Program.rown_word_Label)) |
    "**": "[UNDEFINED]"; |
    SpecSymDefn (local STR error; |
    error = {(spec_sym.key_word.key_word == |
    "SPECIAL_SYMBOL_TERM") & & |
    (spec_sym.rownsymb ! = SpecSymNil())}) |
    ChkSpecSymList (spec_sym.rown_sym, (Program.spec_sym_Label |
    "**": "[UNDEFINED]")
;
166
/* Definition of Function in Semantic Rules */

** BOOL ChkAttrDefnTable(ATRIB n, ATRIB_LIST s1) **
{n == AttrBNil} ? true
  with(s1) {  
    AttrBListNil : false
    AttrBList(n, t1) : (n == ATRIB) ? true
      ChkAttrDefnTable(n, t1)
    }
  }

** BOOL ChkResWordTable(STR k, STR s, RES_WORD_LIST s1) **
{k == "IDENTIFIER\"TERM\""} && (s != \"\")
  ChkResWordList(s, s1) : false
  true : false
  }

/* Unparsing Rules */

** an_interp_term **
  InterpreterDecl(" : \"n=\"tN\"\")

** interpreter_defn **
  InterpreterDefnNil[@ := \"$\$(\$\text{Placeholder}:\text{Interpreter\_defn}$\}$\)]
  InterpreterDefn[@ := \"n\" ]
definition

term_decl

res_key_word

spec_symb_key_word

int_key_word

int_str

integer_val

real_key_word

real_str

real_val

ident_key_word

ident_str

spec_ident_str

any_term_key_word

any_str

spec_any_str

any_wild_symb

list_of_intr_attr_decl

intr_attr_decl

op_list_of_interpreter_defn

168
/* Entry Declarations */
Separator {synthesized separator val};
  separator = Separator.val;
Integer_val {synthesized integer_val val};
  integer_val = integer_val.val;
Real_val {synthesized real_val val};
  real_val = Real.val;
Spec_any_str {synthesized spec_any_str val};
  spec_any_str = Spec_any_str.val;
Spec_ident_str {synthesized spec_ident_str val};
  spec_ident_str = Spec_ident_str.val;
Any Thing {synthesized any_thing val};
  any_thing = Any_thing.val;

/* Parsing Declarations */
Separator ::= (SEPARATOR) {Separator.val = SeparatorType(SEPARATOR)};
Integer_val ::= (INTEGER) {Integer_val.val = IntegerVal(INTEGER)};
Real_val ::= (FLOAT) {Real_val.val = RealVal(FLOAT)};
Spec_any_str ::= (INTEGER) {Spec_any_str.val = AnyInt(INTEGER)};
  | (FLOAT) {Spec_any_str.val = AnyReal(FLOAT)};
  | (SYMBOL) {Spec_any_str.val = AnySpecSym(SYMBOL)};
  | (RESWORD) {Spec_any_str.val = AnyResWord(RESWORD)};
  | (ALPHANUMERIC) {Spec_any_str.val = AnyAlphaNum(ALPHANUMERIC)};
  | (ATTRIBUTE) {Spec_any_str.val = AnyCap(ATTRIBUTE)};
Spec_ident_str ::= (RESWORD) {Spec_ident_str.val = Ident(RESWORD)};
  | (ALPHANUMERIC) {Spec_ident_str.val = IdentAlphaNum(ALPHANUMERIC)};
  | (ATTRIBUTE) {Spec_ident_str.val = IdentUppCase(ATTRIBUTE)};
Any_thing ::= (ATTRIBUTE) {Any_thing.val = AnyThingCap(ATTRIBUTE)};
  | (ALPHANUMERIC) {Any_thing.val = AnyThingAlphaNum(ALPHANUMERIC)};
  | (RESWORD) {Any_thing.val = AnyThingResWord(RESWORD)};
  | (INTEGER) {Any_thing.val = AnyThingInt(INTEGER)};
  | (FLOAT) {Any_thing.val = AnyThingReal(FLOAT)};
  | (TERM) {Any_thing.val = AnyThingElse(TERM)};

/* Transformation Declarations */
transform interpreter_defn on "show" <interpreter_defn> :
  InterpreterDefn<definition>,
  <op_list_of_interpreter_defn>
transform term decl on "Reserved Word Decl" <term decl>:
  ResWordDefn(ResKeyWord("RESERVED WORD TERM"),<res_word>),
on "Special Symb Decl" <term decl>:
  SpecSymDecl(SpecSymnKeyword("SPECIAL SYMBOLOTERM"),
  <expr expr>),

on "IntTerm Decl" <term decl>:
  IntTermDecl(IntKeyword("INT TERM"), <int expr>),

on "Real Decl" <term decl>:
  RealTermDecl(RealKeyword("REAL TERM"), <real expr>),

on "Identifier Decl" <term decl>:
  IdentifierDecl(IdentifierKeyword("IDENTIFIER TERM"), <ident expr>),

on "AnyTerm Decl" <term decl>:
  AnyTermDecl(AnyTermKeyword("ANY TERM"), <any expr>),

transform int_str on "integer" <int_str> : IntStr(integer_val),
on "any" <int_str> : AnyWildInt(AnyWildSym("any")),

transform real_str on "real" <real_str> : RealStr(real_val),
on "any" <real_str> : AnyWildReal(AnyWildSym("any")),

transform ident_str on "identifier" <ident_str> : SpecIdent(spec_ident_str),
on "any" <ident_str> : AnyWildIdent(AnyWildSym("any")),

transform any_str on "string" <any_str> : SpecAnyStr(spec_any_str),
on "any" <any_str> : AnyWildAnyStr(AnyWildSym("any")),

transform separator on "Sexpr_orelse" <separator> : SeparatorType("Sexpr_orelse"),
on "Sorelse" <separator> : SeparatorType("Sorelse"),

transform definition on "Attribute Declarations"
  DefineDecl(s, <list_of_intr_attr decl>) :
    DefineDecl(s, <list_of_intr_attr decl>);
/* Abstract Syntax */
an_uninterptr_defn : UnInterpreterDecl(interpreter_name uninterptr_defn)

uninterptr_defn : UnInterpreterDefnNil()
    | UnInterpreterDefn(undeclaration op_list_of_uninterptr_defn)

undeclaration : UnDefnDecl(term_decl)

optional list op_list_of_uninterptr_defn;

op_list_of_uninterptr_defn : UnOpDeclNil()
    | UnOpDeclList(unop_decl op_list_of_uninterptr_defn)

unop_decl : UnOpDecl(separator undifferentiation)

/* Semantic Rules */
an_uninterptr_defn : UnInterpreterDecl(an_uninterptr_defn$1.name_of_interpreter =
    interpreter_name.name_of_interpreter;
    interpreter_name.interpreter_list =
    an_uninterptr_defn$1.interpreter_list);

/* Unparsing Rules */
an_uninterptr_defn : UnInterpreterDecl(" : " %n=%t\n" ")

uninterptr_defn : UnInterpreterDefnNil(\0 := "%$\{Placeholder:\interpreter_defn\\S\}\$")
    | UnInterpreterDefn(\0 := "%n"")

undeclaration : UnDefnDecl(\0 := "%$\{Keyword:uninterpreted\$\} \" \"")

op_list_of_uninterptr_defn : UnOpDeclNil(\0 :="
    | UnOpDeclList(\0 := "%n" \0)

unop_decl : UnOpDecl(\0 := "%n" ")

/* Transformation Declarations */
transform uninterptr_defn on "show" <uninterptr_defn> :
    UnInterpreterDefn(<undefined>,
    <op_list_of_uninterptr_defn>)
SSL Specification for LITERAL interpreters

/* Abstract Syntax */

literal_interpreter_defn : LiteralInterpreterDecl(interpreter name literal decl)

literal_decl : LiteralDeclNil()

| LiteralDecl(keyword decl op list of literal decl)

optional list op list of literal decl;

op list of literal decl : OpLiteralDeclNil()

| OpLiteralDeclList(op literal decl op list of literal decl)

| OpLiteralDecl(separator keyword decl)

keyword decl : KeywordDeclNil()

| ResKeywordDecl(res key word)

| SpecSymbKeywordDecl(spec symb key word)

| IntKeywordDecl(int key word)

| RealKeywordDecl(real key word)

| IdentKeywordDecl(ident key word)

| AnyTermKeywordDecl(any term key word)

/* Semantic Rules */

literal_interpreter_defn : LiteralInterpreterDecl[literal_interpreter_defn1.name of interpreter =

interprtr name of interpreter;

literal_interpreter_defn1.attr list =

literal_decl attr list;

interprtr name.interprtr list =

literal_interpreter_defn1.interprtr list;

literal_decl : LiteralDeclNil[literal_decl$1.attr list - AttrListNil();

| LiteralDecl[literal_decl$1.attr list -

AttrList(AttrName("LITERAL_EOL"), AttrListNil());];

/* Unparsing Rules */

literal_interpreter_defn : LiteralInterpreterDecl[" \n\n"]

literal_decl : LiteralDeclNil[@ := "$L{Placeholder:<literal declaration>$}"

| LiteralDecl[@ := "$"]

| OpLiteralDeclList[@ := "$n@"]

| OpLiteralDecl[@ := "$n"]

keyword decl : KeywordDeclNil[@ := "$L{Placeholder:<keyword declaration>$}"

| ResKeywordDecl[@ := "$L{Keyword:<literal>$}"

| SpecSymbKeywordDecl[@ := "$L{Keyword:<symb>$}"

| IntKeywordDecl[@ := "$L{Keyword:<int>$}"

| RealKeywordDecl[@ := "$L{Keyword:<real>$}"

| IdentKeywordDecl[@ := "$L{Keyword:<ident>$}"

| AnyTermKeywordDecl[@ := "$L{Keyword:<any term>$}"

/* Transformation Rules */

transform literal decl on "show" <literal_decl> : LiteralDecl(keyword decl),

172
transform keyword_decl on "Reserved Word Decl" <keyword_decl>:
  ResKeyWordDecl(ResKeyWord("RESERVED_WORDTERM")),

on "Special Symb Decl" <keyword_decl>:
  SpecSymbKeyWordDecl(SpecSymbKeyWord("SPECIAL_SYMBOL_TERM")),

on "Integer Decl" <keyword_decl>:
  IntKeyWordDecl(IntKeyWord("INT_TERM")),

on "Real Decl" <keyword_decl>:
  RealKeyWordDecl(RealKeyWord("REAL_TERM")),

on "Identifier Decl" <keyword_decl>:
  IdentKeyWordDecl(IdentKeyWord("IDENTIFIER_TERM")),

on "AnyTerm Decl" <keyword_decl>:
  AnyTermKeyWordDecl(AnyTermKeyWord("ANY_TERM"))
/* Abstract Syntax */

structured_defn : StructuredDefn(intptr_name, intptr defn)

interpstr_name : InterpstrNameNil() |
                InterpstrName(ALPHANUMERIC)

interpstr_defn : [interpstrDefNil()] |
                InterpstrDefn(mandatory defn,
                               optional list of defns)

mandatory_defn : MandatoryDefn(list of rhs interpstr names,
                                  list of semantic rules)

list list of rhs interpstr names:
list of rhs_interpstr_names : ListofRhsInterpstrNamesNil()
                              |
                              ListofRhsInterpstrNames(rhs_interpstr name,
                                                      list of rhs_interpstr names)

rhs_interpstr_name : RhsInterpstrNameNil()
                     |
                     RhsInterpstrName(ALPHANUMERIC)

optional list list of semantic rules:
list of semantic_rules : ListofSemanticRulesNil()
                        |
                        ListofSemanticRules(semantic_rule,
                                                  list of semantic_rules)

semantic_rule : SemanticRuleNil() |
               InitSemanticRule(init_rule) |
               CopySemanticRule(copy_rule) |
               ApplSemanticRule(appl_rule)

optional list optional list of defns:
optical list of defns : OptionalListofDefsNil() |
                       OptionalListofDefs(op_defn,
                                           optional list of defns)

op_defn : OptionalDefn(separator, mandatory defn)

init_rule : InitRuleNil() |
            SynhInitRule(synh_lhs_attr_type, attr name const) |
            InitRuleo(linh_lhs_attr_type, attr name const)

copy_rule : CopyRuleNil() |
           SynhCopyRule(synh_lhs_attr_type, inh_or_synth_type) |
           CopyRuleo(linh_lhs_attr_type, inh_or_synth_type)

appl_rule : ApplRuleNil() |
           SynhApplRule(synh_lhs_attr_type, func_name,
                        list of rhs_attr_type) |
           ApplRuleo(linh_lhs_attr_type, func_name, list of inh_attr_type)

list list of rhs_attr_type:
list of rhs_attr_type : ListofRhsAttrTypeNil() |
                       ListofRhsAttrType(inh_or_synth_type,
                                          list of rhs_attr_type)

inh_or_synth_type : InhOrSynTypeNil() |
                    InhType(linh_rhs_attr_type)
struct structured_defn = StructuredDefn{interprtr_name.family_interprter_list =
  struct structured_defn$1.family_interprter_list = InsertListInterprts(
    structured_defn$1.name_of_interprtr,
    structured_defn$1.interprter_list);
  structured_defn$1.name_of_interprtr =
    interprtr_name.family_interprter_list;
  local ALPHANUMERIC lhc_name;
  lhc_name = interprtr_name.family_interprter_list;
  structured_defn$1.family_interprter_list =
    interprtr_defn$1.family_interprter_list;
  local STR error;
  error = ChkLeftRecursion(interprtr_name.family_interprter_list,
    "[DEFN, CONTAINS LEFT RECURSION]" ; " ");
  structured_defn$1.int_linh =
    structured_defn$1.int_linh;
  interprtr_defn$1.int_interprtr = 1;
  structured_defn$1.synh =
    structured_defn$1.int_linh;
  /* INH */
  structured_defn$1.u_linh_attr_list =
    interprtr_defn$1.u_linh_attr_list;
};

interprtr_name = InterprtrNameNil{interprtr_name.family_interprter = " "};
interprtr_name.family_interprter =
  ChkInterprtrDef(interprtr_name.family_interprter,
    interprtr_name.family_interprter_list);
  "[INTERPRETER ALREADY DEFINED]" ; " ";

interprtr_defn = InterprtrDefNil{interprtr_defn$1.family_interprter_list =
  AtribListNil;
  interprtr_defn$1.lf_interprter_names =
    LrInterprterNamesNil;
  /* INH */
  interprtr_defn$1.u_linh_attr_list =
    AtribListNil;
  InterprtrDef{optional_list_of_defs.inhopt_attr_list =
    mandatory_defn.mand_attr_list;
  interprtr_defn$1.attr_list =
    mandatory_defn.mand_attr_list;
optional_list_of_defs\_in\_int\_attr_list:
  interpreter_defs\_list:
  interpreter_defs\_list:
  interpreter_defs\_list:
im\_name\_interpreter
  interpreter_defs\_list:
  interpreter_defs\_list:
  interpreter_defs\_list:
  interpreter_defs\_list:

mandatory\_defn

  : MandatoryDefn[list_of\_semantic\_rules,\_inh\_attr\_list
                  ,\n                  Atribbl\_STN;
                  mandatory\_defn1,\_matt\_attr\_list;
                  list_of\_semantic\_rules,\_synh\_attr\_list;
                  list_of\_rhs\_interpreter\_names,\_interpreter\_list;
                  (\n                  list_of\_semantic\_rules,\_loc\_list\_interpreters;
                  mandatory\_defn1,\_synh\_attr\_list;
                  list_of\_semantic\_rules,\_frac\_synh;
                  list_of\_semantic\_rules,\_frac\_inh;
                  mandatory\_defn1,\_frac\_inh;
                  /* INH */
                  interpreter_defs\_1,\_inh\_attr\_list;
                  (\n                  mandatory\_defn1,\_inh\_attr\_list;
                  optional_list_of_defs\_inh\_attr\_list;
                  mandatory\_defn1,\_inh\_attr\_list;
                  mandatory\_defn1,\_inh\_attr\_list;
                  mandatory\_defn1,\_inh\_attr\_list;
                  mandatory\_defn1,\_inh\_attr\_list;
                  mandatory\_defn1,\_inh\_attr\_list;

list_of\_rhs\_interpreter\_names

  : Listoffh\_Interp\_NamesNil
     \n     list_of\_rhs\_interpreter\_names\_1,\_loc\_list\_interpreters;
    \n    \n    \n    \n    \n    \n
/\n
176
optional_list_of_defs : OptionalListOfDefnsNil
    optional_list_of_defns$1.1r_interptr_names =
    / * LH.InterptrNamesNil; *
    / * ] */
    optional_list_of_defns$1.u_instr_attr_list =
    optional_list_of_defns$1.d_inh_attr_attr_list;
    | OptionalListOfDefns(*/
    local STR error;
    error = (CH MANY OptListDefns(op_defn.attr_list,
    optional_list_of_defns$1.inhopt_attr_attr_list)
    ? "" : "[INCOMP., SYNTH., ATTR.]";
    optional_list_of_defns$2.inhopt_attr_attr_list =
    optional_list_of_defns$2.inhopt_attr_attr_list;
    optional_list_of_defns$2.l_interptr_list =
    optional_list_of_defns$2.l_interptr_list;
    op_defn.l_interptr_list = OptionalListOfDefns(*/
    optional_list_of_defns$2.1r_interptr_names =
    op_defn.name_of_interptr
    | OptionalListOfDefns(*/
    op_defn.int_inh = optional_list_of_defns$1.int_inh;
    op_defn.frac_inh = optional_list_of_defns$1.frac_inh;
    optional_list_of_defns$2.int_inh =
    optional_list_of_defns$2.int_inh;
    optional_list_of_defns$2.frac_inh = op_defn.frac_synth;
    | INH */
    op_defn.d_inh_attr_attr_list = OptionalListOfDefns(*/
    op_defn.d_inh_attr_attr_list = op_defn.u_inh_attr_attr_list;
    optional_list_of_defns$2.d_inh_attr_attr_list =
    optional_list_of_defns$2.u_inh_attr_attr_list;
    | OptionalListOfDefns(*/
    op_defn$1.attr_attr_list = mandatory_defn.mand_attr_attr_list;
    mandatory_defn.l_interptr_list = op_defn$1.l_interptr_list;
    op_defn$1.name_of_interptr = mandatory_defn.name_of_interptr;
    mandatory_defn.int_inh = op_defn$1.int_inh;
    mandatory_defn.frac_inh = op_defn$1.frac_inh;
    op_defn$1.frac_synth = mandatory_defn.frac_synth;
    | INH */
    op_defn$1.u_inh_attr_attr_list = mandatory_defn.u_inh_attr_attr_list;
    mandatory_defn.d_inh_attr_attr_list = op_defn$1.d_inh_attr_attr_list;
    | OptionalListOfDefns(*/
    list_of_semantic_rules : ListOfSemanticRulesNil()
    list_of_semantic_rules$1.synth_attr_attr_list =
    list_of_semantic_rules$1.inh_attr_attr_list;
    list_of_semantic_rules$1.frac_synth =
    list_of_semantic_rules$1.frac_inh;
    | INH */
    list_of_semantic_rules$1.u_inh_attr_attr_list =
list of semantic rules$1.d_inh attr list;
list of semantic rules$1.laip
  ListAttrPairNil;

// list of semantic rules$1.synh attr list;
list of semantic rules$2.synh attr list;
list of semantic rules$2.inh attr list;
InsertAttrList(semantic rule.attr,
  list of semantic rules$1.inh attr list);
local STR error1;
error1 - (ChkAttrList(semantic rule.attr,
  list of semantic rules$1.inh attr list))
  ? "[ATTR MULTIPLE DEFINED]" : "";
semantic rule.loc list interprtrs
  list of semantic rules$1.loc list interprtrs;
list of semantic rules$2.loc list interprtrs
  list of semantic rules$1.loc list interprtrs;
semantic rule.int inh - list of semantic rules$1.int inh;
semantic rule.frac inh - list of semantic rules$1.frac inh;
list of Semantic_rules$2.int inh
  list of semantic rules$1.int inh;
list of semantic rules$2.frac inh
  list of semantic rules$1.frac inh + 1;
list of semantic rules$1.frac synh
  list of semantic rules$2.frac synh;
/* INH */
list of semantic rules$1.u_inh_attr list
  list of semantic rules$2.u_inh_attr list;
semantic rule.d_inh_attr list
  list of semantic rules$1.d_inh_attr list;
semantic rule$1.d_inh_attr list;

// InitSemanticRule(semantic rule$1.attr = init_rule.attr;
init_rule.int inh = semantic rule$1.int inh;
init_rule.frac inh = semantic rule$1.frac inh;
init_rule.loc_list interprtrs =
  semantic rule$1.loc_list interprtrs;
/* INH */
semantic rule$1.u_inh_attr list
  semantic rule$1.d_inh_attr list;
CopySemanticRule(semantic rule$1.attr = copy_rule.attr;
copy_rule.loc_list interprtrs =
  semantic rule$1.loc_list interprtrs;
copy_rule.int inh = semantic rule$1.int inh;
copy_rule.frac inh = semantic rule$1.frac inh;
/* INH */
copy_rule.d_inh_attr list
  semantic rule$1.d_inh_attr list;
semantic rule$1.u_inh_attr list =
  copy_rule.u_inh_attr list;
CopySemanticRule(semantic rule$1.attr = appl_rule.attr;
appl_rule.loc_list interprtrs =
  semantic rule$1.loc_list interprtrs;
init_rule : InitRuleNil{init_rule$1.attr = Attribution Nil; / * INN */ init_rule$1.alp = AttributePairNil;}
  | SynhInitRule{init_rule$1.attr = syn_lhs_attr_type.attr; local STR error1;
  error1 = CHKAttrDefTable(attr_name.attr, [Prog.attr_defn_table])
  ? "UNDEFINED":
  local STR error2;
  error2 = ((syn_lhs_attr_type.attr != Attribution Nil) &&
  (attr_name.attr != Attribution Nil)) &&
  (syn_lhs_attr_type.attr != attr_name.attr))
  ? "TYPE MISMATCH": "";
  / * INH */
  init_rule$1.alp = AttributePairNil;}
  | InhInitRule{init_rule$1.attr = Attribution Nil;
  inh_lhs_attr_type.loc_list_introntrs = init_rule$1.loc_list_introntrs;
  local STR error1;
  error1 = CHKAttrDefTable(attr_name.attr, [Prog.attr_defn_table])
  ? "UNDEFINED":
  local STR error2;
  error2 = ((inh_lhs_attr_type.inh_lhs_attr != Attribution Nil) &&
  (attr_name.attr != Attribution Nil)) &&
  (inh_lhs_attr_type.inh_lhs_attr != attr_name.attr))
  ? "TYPE MISMATCH": "";
  / * INH */
  init_rule$1.alp = inh_lhs_attr_type.alp;}

copy_rule : CopyRuleNil{copy_rule$1.attr = Attribution Nil; / * INH */
  copy_rule$1.u_inh_attr_list =
  copy_rule$1.d_inh_attr_list;
  copy_rule$1.alp = AttributePairNil;}
  | SynhCopyRule{copy_rule$1.attr = syn_lhs_attr_type.attr;
  inh_or_synh_type.loc_list_introntrs =
  copy_rule$1.loc_list_introntrs;
  local STR error1;
  error1 = ((syn_lhs_attr_type.attr != Attribution Nil) &&
  (inh_or_synh_type.attr != Attribution Nil)) &&
  (syn_lhs_attr_type.attr != inh_or_synh_type.attr))
  ? "TYPE MISMATCH": "";
  local STR error2;
  error2 = ((syn_lhs_attr_type.attr != Attribution Nil) &&
  (inh_or_synh_type.inh_rhs_attr != Attribution Nil)) &&
  (syn_lhs_attr_type.attr != inh_or_synh_type.inh_rhs_attr))
  ? "TYPE MISMATCH": "";
  local STR error3;
  error3 = ((syn_lhs_attr_type.attr != Attribution Nil) &&
  (inh_or_synh_type.circ_lhs_attr != Attribution Nil)) &&
  (syn_lhs_attr_type.attr != inh_or_synh_type.circ_lhs_attr))
  ? "$CIRC, ATTR, DEFN.": "";
  / * INH */
  copy_rule$1.u_inh_attr_list =
  inh_or_synh_type.u_inh_attr_list;
  inh_or_synh_type.d_inh_attr_list =
  copy_rule$1.d_inh_attr_list;
  copy_rule$1.alp = AttributePairNil;}
  | InhCopyRule{copy_rule$1.attr = Attribution Nil;
  inh_lhs_attr_type.loc_list_introntrs = copy_rule$1.loc_list_introntrs;
  inh_or_synh_type.loc_list_introntrs = copy_rule$1.loc_list_introntrs;
  local STR error;
  error = ((inh_lhs_attr_type.inh_lhs_attr != Attribution Nil) &&
  (inh_or_synh_type.inh_rhs_attr != Attribution Nil)) &&
  (inh_lhs_attr_type.inh_lhs_attr != inh_or_synh_type.inh_rhs_attr)
InhType\{inh\_or\_synth\_type$1$.attr = AttrNil
Inh\_or\_synth\_type$1$.cire\_lhs\_attr = AttrNil
/* INH */
inh\_or\_synth\_type$1$.cire\_lhs\_attr = AttrNil
inh\_or\_synth\_type$1$.d\_inh\_attr\_list .

Inh\_or\_synth\_type$1$.d\_inh\_attr\_list .

| Synh\_lhs\_attr\_type . SynhLhsAttrType\{synh\_lhs\_attr\_type$1$.attr = attr\_name.attr;
local STR error;
error = (ChkAttrDefTable(attr\_name.attr,
[Prog.attr\_defn\_table])
?? "[UNDEFINED]\$:"

| Synh\_rha\_attr\_type . SynhRhsAttrType\{synh\_rha\_attr\_type$1$.attr = AttrNil
synh\_rha\_attr\_type$1$.cire\_lhs\_attr = AttrNil;

| Synh\_lhs\_attr\_type . SynhLhsAttrType\{synh\_lhs\_attr\_type$1$.attr = attr\_name.attr;
local STR error;
error = (ChkAttrDefTable(attr\_name.attr,
[Prog.attr\_defn\_table])
?? "[UNDEFINED]\$:"

| Synh\_rha\_attr\_type . SynhRhsAttrType\{synh\_rha\_attr\_type$1$.attr = AttrNil
synh\_rha\_attr\_type$1$.cire\_lhs\_attr = AttrNil;

| Synh\_lhs\_attr\_type . SynhLhsAttrType\{synh\_lhs\_attr\_type$1$.attr = attr\_name.attr;
local STR error;
error = (ChkAttrDefTable(attr\_name.attr,
[Prog.attr\_defn\_table])
?? "[UNDEFINED]\$:"

| Synh\_rha\_attr\_type . SynhRhsAttrType\{synh\_rha\_attr\_type$1$.attr = AttrNil
synh\_rha\_attr\_type$1$.cire\_lhs\_attr = AttrNil;

| Inh\_lhs\_attr\_type . InhLhsAttrType\{local STR error;
error = (ChkAttrDefTable(attr\_name.attr,
[Prog.attr\_defn\_table])

181
/* Function Definitions */
BOOL ChkInterpDef(ALPHANUMERIC n, LIST_INTERPRTRRS v) {
    with(v) {
        ListInterptrsNil : false,
        ListInterptrs(n, t1) : (n = n) ? true : ChkInterpDef(n, t)
    }
};

ATTRIB_LIST InsertAttrList(ATTRIB v, ATTRIB_LIST l1) {
    (v != AttrbNil) ? with(l1) {
        AttrbListNil : v;,
        AttrbList(hd, tl) : (hd > v) ? v;:
        : (hd = v) ? hd;:tl
        : hdd:tl
        hdd:InsertAttrList(v, tl)
    } : l1
};

BOOL ChkAttrList(ATTRIB v, ATTRIB_LIST l1) {
    with(l1) {
        AttrbListNil : false,
        AttrbList(ATTRIB, tl) : ((ATTRIB = v) && (v != AttrbNil))
        ? true : ChkAttrList(v, tl)
    }
};

BOOL ChkMandOptListDefns(ATTRIB_LIST s1, ATTRIB_LIST s2) {
    with(s2) {
        AttrbListNil : s1 == AttrbListNil) ? true : false,
        AttrbList(h2, t2) : with(s1) {
            AttrbListNil : false,
            AttrbList(h1, t1) : (h1 = h2) ? ChkMandOptListDefns(t1, t2) : false
        }
    }
};

SYNH_ATTR_LIST InsertSynhList(ALPHANUMERIC n, ATTRIB_LIST s1, SYNTH_ATTR_LIST s2) {
    ((n == "") && (s1 != AttrbListNil))
    ? with(s1) {
        AttrbListNil : s2,
        AttrbList(ATTRIB, tl) : SynhDecl(n, ATTRIB)::InsertSynhList(n, tl, s2)
    } : s2
};

BOOL ChkListInterptrs(ALPHANUMERIC n, LIST_INTERPRTRRS s1) {
    (n == "") ? true
    : with(s1) {
        ListInterptrsNil : false,
        ListInterptrs(ALPHANUMERIC, tl) : (ALPHANUMERIC = n) ? true
        : ChkListInterptrs(n, tl)
    }
};

LIST_INTERPRTRRS InsertListInterptrs(ALPHANUMERIC n, LIST_INTERPRTRRS s1) {
    (n == "") ? n::s1 : s1
};

ALPHANUMERIC GetInterpName(INT nl, LOC_LIST_INTERPRTRRS s1) {
BOOL ChkSynAttrList(ALPHANUMERIC i, ATTRIB n, SYNTH_ATTR_LIST s1) {
    ((i == "") && (n == AttrNil))
    ? with(s1) {
        SynAttrListNil1: true,
        SynAttrDec1(SynDec1(ALPHANUMERIC, AttrNil), t1) : 
        ((ALPHANUMERIC && (n == ATTRNIL)) ? false : ChkSynAttrList(i, n, t1)
        : false)
    } : true
}

BOOL ChkLocListInterprters(INT n1, LOCAL_LIST_INTERPRTRS s1) {
    (n1 == 0) ? true
    : with(s1) {
        LocListInterprtersNil : false,
        LocListInterprtersPair(n2, ALPHANUMERIC), t1 : (n1, n2) ? true
        : ChkLocListInterprters(s1, t1)
    }
}

BOOL ChkLeftRecursion(ALPHANUMERIC n1, LR.INTERPRTR_NAMES s1) {
    (n1 == ")") || (s1 == lrInterprtrNamesNil)
    ? false
    : with(s1) {
        lrInterprtrNamesNil : false,
        lrInterprtrNames(ALPHANUMERIC, t1) : (n1, ALPHANUMERIC) ? true
        : ChkLeftRecursion(s1, t1)
    }
}

/* INH */
BOOL ChkInhAttrList(ALPHANUMERIC n, INH_ATTR_LIST s1) {
    (n == ")") ? with(s1) {
        InhAttrListNil : false,
        InhAttrList(InhAttrList(ALPHANUMERIC, p), t1) : (ALPHANUMERIC - n) ? true
        : ChkInhAttrList(n, t1)
    } : false
}

INH_ATTR_LIST InsertSymbTable(ALPHANUMERIC n, ATTRIB_LIST s1, INH_ATTR_LIST s2) {
    (n == ")") && (s1 != AttrListNil))
    ? InhAttr(n, s1):s2
    : s2
}

ATTRIB_LIST GetAttrList1(ALPHANUMERIC n, INH_ATTR_LIST s1) {
    with(s1) {
        InhAttrListNil : AttrListNil,
        InhAttrList(InhAttr(ALPHANUMERIC, s), t1) : (ALPHANUMERIC - n) ? 
        : GetAttrList1(n, t1)
    }
}

ATTRIB_LIST GetAttrList2(INT n, LIST_ATTR_INT_PAIR s1) {
    with(s1) {
        ListAttrIntPairNil : AttrListNil,
        ListAttrIntPair(ListAttrIntPair(ALPHANUMERIC, AttrListNil), t1) : AttrListNil,
        ListAttrIntPair(ListAttrIntPair(ATTRIB, INT), t1) : (INT == n) ? 
        : GetAttrList2(n, t1)
    }
}

BOOL ChkAttribLists(ATTRIB_LIST s1, ATTRIB_LIST s2) {
(c) : AttrListNil() 4 (c2 : AttrListNil())
? true:
| (c) : AttrListNil() 4 (c2 : AttrListNil())
| false:
| (c) : AttrListNil() 4 (c2 : AttrListNil())
| false: with(a1) {
| AttrListNil : false,
| AttrList(ATTRIN, t1) : ChkAttrList(ATTRIN, s2) ? ChkAttrLists(t1, s2)
| true
|
}

HDUL ChkAttrIntPair(ATTR_INT_PAIR a1, LIST ATTR_INT_PAIR s1) {
with(a1) {
| ListAttrIntPairNil : false,
| ListAttrIntPair(a2, s2) : {
| (a1 : AttrIntPairNil) 4 (a2 : AttrIntPairNil) 4
| (a1, a2)) ? true
| : ChkAttrIntPair(a1, s2)
|
}

/* Entry Declarations */
Interprtr_name (synthesized interpreter_name val);
interpreter_name . Interprtr_name.val;
Rhs_interprtr_name (synthesized rhs_interprtr_name val);
rhs_interprtr_name . Rhs_interprtr_name.val;
Interprtr_number (synthesized interprtr_number val);
interprtr_number . Interpreter_number.val;
Func_name (synthesized func_name val);
func_name . Func_name.val;
Const (synthesized const val);
const Const.val;

/* Parsing Declarations */
Interprtr_name ::= (ALPHANUMERIC) (Interprtr_name.val =
| interpreterName(ALPHANUMERIC));

Rhs_interprtr_name ::= (ALPHANUMERIC) (Rhs_interprtr_name.val =
| RhsInterprtrName(ALPHANUMERIC));

Attr_name ::= (ATTRIBUTE) (Attr_name.val = AttrName(AttrName(ATTRIBUTE)));

Interprtr_number ::= (INTEGER) (Interprtr_number.val =
| interpreterNum(STRtoINT(INTEGER)));

Func_name ::= (ALPHANUMERIC) (Func_name.val = FuncName(ALPHANUMERIC));

Const ::= (SYMBOL) [Const.val = ConstSymb(SYMBOL)];
| (RESWORD) [Const.val = ConstResWord(RESWORD)];
| (ATTRWORD) [Const.val = ConstAttrWord(ATTRWORD)];
| (ALPHAWORD) [Const.val = ConstAlphaNum(ALPHANUMERIC)];
| (INTEGER) [Const.val = ConstInt(INTEGER)];
| (FLOAT) [Const.val = ConstReal(FLOAT)];
| (TERM) [Const.val = Const Anything(TERM)];

/* Unparsing Rules */
structured_defn : StructuredDefn(0 : ' error "$n" "n"

Interprtr_name : InterprtrNameNil(0 := "$S[Placeholder:<interprtr_name>$S]"
| InterprtrName(0 := '" error

Interprtr_defn : InterprtrDefnNil(0 := "$S[Placeholder:<interprtr_defn>$S]"
| InterprtrDefn(0 := " "$n"

mandatory_defn : MandatoryDefn(0 := "$S[Keyword:structure$S] (" " " "$n" "$n"

list_of_rhs_interprtr_names : ListOfRhsInterprtrNamesNil(0 :=)
/* Transformation Rules */
transform interpret-def on "show" <interpretd-def> :
  interpret-def(<mandatory-def>,
                <optional-list-of-defs>)
  
transform semantic-rule on "i_rule" <semantic-rule> :
  initSemanticRule(<init-rule>),
  on "c_rule" <semantic-rule> :
    CopySemanticRule(<copy_rule>),
  on "a_rule" <semantic-rule> :
    ApplSemanticRule(<appl_rule>),
  
transform init-rule on "synthesized-rule" <init-rule> :
  SynInitRule(<syn_left_attr_type>,
              <attr-name>,
              <const>),
  on "inherited-rule" <init-rule> :
    InhInitRule(<inh_left_attr_type>,
                <attr-name>,
                <const>),
  
transform copy-rule on "synthesized-rule" <copy-rule> :
  SynCopyRule(<syn_left_attr_type>,
              <inh_or_synch_type>),
  on "inherited-rule" <copy-rule> :
    InhCopyRule(<inh_left_attr_type>,
                <inh_or_synch_type>),
  
transform appl-rule on "synthesized-rule" <appl-rule> :
  SynApplRule(<syn_left_attr_type>,
               <func-name>,
               <list_of_rhs_attr_type>),
  on "inherited-rule" <appl-rule> :
    InhApplRule(<inh_left_attr_type>,
                <func-name>,
                <list_of_rhs_attr_type>),
  
transform inh_or_synch_type on "inherited-rule" <inh_or_synch_type> :
  InhType(<inh_left_attr_type>),
  on "synthesized-rule" <inh_or_synch_type> :
    SynType(<syn_left_attr_type>)
  
transform synch_rhs_attr_type on "rhs_interpreter" <synch_rhs_attr_type> :
  SynchRhsAttrTypeRhsInEr(<attr-name>,
                        <interpreter-number>),
  on "lhs_interpreter" <synch_rhs_attr_type> :
    SynchRhsAttrTypeLhsInEr(<attr-name>)
  
transform mandatory-def on "sem_rules" MandatoryDef(s,ListOfSemanticRulesNil) :
  MandatoryDef(s,ListOfSemanticRules(<semantic_rule>,[list_of_semantic_rules])))

186
APPENDIX 6
VITA AUCTORIS

Wadia Farook A. was born in 1969 in Bombay, India. He graduated from Chauhan Institute of Science, Bombay, India in 1986. From there he went on to the University of Poona, Pune, India where he obtained a B. E. in Computer Technology in 1990. He is currently a candidate for the Master's degree in Computer Science at the University of Windsor and hopes to graduate in the Spring of 1993.