
Ast - A Generator for
Abstract Syntax Trees

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Toolbox for Compiler Construction

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1. Introduction

Ast is a generator for program modules that define the structure of abstract syntax trees and provide general tree manipulating procedures. The defined trees may be decorated with attributes of arbitrary types. Besides trees, graphs can be handled, too. The structure of the trees is specified by a formalism based on context-free grammars. The generated module includes procedures to construct and destroy trees, to read and write trees from (to) files, and to traverse trees in some commonly used manners. The mentioned readers and writers process ascii as well as binary tree representations. Most procedures work for graphs as well.

The advantages of this approach are: record aggregates are provided which allow a concise notation for node creation. It is possible to build trees by writing terms. An extension mechanism avoids chain rules and allows, for example lists with elements of different types. Input/output procedures for records and complete graphs are provided. The output procedures and the interactive graph browser facilitate the debugging phase as they operate on a readable level and know the data structure. The user does not have to care about algorithms for traversing graphs. He/she is freed from the task of writing large amounts of relatively simple code. All of these features significantly increase programmer productivity.

Ast is implemented in Modula-2 as well as in C and generates C, C++, Java, or Modula-2 source code. The following sections define the specification language, explain the generated output, discuss related approaches, and present some examples.

2. Specification Language

The structure of trees and directed graphs is specified by a formalism based on context-free grammars. However, we primarily use the terminology of trees and types in defining the specification language. Its relationship to context-free grammars is discussed later.

2.1. Node Types

A tree consists of *nodes*. A node may be related to other nodes in a so-called *parent-child* relation. Then the first node is called a *parent* node and the latter nodes are called *child* nodes. Nodes without a parent node are usually called *root* nodes, nodes without children are called *leaf* nodes.

The structure and the properties of nodes are described by *node types*. Every node belongs to a node type. A specification for a tree describes a finite number of node types. A node type specifies the names of the child nodes and the associated node types as well as the names of the attributes and the associated attribute types. A node type is introduced by a name which can be an identifier or a string. The names of all node types have to be pairwise distinct. A node type can be regarded as a *nonterminal*, a *terminal*, or an *abstract* entity. Nonterminals are characterized by the character '=' following its name, terminals by the character ':', and abstract node types by the characters ':='. Undefined node types are implicitly defined to be terminals without attributes. The distinction between nonterminals and terminals is only of interest if concrete syntax is described. In the case of abstract syntax this distinction does not make sense and therefore nonterminal node types and eventually abstract ones suffice. Abstract node types are explained in section 2.6.

Example:

```
If      = .
While   = .
'()'    = .
Ident  : .
":="    : .
SCOPE  := .
```

The example defines the node types *If*, *While*, and *'()'* to be nonterminals, the node types *Ident* and *":="* to be terminals, and *SCOPE* to be an abstract node type.

The following names are reserved for keywords and can not be used for node types:

BEGIN	CLOSE	DECLARE	DEMAND	END
EVAL	EXPORT	FOR	FUNCTION	GLOBAL
IGNORE	IMPORT	IN	INH	INHERITED
INPUT	LEFT	LOCAL	MODULE	NONE
OUT	OUTPUT	PARSER	PREC	PROPERTY
REMOTE	REV	REVERSE	RIGHT	RULE
SCANNER	SELECT	STACK	START	SUBUNIT
SYN	SYNTHESIZED	THREAD	TREE	VIEW
VIRTUAL	VOID			

2.2. Children

Children describe subtrees. They are distinguished by *selector* names which have to be unambiguous within one node type. A child has a certain node type.

Example:

```
If      = Expr: Expr Then: Stats Else: Stats .
While   = Expr: Expr Stats: Stats .
```

The example introduces two node types called *If* and *While*. A node of type *If* has three children which are selected by the names *Expr*, *Then*, and *Else*. The children have the node types *Expr*, *Stats*, and *Stats*.

If a selector name is equal to the associated name of the node type it can be omitted. Therefore, the above example can be abbreviated as follows:

```
If      = Expr Then: Stats Else: Stats .
While   = Expr Stats .
```

2.3. Attributes

Besides children, every node type can specify an arbitrary number of *attributes* of arbitrary types. Like children, attributes are characterized by a selector name and a certain type. The descriptions of attributes are enclosed in brackets. The types for attributes are given by names taken from the target language or from the set of node types. The type of an attribute can be the general tree pointer types *tTREE* and *TREE*, too. Missing types are assumed to be *int* or *INTEGER* depending on the target language (C, C++, Java, or Modula-2). Children and attributes can be given in any order.

If the type of an attribute is a node type, *tTREE*, or *TREE*, the attribute is called *tree-valued*, otherwise it is not *tree-valued*. In contrast to children, *ast* does not follow a *tree-valued* attribute during a graph traversal. All attributes are considered to be neither *tree* nor *graph* structured. Only the user knows about this fact and therefore he/she should take care. Exceptions are the graph browser procedure *DrawTREE* which can launch a separate browser on a subtree rooted at a tree-

valued attribute and the tree transformation tool *puma* which does type checking for tree-valued attributes.

Example (in C):

```
Binary      = Lop: Expr Rop: Expr [Operator: int] .
Unary       = Expr [Operator] .
IntConst   = [Value] .
RealConst  = [Value: float] .
```

For example the node types *IntConst* and *RealConst* describe leaf nodes with an attribute named *Value* of types int or float respectively. *Binary* and *Unary* are node types with an attribute called *Operator* of type int.

Example (in C):

```
Node      = [a1: Binary] [a2: Tree] [a3: tTree] [a4: int] .
```

The attributes *a1*, *a2*, and *a3* are tree-valued, while the attribute *a4* is not tree-valued.

2.4. Declare Clause

The DECLARE clause allows the definition of children and attributes for several node types at one time. Following the keyword DECLARE, a set of declarations can be given. The syntax is the same as described above with the exception that several node type names may introduce a declaration. If there already exists a declaration for a specified node type, the children and attributes are added to this declaration. Otherwise a new node type is introduced.

Example:

```
DECLARE
  Decls Stats Expr = [Level] [Env: tEnv] .
  Expr = Code [Type: tType] .
```

2.5. Extensions

To allow several alternatives for the types of children an *extension* mechanism is used. A node type may be associated with several other node types enclosed in angle brackets. The first node type is called *base* or *super* type and the latter types are called *derived* types or *subtypes*. A derived type can in turn be extended with no limitation of the nesting depth. The extension mechanism induces a subtype relation between node types. This relation is transitive. Where a node of a certain node type is required, either a node of this node type or a node of a subtype thereof is possible.

Example:

```
Stats      = <
  If       = Expr Then: Stats Else: Stats .
  While    = Expr Stats .
> .
```

In the above example *Stats* is a base type describing nodes with neither children nor attributes. It has two derived types called *If* and *While*. Where a node of type *Stats* is required, nodes of types *Stats*, *If*, and *While* are possible. Where a node of type *If* is required, nodes of type *If* are possible, only.

Besides extending the set of possible node types, the extension mechanism has the property of extending the children and attributes of the nodes of the base type. The derived types possess the children and attributes of the base type. They may define additional children and attributes. In

other words they *inherit* the structure of the base type. The selector names of all children and attributes in an extension hierarchy have to be distinct. The syntax of extensions has been designed this way in order to allow single inheritance, only. Multiple inheritance is available, too. It is described in the next section.

Example:

```
Stats      = Next: Stats [Pos: tPosition] <
  If       = Expr Then: Stats Else: Stats .
  While    = Expr Stats .
> .
```

Nodes of type *Stats* have one child selected by the name *Next* and one attribute named *Pos*. Nodes of type *While* have three children with the selector names *Next*, *Expr*, and *Stats* and one attribute named *Pos*.

A node of a base type like *Stats* usually does not occur in an abstract syntax tree for a complete program. Still, *ast* defines this node type. It could be used as placeholder for unexpanded nonterminals in incomplete programs which occur in applications like syntax directed editors.

2.6. Multiple Inheritance

The extension mechanism described in the previous section allows for single inheritance of children and attributes. The syntax of the extensions has been designed to reflect the notation of context-free grammars as close as possible. For multiple inheritance a different syntax and the concept of *abstract node types* are used.

Abstract node types are characterized by the definition characters *':='* instead of *'='* or *':'* which are used for nonterminals or terminals. They are termed abstract because they describe only the structure of nodes or parts thereof but nodes of this types do not exist. Therefore no code is generated by *ast* for abstract node types: no constant, no record type, no constructor procedure, etc.. Abstract node types can only be used as base types in combination with multiple inheritance.

For multiple inheritance the following syntax is used: The name of a node type may be followed by a left arrow '*<-*' and a list of names. This construct is available for all three kinds of node types: nonterminals, terminals, and abstract node types. The names after the left arrow have to denote abstract node types. The meaning is that the node type inherits the structure of all listed abstract node types. Multiple inheritance is possible from abstract node types to non abstract ones and among abstract node types. Among non abstract node types only single inheritance is allowed.

Example:

```
DECLS      := [Objects: tObjects THREAD] <
  NODECLS  := .
  DECL     := [Ident: tIdent INPUT] Next:DECLS .
> .

ENV        := [Env: tEnv INH] .

USE <- ENV := [Ident: tIdent INPUT] [Object: tObject SYN] .

SCOPE <- ENV := [Objects: tObjects SYN] [NewEnv: tEnv SYN] .
```

```

Root          = Proc .
Decls <- DECLS ENV = <
  NoDecls     = .
  Decl <- DECL = <
    Var       = .
    Proc <- SCOPE = Decls Stats .
  > .
> .
Stats <- ENV   = <
  NoStats     = .
  Stat        = <
    Assign    = Name Expr .
    Call <- USE = .
  > .
> .
Expr <- ENV    = <
  Plus        = Lop: Expr Rop: Expr .
  Const       = [Value] .
  Name <- USE  = .
> .

```

The above example uses multiple inheritance and abstract node types to describe the identification problem of programming languages. The node types written with all upper-case letters represent abstract node types. DECLS specifies lists of declared objects, SCOPE describes scopes or visibility regions, ENV stands for environment and is used to distribute scope information, and USE is intended to be used at the application of identifiers. In the second part of the example, the abstract node types are connected to nonterminal node types. *Decls* is the concrete node type to describe lists of declarations. *Decl* represents one declaration and there are two alternatives, *Var* and *Proc*, variables and procedures. A procedure introduces a scope and therefore it inherits from SCOPE. At the node types *Call* and *Name* identifiers are used and thus they inherit from USE. Finally, the node types *Decls*, *Stats*, and *Expr* are regions where the environment information has to be distributed and they inherit from ENV.

2.7. Modules

The specification of node types can be grouped into an arbitrary number of modules. The modules allow to combine parts of the specification that logically belong together. This feature can be used to structure a specification or to extend an existing one. A module consists of target code sections (see section 2.12.) and specifications of node types with attribute declarations. The information given in the modules is merged in the following way: the target code sections are concatenated. If a node type has already been declared the given children, attributes, and subtypes are added to the existing declaration. Otherwise a new node type is introduced. This way of modularization offers several possibilities:

- Context-free grammar and attribute declarations (= node types) can be combined in one module.
- The context-free grammar and the attribute declarations can be placed in two separate modules.
- The attribute declarations can be subdivided into several modules according to the tasks of semantic analysis. For example, there would be modules for scope handling, type determination, and context conditions.

- The information can be grouped according to language concepts or nonterminals. For example, there would be modules containing the grammar rules and the attribute declarations for declarations, statements, and expressions.

Example:

```

MODULE my_version
Stats          = [Env: tEnv] <
  While        = Init: Stats Terminate: Stats . /* add children */
  Repeat       = Stats Expr . /* add node type */
> .
END my_version

```

2.8. Properties

The description of children and attributes can be refined by the association of so-called properties. These properties are expressed by the keywords listed in Table 1.

The properties have the following meanings: *Input* attributes (or children) receive a value at node-creation time, whereas non-input attributes may receive their values at later times. *Output* attributes are supposed to hold a value at the end of a node's existence, whereas non-output attributes may become undefined or unnecessary earlier. *Synthesized* and *inherited* describe the kinds of attributes occurring in attribute grammars. They have no meaning for *ast*. The property *thread* supports so-called threaded attributes: An attribute declaration [a THREAD] is equivalent to the declaration of a pair of attributes with the suffixes In and Out: [aIn] [aOut]. These attributes have to be accessed with their full name including the suffixes. The property *reverse* specifies how lists should be reversed. It is discussed in section 2.11. The property *ignore* instructs *ast* to disregard or omit an attribute or a child. It is useful in connection with the concept of views (see section 2.10.). The property *virtual* is meaningful in attribute grammars. It is used to describe dependencies among attributes. However, no space will be allocated for those attributes and the attribute computations for those attributes will be omitted in the generated attribute evaluator. Within *ast* the properties *input*, *reverse*, and *ignore* are of interest, only.

Properties are specified either locally or globally. Local properties are valid for one individual child or attribute. They are listed after the type of this item. Example:

```
Stats = Next: Stats IN REV [Pos: tPosition IN] [Level INH] .
```

Global properties are valid for all children and attributes defined in one or several modules. They are valid in addition to the local properties that might be specified. In order to describe global

Table 1: Properties for Children and Attributes

long form	short form
INPUT	IN
OUTPUT	OUT
SYNTHESIZED	SYN
INHERITED	INH
THREAD	
REVERSE	REV
IGNORE	
VIRTUAL	

properties, a module may contain several property clauses which are written in the following form:

```
PROPERTY properties [ FOR module_names ]
```

The listed properties become valid for the given modules. If the FOR part is missing, the properties become valid for the module that contains the clause.

Example:

```
PROPERTY INPUT
PROPERTY SYN OUT FOR Mapping
```

Input attributes are included into the parameter list of the node constructor procedures (see section 3). The global property *input* replaces the symbol '->' of former versions of *ast*. For compatibility reasons this symbol still works in a restricted way: The symbol '->' could be included in a list of children and attributes as a shorthand notation to separate input from non-input items. In a list without this symbol all children and attributes are treated as input items. This meaning of the symbol '->' is still in effect as long as *ast* does not encounter a global property clause. After encountering such a clause, local and global properties are in effect only – the symbol '->' is ignored.

Example:

```
Stats          = Next: Stats REV [Pos: tPosition] -> [Level INH] <
  If           = Expr Then: Stats Else: Stats .
  While       = -> Expr IN Stats IN .
> .
```

The node types of the example possess the children and attributes listed in Table 2.

2.9. Subunits

Usually, an *ast* specification is translated into one program module. This module receives the name that immediately follows the keyword TREE. If several modules contain a name, the first one

Table 2: Example of Properties

node type	selector name	associated type	kind	properties
Stats	Next	Stats	child	IN REV
	Pos	tPosition	attribute	IN
	Level	int	attribute	INH
If	Next	Stats	child	IN REV
	Pos	tPosition	attribute	IN
	Level	int	attribute	INH
	Expr	Expr	child	IN
	Then	Stats	child	IN
While	Else	Stats	child	IN
	Next	Stats	child	IN REV
	Pos	tPosition	attribute	IN
	Level	int	attribute	INH
	Expr	Expr	child	IN
	Stats	Stats	child	IN

is chosen. If none of the modules contains a name, the default name *Tree* is used. For target languages C, C++, and Modula it is possible to generate several modules out of an *ast* specification. Then there is exactly one module called *main unit* that describes the tree structure and an arbitrary number of modules called *subunits*. This is of interest if the generated source code becomes too large for one compilation unit. Then either some or all desired procedures could be placed into separate subunits. In the extreme, there might be a subunit for every procedure. It is possible to have two or more versions of one procedure (e. g. WriteTREE) where every one uses a different view (see section 2.10).

The names of the main unit and the subunits are described in the header of an *ast* specification:

```
[ TREE [ Name ] ] [ SUBUNIT Name ] [ VIEW Name ]
```

The name after the keyword VIEW is necessary if abstract syntax trees are to be processed by program modules generated with other tools such as e. g. *puma* [Groa] that need to know the definition of the tree structure. *Ast* has an option that requests to write a binary version of the tree definition to a file whose name is derived from the name given after the keyword VIEW by appending the suffix ".TS" (Default: "Tree.TS").

Every unit has to be generated by a separate run of *ast*. If a subunit name is present, then a subunit is generated – otherwise a main unit is generated. The options select the procedures to be included in the units. It is probably wise not to include the subunit name in an *ast* specification. If this name is added "on the fly" with UNIX commands then different subunits can be generated from one specification without the need to change it.

Example:

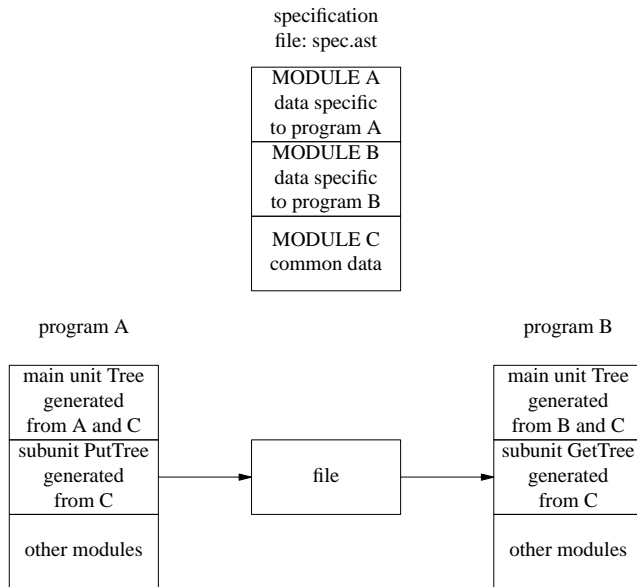
```
ast -dim spec.ast
echo SUBUNIT read | cat - spec.ast | ast -dir
echo SUBUNIT write | cat - spec.ast | ast -diw
or
echo TREE MyTree | cat - spec.ast | ast -dim
echo TREE MyTree SUBUNIT read | cat - spec.ast | ast -dir
echo TREE MyTree SUBUNIT write | cat - spec.ast | ast -diw
```

2.10. Views

An *ast* specification can be roughly seen as a collection of node types and associated children and attributes. A so-called *view* selects a subset of this collection and it may attach further properties to some parts of this collection. In the current version of *ast*, views are not available if the target language is Java.

The concept of views is necessary for instance if two programs communicate a common data structure via a file. Every program might need additional data which should neither appear in the other program nor in the file. In order to make this work both programs must agree upon the coding of the node types in the shared part of the data structure. This is accomplished by using one common *ast* specification that contains the description of the complete data structure. Every program uses a specific view and selects only those parts of the common specification that are of interest. See Figure 1 for an example.

Another need for views arises if several attribute evaluators operate one after the other on one tree. The output attributes of a preceding evaluator become the input attributes of a succeeding one. Here it is necessary to be able to change the properties of attributes. In one view the attributes are regarded as output and in the other one they are regarded as input. The usage of views for the specification of several attribute evaluators is described in [Grob].



UNIX commands to generate the compilation units:

```
echo          SELECT A C | cat - spec.ast | ast -dim
echo SUBUNIT PutTree SELECT  C | cat - spec.ast | ast -dip
echo          SELECT B C | cat - spec.ast | ast -dim
echo SUBUNIT GetTree SELECT  C | cat - spec.ast | ast -dig
```

Fig. 1: Programs Sharing a Part of a Data Structure

Furthermore, views are necessary if abstract syntax trees are to be processed by program modules generated with other tools such as e. g. *puma* [Groat] that need to know the definition of the tree structure. In general, there might be several tree processing modules and every one uses a different view. In this case, the views have to be communicated to the other tool in a file. *ast* has an option that requests to write a binary version of the tree definition to a file whose name is derived from the name given after the keyword VIEW by appending the suffix ".TS" (Default: "Tree.TS", see section on "Subunits").

The concept of views is based on the global properties:

```
PROPERTY properties FOR module_names
```

allows the dynamic addition of properties.

```
PROPERTY IGNORE FOR module_names
```

allows the suppression of all definitions given in the listed modules. Additionally there is the so-called select clause:

```
SELECT module_names
```

This is equivalent to:

```
PROPERTY IGNORE FOR module_names_not_given
```

It is wise to assign names to all modules of an *ast* specification, because otherwise they can not be selected with the select clause. Furthermore, the property or select clauses that express views should probably not be included in the file containing the *ast* specification. The reason is that this form is not flexible, because it is relatively hard to change. It is better to add the one line that is necessary for views "on the fly" using UNIX commands like echo and cat (see Figure 1).

2.11. Reversal of Lists

Recursive node types like *Stats* in the abstract grammar of the example below describe lists of subtrees. There are at least two cases where it is convenient to be able to easily reverse the order of the subtrees in a list. The facility provided by *ast* is a generalization of an idea presented in [Par88].

2.11.1. LR Parsers

Using LR parsers, one might be forced to parse a list using a left-recursive concrete grammar rule because of the limited stack size. The concrete grammar rules of the following examples are written in the input language of the parser generator *Lark* [Groc] which is similar to the one of Yacc [Joh75]. The node constructor procedures within the semantic actions are the ones provided by *ast* (see section 3).

Example:

concrete grammar (with tree building actions):

```
Stats:                               { $$ = mStats0 (); } .
Stats: Stats Stat ';'                 { $$ = mStats1 ($2, $1); } .
Stat : WHILE Expr DO Stats END        { $$ = mWhile ($2, $4); } .
```

abstract grammar:

```
Stats      = <
  Stats0    = .
  Stats1    = Stat Stats .
> .
```

A parser using the above concrete grammar would construct statement lists where the list elements are in the wrong order, because the last statement in the source would be the first one in the list. The WHILE rule represents a location where statement lists are used.

To easily solve this problem *ast* can generate a procedure to reverse lists. The specification has to describe how this should be done. At most one child of every node type may be given the property *reverse*. The child's type has to be the node type itself or an associated base type. The generated list reversal procedure *ReverseTREE* then reverses a list with respect to this indicated child. The procedure *ReverseTREE* has to be called exactly once for a list to be reversed. This is the case at the location where a complete list is included as subtree (e. g. in a WHILE statement).

Example:

concrete grammar (with tree building actions):

```
Stats:                               { $$ = mStats0 ();          } .
Stats: Stats Stat ';'                { $$ = mStats1 ($2, $1); } .
Stat : WHILE Expr DO Stats END { $$ = mWhile ($2, ReverseTREE ($4)); } .
```

abstract grammar:

```
Stats      = <
  Stats0   = .
  Stats1   = Stat Stats REVERSE .
> .
```

It is possible to represent lists differently in an abstract syntax. A more sophisticated solution is given in the next example. The procedure ReverseTREE handles this variant, too.

Example:

concrete grammar (with tree building actions):

```
Stats: { $$ = mNoStat (); } .
Stats: Stats IF Expr THEN Stats ELSE Stats END ';'
      { $$ = mIf ($3, ReverseTREE ($5), ReverseTREE ($7), $1); } .
Stats: Stats WHILE Expr DO Stats END ';'
      { $$ = mWhile ($3, ReverseTREE ($5), $1); } .
```

abstract grammar:

```
Stats      = <
  NoStat   = .
  Stat     = Next: Stats REVERSE <
            If      = Expr Then: Stats Else: Stats .
            While   = Expr Stats .
> .
```

2.11.2. LL Parsers

Using LL parsers a similar problem as in the LR case can arise if extended BNF is used. Lists are parsed with an iteration which is turned into a loop statement as follows: (The identifiers Stats0, Stats1, Stat0, and Stat1 in the concrete grammar rules denote the symbolic access to the L-attribution mechanism provided by *Ell* [GrV]. These identifiers should not be mixed up with the similar ones used as node names in the abstract syntax.)

Example:

concrete grammar (with tree building actions):

```
Stats: { *Stats0=mStats0 (); } ( Stat ';' { *Stats0=mStats1 (Stat1, Stats0); } ) * .
Stat : WHILE Expr DO Stats END { *Stat0=mWhile (Expr1, ReverseTREE (Stats1)); } .
```

abstract grammar:

```
Stats      = <
  Stats0   = .
  Stats1   = Stat Stats REVERSE .
> .
```

The list elements (statements) are inserted in the wrong order within the first concrete grammar

rule. The order is corrected by a call of the procedure ReverseTREE in the second concrete grammar rule.

2.12. Target Code

An *ast* specification may include several sections containing so-called *target code*. These sections follow the keywords TREE or SUBUNIT. Target code is code written in the target language which is copied unchecked and unchanged to certain places in the generated module. It has to be enclosed in braces '{ ' }'. Balanced braces within the target code are allowed. Unbalanced braces have to be escaped by a preceding '\ ' character. In general, the escape character '\ ' escapes everything within target code. Therefore, especially the escape character itself has to be escaped.

The meaning of the sections is as follows:

```
IMPORT:      references to other target language modules, for example to provide definitions of
              types for attribute declarations.
EXPORT:      declarations to be included in addition to the declaration of the tree type.
GLOBAL:      declarations to be included in the implementation module at global level. This is
              where to put macro definitions to select code generation options.
LOCAL:       same as GLOBAL within ast.
BEGIN:       initialization statements.
CLOSE:       finalization statements.
```

The exact use of these sections varies according to the target language, as discussed below.

2.12.1. C and C++

The meaning of the sections is as follows:

```
IMPORT:      declarations such as #include directives to be included in the header file.
EXPORT:      declarations to be included in the header file after the declaration of the tree type
              iTREE.
GLOBAL:      declarations to be included in the implementation module at global level.
BEGIN:       statements to initialize the declared data structures.
CLOSE:       statements to finalize the declared data structures.
```

Example in C or C++:

```
TREE SyntaxTree
IMPORT {# include "Idents.h" }
EXPORT { typedef tSyntaxTree MyTree; }
GLOBAL {# include "Idents.h"
        typedef struct { unsigned Line, Column; } tPosition; }
BEGIN { ... }
CLOSE { ... }
```

2.12.2. Modula-2

The meaning of the sections is as follows:

IMPORT:	declarations to be included in the definition module at a place where IMPORT statements are legal.
EXPORT:	declarations to be included in the definition module after the declaration of the tree type <i>TREE</i> .
GLOBAL:	declarations to be included in the implementation module at global level.
BEGIN:	statements to initialize the declared data structures.
CLOSE:	statements to finalize the declared data structures.

Example in Modula-2:

```
TREE SyntaxTree
IMPORT { FROM Idents IMPORT tIdent; }
EXPORT { TYPE MyTree = tSyntaxTree; }
GLOBAL { FROM Idents IMPORT tIdent;
        TYPE tPosition = RECORD Line, Column: CARDINAL; END; }
BEGIN { ... }
CLOSE { ... }
```

2.12.3. Java

The meaning of the sections is as follows:

IMPORT:	If no IMPORT sections are present <i>ast</i> includes import statements for classes in the reuse package. If an IMPORT section is present then a statement equivalent to the following should be included: <pre>import de.cocolab.reuse.*;</pre>
EXPORT:	additional members to be included in the TREE class.
GLOBAL:	macro definitions to select code generation options.
BEGIN:	statements to be executed when the TREE class is loaded.
CLOSE:	statements to be executed when the TREE.close () method is called.

Example in Java:

```
TREE SyntaxTree
IMPORT { import de.cocolab.reuse.*;
        import com.package.*; }
EXPORT { public int member; }
GLOBAL { # define readMyType(a) ... }
BEGIN { ... }
CLOSE { ... }
```

2.13. Common Node Fields

Sometimes it is desirable to include certain fields into all node types. For languages except Java this can be done directly by defining the macro *TREE_NodeHead* in the IMPORT or EXPORT target code sections. For Java, use the GLOBAL target code section. These fields become members of the variant *yyHead* and they can be accessed as shown in the following examples:

Example in C or C++:

```
# define Tree_NodeHead int MyField1; MyType MyField2;
t->yyHead.MyField1 = ... ;
```

Example in Modula-2:

```
# define Tree_NodeHead MyField1: INTEGER; MyField2: MyType;
t^.yyHead.MyField1 := ... ;
```

Example in Java:

```
# define Tree_NodeHead public int MyField1; public MyType MyField2;
t.MyField1 = ... ;
```

Macros may be defined to process these additional fields during tree operations (see Table 3). These macros are fully implemented only for C and Java. These are similar to the type specific operations described in the next section except that the argument is a reference to the node rather than the value of an individual attribute.

Table 3: Node Head Operations

operation	macro name	purpose
initialization	beginNodeHead(a)	initialize values during node creation
finalization	closeNodeHead(a)	finalize values at node destruction
ascii read	readNodeHead(a)	read values
ascii write	writeNodeHead(a)	write values
binary read	getNodeHead(a)	get values
binary write	putNodeHead(a)	put values
copy	copyNodeHead(a, b)	copy values
equal	equalNodeHead(a, b)	test if values are equal

Note: In Java, the function of binary read/write is achieved via the serialization facility.

2.14. Type Specific Operations

Procedures generated by *ast* apply several operations to attributes: initialization, finalization, ascii read and write, binary read and write, and copy (see Table 4). *Initialization* is performed whenever a node is created. It can range from assigning an initial value to the allocation of dynamic storage or the construction of complex data structures. *Finalization* is performed immediately before a node is deleted and may e. g. release dynamically allocated space. The *read* and *write* operations enable the readers and writers to handle the complete nodes including all attributes, even those of user-defined types. The operation *copy* is needed in order to duplicate values of attributes of user-defined types. By default, *ast* just copies the bytes of an attribute in order to duplicate it. Therefore, pointer semantics is assumed for attributes of a pointer type. If value semantics is needed, the user has to take care about this operation. The operation *equal* checks whether two attributes are equal. It is used as atomic operation for the procedure that tests the equality of trees.

The operations are type specific in the sense that every type has its own set of operations. All attributes having the same type (target type name) are treated in the same way. If the target language permits type aliases, choosing different type names for one type introduces subtypes and allows to treat attributes of different subtypes differently. Type specific operations for the predefined types of

Table 4: Type Specific Operations

operation	macro name	language	default macro
initialization	beginTYPE(a)		
finalization	closeTYPE(a)		
ascii read	readTYPE(a)	C or C++ Modula-2 Java	yyReadHex (& a, sizeof (a)); yyReadHex (a); a = new TYPE (yyin.readL ());
ascii write	writeTYPE(a)	C or C++ Modula-2 Java	yyWriteHex (& a, sizeof (a)); yyWriteHex (a); yyout.write (a.toString ());
binary read	getTYPE(a)	C or C++ Modula-2 Java	yyGet (& a, sizeof (a)); yyGet (a); see note
binary write	putTYPE(a)	C or C++ Modula-2 Java	yyPut (& a, sizeof (a)); yyPut (a); see note
copy	copyTYPE(a, b)	Java	a = (b);
equal	equalTYPE(a, b)	C or C++ Modula-2 Java	memcmp (& a, & b, sizeof (a)) == 0 yyIsEqual (a, b) (a.equals (b))

Note: In Java, the function of binary read/write is achieved via the serialization facility.

a target language and for the types defined in the library *reuse* [Groa, Grob, Nas] are predefined within *ast* (see Appendices 8 to 11). For user-defined types, *ast* assumes default operations (see Table 4). The procedures *yyReadHex* and *yyWriteHex* read and write the bytes of an attribute as hexadecimal values. The procedures *yyGet* and *yyPut* read and write the bytes of an attribute unchanged (without conversion). The operations are defined by a macro mechanism. The procedure *yyIsEqual* checks the bytes of two attributes for equality. TYPE is replaced by the concrete type name. *a* is a formal macro parameter referring to the attribute. The predefined procedures mentioned in Table 4 use the global variable *yyf* of type FILE * (C, C++) [Grob] or IO.tFile (Modula-2) [Groa] or the static variables *yyin* of type de.cocolab.reuse.CocktailReader and *yyout* of type de.cocolab.reuse.CocktailWriter (Java) [Nas] describing the file used by the readers and writers.

Tree-valued attributes are always of type tTREE in C, C++ and Modula-2 and so the same set of operations is used regardless of whether the attribute is declared to be of type tTREE or one of the node types. In Java there is a separate set of operations for each node type.

It is possible to redefine the operations by including new macro definitions in the GLOBAL section. The following example demonstrates the syntax for doing this. It shows how records of the type tPosition might be handled and how subtypes can be used to initialize attributes of the same type differently. Recall that *ast* already knows how to handle tPosition – what follows is only a demonstration.

Example in C or C++:

```

IMPORT {
# include "Sets.h"
typedef struct { unsigned Line, Column; } tPosition;
typedef tSet Set100;
typedef tSet Set1000;
}

GLOBAL {
# define begintPosition(a) a.Line = 0; a.Column = 0;
# define readtPosition(a) fscanf (yyf, "%d,%d", & a.Line, & a.Column);
# define writetPosition(a) fprintf (yyf, "%d, %d", a.Line, a.Column);

# define beginSet100(a) MakeSet (& a, 100);
# define closeSet100(a) ReleaseSet (& a);
# define readSet100(a) ReadSet (yyf, & a);
# define writeSet100(a) WriteSet (yyf, & a);

# define beginSet1000(a) MakeSet (& a, 1000);
# define closeSet1000(a) ReleaseSet (& a);
# define readSet1000(a) ReadSet (yyf, & a);
# define writeSet1000(a) WriteSet (yyf, & a);
}

```

Example in Modula-2:

```

IMPORT {
FROM Sets IMPORT tSet;
TYPE tPosition = RECORD Line, Column: CARDINAL; END;
TYPE Set100 = tSet;
TYPE Set1000 = tSet;
}

GLOBAL {
FROM IO IMPORT ReadI, WriteI, WriteC;
FROM Sets IMPORT MakeSet, ReleaseSet, ReadSet, WriteSet;

# define begintPosition(a) a.Line := 0; a.Column := 0;
# define readtPosition(a) a.Line := ReadI (yyf); a.Column := ReadI (yyf);
# define writetPosition(a) WriteI (yyf, a.Line, 0); WriteC (yyf, ' '); \
WriteI (yyf, a.Column, 0);

# define beginSet100(a) MakeSet (a, 100);
# define closeSet100(a) ReleaseSet (a);
# define readSet100(a) ReadSet (yyf, a);
# define writeSet100(a) WriteSet (yyf, a);

# define beginSet1000(a) MakeSet (a, 1000);
# define closeSet1000(a) ReleaseSet (a);
# define readSet1000(a) ReadSet (yyf, a);
# define writeSet1000(a) WriteSet (yyf, a);
}

```

Example in Java:

```

IMPORT {
  import de.cocolab.reuse.*; // including Set and Position
  // The C preprocessor is used within ast, so we can define
  // type aliases like this:
  # define Set100 Set
  # define Set1000 Set
}

GLOBAL {
  // Note in Java we have the type "Position" rather than "tPosition".
  # define beginPosition(a) a = new Position (0, 0);
  # define readPosition(a) a.line = yyin.readI (); a.column = yyin.readI ();
  # define writePosition(a) yyout.write (a.line); yyout.write ( ' '); \
  yyout.write (a.column);

  # define beginSet100(a) a = new Set (100);
  # define closeSet100(a) a = null;
  # define readSet100(a) a = readSet (yyin);
  # define writeSet100(a) writeSet (yyout, a);

  # define beginSet1000(a) a = new Set (1000);
  # define closeSet1000(a) a = null;
  # define readSet1000(a) a = readSet (yyin);
  # define writeSet1000(a) writeSet (yyout, a);
}

EXPORT {
  private Set readSet (CocktailReader in) {
    // code to read a set
  }

  private void writeSet (CocktailWriter out, Set s) {
    // code to write a set
  }
}

```

In the case of C++ the modules *Idents* and *StringM* of the library *reuse* [Grob] are implemented as classes. Thus several objects might be created from these classes. If attributes are declared with the types *tIdent* or *tStringRef* then *ast* will generate code that uses some methods of these classes. Now it has to be described to which of the objects a method call refers to. This is handled in the following way. The generated code looks like this:

```

# ifndef Idents_PREFIX
# include "Global.h"
# define Idents_PREFIX gIdents.
# endif

# ifndef String_PREFIX
# include "Global.h"
# define String_PREFIX gStringM.
# endif

Idents_PREFIX NoIdent;
Idents_PREFIX MakeIdent (...);
Idents_PREFIX WriteIdent (...);

String_PREFIX PutString (...);
String_PREFIX WriteString (...);

```

By default, the globally created objects *gIdents* and *gStringM* from the library *reuse* are used. This can be changed by providing definitions for the macros *Idents_PREFIX* and *String_PREFIX* in the GLOBAL section. Example:

```

# include "Idents.h"
# include "StringM.h"

# define Idents_PREFIX my_idents_object.
# define String_PREFIX my_string_object->

Idents my_idents_object;
StringM * my_string_object = new StringM;

```

In the case of Java there is a similar consideration with respect to the *Ident* type and the associated *IdentTable* class [Nas]. The generated code looks like this:

```

# ifndef Idents_PREFIX
# define Idents_PREFIX Global.idents.
# endif

Idents_PREFIX makeIdent (...);

```

The prefix is only needed when calling *makeIdent* to create a new *Ident* instance. All other operations are simply methods on an *Ident* object. By default, the statically created object *idents* from the library class *Global* is used. This can be changed by providing a definition for the macro *Idents_PREFIX* in the GLOBAL section. Example:

```

GLOBAL {
  # define Idents_PREFIX my_idents_object.
}

EXPORT {
  static IdentTable my_idents_object = new IdentTable (100);
}

```

2.15. Storage Management

This section does not apply where the target language is Java: the provided garbage collector is used.

The storage management for the nodes to be created is completely automatic. Usually, the user does not have to care about it. The predefined storage management works as follows: Every generated tree module contains its own heap manager which is designed in favour of speed. The constructor procedures use an in-line code sequence to obtain storage (see below). The heap manager does not maintain free lists. It only allows to free the complete heap of one module using the procedure *ReleaseTREMModule*. The procedure *ReleaseTREE* does not free the node space, it only finalizes the attributes of the nodes. The predefined behaviour can be changed by including two macro definitions in the GLOBAL section.

For C the macros are initialized as follows:

```

# define yyALLOC(size1, size2) \
(TREE_PoolFreePtr -= size1) >= TREE_PoolStartPtr ? \
(tTREE) TREE_PoolFreePtr : TREE_Alloc (size2)
# define yyFREE(ptr, size)

```

For C++ the macros are initialized as follows:

```
# define yyALLOC(size1, size2) yyALLOCI (size1, size2)
# define yyFREE(ptr, size)
inline tTREE TREE::yyALLOCI (unsigned long yysize1, unsigned long yysize2)
{ return TREE_PoolFreePtr >= TREE_PoolStartPtr + yysize1 ?
  (tTREE) (TREE_PoolFreePtr -= yysize1) : TREE_Alloc ((unsigned short) yysize2); }
```

For Modula-2 the macros are initialized as follows:

```
# define yyALLOC(ptr, size) ptr := yyPoolFreePtr; \
  IF SYSTEM.ADDRESS (ptr) >= yyPoolMaxPtr THEN ptr := yyAlloc (); END; \
  INC (yyPoolFreePtr, size);
# define yyFREE(ptr, size)
```

The following lines switch the heap manager to a global storage allocator with free lists:

```
# define yyALLOC(size1, size2) (tTree) Alloc (size2)
# define yyFREE(ptr, size) Free (size, ptr);
```

Now *ReleaseTREE* will work as expected whereas *ReleaseTREEModule* does not work any more.

In the case of C and C++, the macro `yyALLOC` has two size arguments: While 'size2' specifies the number of bytes needed for the creation of a tree node, 'size1' specifies the corresponding *aligned* size. The aligned size 'size1' might be increased in comparison to 'size2' in order to fulfill the alignment requirements of the current machine. `yyALLOC` has to define an expression which yields a pointer to a storage area of at least 'size2' bytes. The macro `yyFREE` is used to indicate that 'size' bytes at the location 'ptr' can be released.

3. About the Generated Program Module

Ast is able to generate code for two types of target language: procedural and object-oriented. For procedural languages node types are mapped to members of a variant or union type, and the generated procedures take an argument of this type. Procedure names are of the form *OperationTREE* where *TREE* is replaced by the tree module name, default *Tree*.

For object-oriented languages node types map to classes and in general the procedures are methods applied to an instance and take no argument. Method names are of the form *operation()*. As the names are within a name scope there is no need to qualify them with the name of the tree module.

Though the two schemes have much in common, there is enough difference to warrant separate descriptions. Currently the mapping for C++ is similar to the C mapping, and so it is described under the Procedural heading.

3.1. Procedural Mapping

A specification is translated by *ast* into a program module consisting of a definition part and an implementation part. Only the definition part or header file respectively is sketched here – Appendices 4 to 6 contain the general schemes. The definition part contains primarily type declarations describing the structure of the trees and the headings of the generated procedures.

Every node type is turned into a constant declaration and a struct or record declaration. That is quite simple, because node types and record declarations are almost the same concepts except for the extension mechanism and some shorthand notations. All these records become members of a union type or a variant record used to describe tree nodes in general. This variant record has a tag field called *Kind* which stores the code of the node type. A pointer to the variant record is a type representing trees. Like all generated names, this pointer type is derived from the name of the specification. Table 5 briefly explains the exported objects (replace *TREE* by the name of the generated module (see section 2.12.) and <node type> by all the names of node types). In Modula-2 the

names of the constants to code the node types and the names of the record variants are identical to the names of the node types. In other languages only the names of the union members are identical, the constant names are prefixed with the letter 'k' standing for *Kind*. In C++ a class named *TREE* is generated, additionally. All exported variables and procedures as well as the internal data structure are declared as members of this class. Thus it is possible to create and delete several tree objects which are independent from each other. This allows for a detailed control of memory usage, for example.

The parameters of the procedures *m<nodetype>* have to be given in the order of the *input* attributes in the specification. Attributes of the base type (recursively) precede the ones of the derived type. The procedure *ForallTREE* allows for the execution of a procedure given as parameter for every element (node) of a list. Lists are indicated by the property *REVERSE* - the child with this property is the pointer to the succeeding list element. The procedures *TraverseTREED* and *TraverseTREEBU* visit all nodes of a tree or a graph respectively. At every node a procedure given as parameter is executed. An assignment of a tree or graph to a variable of type *tTREE* can be done in two ways: The usual assignment operators '=' or ':=' yield pointer semantics. The procedure *CopyTREE* yields value semantics by duplicating a given graph.

The construction of the pointer and the union type above does not enforce the tree typing rules through the types of the target language. In fact, it is possible to construct trees that violate the specification. The user is responsible to adhere to the type rules. Most of the generated procedures do not care about the type rules. Moreover, type violations are possible and such erroneous trees are handled correctly by all procedures. The procedure *CheckTREE* can be used to check if a tree is properly typed. In case of typing errors the involved parent and child nodes are printed on *standard error*.

The binary graph writer procedure *PutTREE* produces a binary file containing the graph in linearized form. The nodes are written according to a depth first traversal. Edges are either represented by concatenation of nodes or by symbolic (integer) labels. The following kinds of records specified by C types are written to the output file:

```
# define yyNil          0374
# define yyNoLabel     0375
# define yyLabelDef    0376
# define yyLabelUse    0377

typedef unsigned char  TREE_tKind; /* less than 252 node types */
typedef unsigned short TREE_tKind; /* more than 251 node types */
typedef unsigned short TREE_tLabel;

struct { char yyNil          ; } NoTree;
struct { char yyLabelUse; TREE_tLabel <label>; } LabelUse;
struct { char yyLabelDef; TREE_tLabel <label>;
        TREE_tKind Kind; <attributes> } LabelDef;
struct { char yyNoLabel ; TREE_tKind Kind; <attributes> } NoLabel;
struct { char Kind      ; <attributes> } Kind;
```

Record fields whose name starts with *yy* have a constant value as defined. <label> is an integer representing a certain address. <attributes> are written with the type specific *put* macros which either copy the bytes of an attribute unchanged or do whatever the user has specified. If the value of the tag field *Kind* is less than 252 then the format *Kind* is used, otherwise the format *NoLabel* is used to write unlabeled nodes.

Table 5: Generated Objects and Procedures (Class Members)

object/procedure	description
k<node type>	named constant to encode a node type in C and C++
<node type>	named constant to encode a node type in Modula-2
<node type>	name of union member or record variant for a node type
tTREE	pointer type, refers to variant record type describing all node types
TREERoot	variable of type tTREE, can serve as root (additional variables can be declared)
TREE_NodeName	array mapping node types to names (strings) in C and C++
TREE_NodeSize	array mapping node types to the size of the nodes in C and C++
yyNodeSize	array mapping node types to the size of the nodes in Modula-2
MakeTREE	node constructor procedure without attribute initialization
TREE_IsType	test a node for a certain type
n<node type>	node constructor procedures with attribute initialization according to the type specific operations
m<node type>	node constructor procedures with attribute initialization from a parameter list for <i>input</i> attributes
ReleaseTREE	node or graph finalization procedure, all attributes are finalized, all node space is deallocated
ReleaseTREEModule	deallocation of all graphs managed by a module
WriteTREENode	ASCII node writer procedure
ReadTREE	ASCII graph reader procedure
WriteTREE	ASCII graph writer procedure
GetTREE	binary graph reader procedure
PutTREE	binary graph writer procedure
TraverseTREETD	top down graph traversal procedure (reverse depth first)
TraverseTREEBU	bottom up graph traversal procedure (depth first search)
ReverseTREE	procedure to reverse lists
ForallTREE	list traversal procedure
CopyTREE	graph copy procedure
CheckTREE	graph syntax checker procedure
QueryTREE	graph browser procedure with ASCII user interface
DrawTREE	graph browser procedure with graphic user interface
SetDepthTREE	set drawing depth of graph browser procedure
SetBoxTREE	set geometry for nodes of graph browser procedure
IsEqualTREE	equality test procedure for trees
BeginTREE	procedure to initialize user-defined data structures
CloseTREE	procedure to finalize user-defined data structures

Graphs that have been written to a file with the procedure *PutTREE* can be read from file into memory with the procedure *GetTREE*.

The procedures *WriteTREE* and *ReadTREE* perform input and output of graphs similar to the procedures *PutTREE* and *GetTREE*. The differences are that a human readable ASCII notation is used which causes the files to become considerably larger.

The procedure *IsEqualTREE* is used to test structural equivalence of trees. It is not designed to handle general graphs.

3.2. Object-oriented Mapping

A specification is translated by *ast* into a program module consisting of a class for every non-abstract node type. Only the public interfaces are sketched here – Appendix 7 contains the general scheme.

Every non-abstract node type is turned into a constant declaration and a class. That is quite simple, because node types and classes are the same concepts as are the extension mechanism and single inheritance (abstract node types are not mapped to classes and so we do not need multiple inheritance in the target language). All these classes have a common base class used to describe tree nodes in general. This class has a tag field called *kind* which stores the code of the node type. A reference to the base class is a type representing trees. Like all generated names, this class type is derived from the name of the specification. Table 6 briefly explains the exported objects (replace TREE by the name of the generated module (see section 2.12.) and <node type> by all the names of node types). The names of the node classes are the same as in the specification, the constant names are prefixed with the letter 'k' standing for *kind*.

The parameters of the constructors have to be given in the order of the *input* attributes in the specification. Attributes of the base type (recursively) precede the ones of the derived type. The procedure *forall* allows for the execution of a procedure given as parameter for every element (node) of a list. Lists are indicated by the property REVERSE - the child with this property is the reference to the succeeding list element. The procedures *traverseTD* and *traverseBU* visit all nodes of a tree or a graph respectively. At every node a procedure given as parameter is executed.

In Java, procedure parameters are implemented via an interface TREE.ProcTree which has a single method *proc (TREE yyt)*. This method has no 'throws' clause, and so it is necessary to catch all exceptions that might be thrown by the code within the user procedure. If it is desired to retain the default action for exceptions thrown within such procedures then the following scheme may be used to 'hide' the exception from the ProcTree interface.

```
import de.cocolab.reuse.MaskedException;
...
Tree t;
try {
  t.traverseTD (new Tree.ProcTree () {
    public void proc (Tree yyt) {
      try {
        // code which might throw an IOException
        yyt.writeNode (out);
      }
      catch (java.io.IOException e) {
        // wrap the exception in a MaskedException, which need not be caught
        throw new MaskedException (e);
      }
    }
  });
} catch (MaskedException e) {
  // unwrap and rethrow exception, to get the usual stack trace and termination
  throw (java.io.IOException) (e.exception);
}
```

Table 6: Generated Objects and Class Members

object/procedure	description
k<node type>	named constant to encode a node type
<node type>	name of class for a node type
TREE	class type, a supertype of all node types
NodeNames	array mapping node types to names (strings)
make	node constructor procedure without attribute initialization
isType	test a node for a certain type
constructor ()	node constructor procedures with attribute initialization according to the type specific operations
constructor (...)	node constructor procedures with attribute initialization from a parameter list for <i>input</i> attributes
writeNode	ASCII node writer procedure
read	ASCII graph reader procedure
write	ASCII graph writer procedure
get	binary graph reader procedure
put	binary graph writer procedure
traverseTD	top down graph traversal procedure (reverse depth first)
traverseBU	bottom up graph traversal procedure (depth first search)
reverse	procedure to reverse lists
forall	list traversal procedure
copy	graph copy procedure
clone	same as copy in Java
check	graph syntax checker procedure (reports NoTREE)
query	graph browser procedure with ASCII user interface
isEqual	equality test procedure for trees
begin	procedure to initialize user-defined data structures
close	procedure to finalize user-defined data structures

An assignment of a tree or graph to a variable of type *TREE* can be done in two ways: The usual assignment operator '=' yields reference semantics. The procedure *copy* yields value semantics by duplicating a given graph.

The constructors of the node classes enforce the tree typing rules through the types of the target language. So, it is not possible to construct trees that violate the specification except by passing *NoTREE* or *null* as a child. The procedure *check* can be used to check if a tree is properly constructed. In case of typing errors the involved parent and child nodes are printed on *standard error*.

The binary graph writer procedure *put* produces a binary file containing the graph in linearized form. In Java this is implemented by object serialization.

Graphs that have been written to a file with the procedure *put* can be read from file into memory with the procedure *get*.

The procedures *write* and *read* perform input and output of graphs in human readable ASCII notation. The user is responsible for making sure that appropriate procedures are defined for converting any user defined attribute types to and from strings, see "Type Specific Operations".

The procedure *isEqual* is used to test structural equivalence of trees. It is not designed to handle general graphs.

3.3. Graph Browsers

The procedure *QueryTREE/query* allows to browse a tree and to inspect one node at a time using an (old-fashioned) ASCII user interface. A node including the names and the values of its attributes is printed on *standard output*. Then the user is prompted to provide one of the following commands from *standard input*:

```
parent          display parent node
goto <n>        display node at line number <n>
quit           quit procedure
<selector>     display specified child (first match, abbreviation possible)
<selector><space> display specified child (exact match, no abbreviation)
```

All commands can be abbreviated to an unambiguous prefix. Usually, a first match strategy is used to determine a child from its (abbreviated) selector name. With this search strategy, children whose name is a prefix of others may not be accessible. If an unabbreviated selector name is supplied together with a following space character an exact match strategy is used, which allows to access every child. The empty command behaves like *parent*.

The procedure *DrawTREE* provides a browser for trees and graphs with a graphic user interface. Nodes are displayed as labelled rectangles and edges (links to children) as arrows. A clearly arranged layout is calculated automatically. Attributes can be viewed similarly to *QueryTREE*. The graphic browser provides scrolling, zooming, and direct access to the nodes using menu and mouse operations.

See the screenshot for an example of the browser window. It displays the abstract syntax tree (graph) for a sequence of three MiniLax statements. (The identifier *skip* denotes the call of a procedure.)

```
IF n < 0 THEN n := 1 ELSE skip END;
n := 2;
skip;
```

The nodes for the three statements are arranged underneath each other at the left-hand side. The children of the node If describe the condition, the THEN part, and the ELSE part of the IF statement. The children of the node Assign describe the left-hand side and the right-hand side of the assignment statement. The node Ident with the thick border has been selected. The attributes and children of this node are shown in a subwindow.

The procedure *DrawTREE* can be generated for the languages C and C++. For compilation and linking the public domain package tcl/tk version 8.0 or higher is required. Under Unix linking is done with commands like:

```
cc -L$X11/lib -ltk80 -ltcl80 -lX11 -lm -ldl ../libreuse.a or
cc -L$X11/lib -ltk8.0 -ltcl8.0 -lX11 -lm ../libreuse.a -lc
```



```

2.0 = 400 %
1.0 = 200 %
0.0 = 100 %
-1.0 = 50 %
-2.0 = 25 %

```

The labels of the nodes are the names of the node types. They are truncated to the first 9 characters. After opening a node the full information becomes visible in a subwindow. An arrow at the right-hand side of a node indicates a suppressed subtree. This arrow is also called a folding indicator. By default, nodes to a maximal depth of 6 are shown. This limit can be changed with the operation 'depth' in the menu. The new value of depth will be effective for all subsequent 'draw' operations. The restriction to a maximal depth is not effective for nodes in lists.

The tree browser provides a call-back mechanism for the attributes shown in a subwindow. There are tree-valued attributes and non-tree-valued attributes. Tree-valued attributes are marked with the character '+'. A mouse click on a tree-valued attribute starts a new copy of the tree browser on this subtree. A mouse click on a non-tree-valued attribute calls the macro *DrawAttr* with two arguments: a pointer to the current node and a string giving the name of the selected attribute. By default, this macro does nothing. It can be defined to execute arbitrary code. In the following example the macro *DrawAttr* is defined to call the procedure *draw_attr*. This procedure decides upon its arguments what to do and it may call for example another tree browser procedure named *Drawmy_tree*.

```

GLOBAL {
# include "my_tree.h"

# define DrawAttr(addr, name) draw_attr (addr, name)

static void draw_attr (tTree tree, char * name)
{
    switch (tree->Kind) {
    case knode:
        if (strcmp (name, "attribute") == 0)
            Drawmy_tree (tree->node.attribute);
    }
}
}

```

The procedure *SetDepthTREE* sets the default drawing depth for the graph browser *DrawTREE*. Trees and graphs are not drawn completely. Only certain levels of nodes are shown and the rest is suppressed. By default, 6 levels of nodes are shown, only. This number can be changed using the procedure *SetDepthTREE* or interactively when the browser is running. Setting the level to a high number such as e. g. 999 yields a complete picture of even large graphs. This feature of suppressing parts of the tree is not applied to lists of nodes. All elements of lists are shown. Lists are specified using the property REVERSE.

The procedure *SetBoxTREE* sets the geometry of the rectangles that represent nodes. The two arguments give the width and the height of the rectangles in pixels. The default values are 60 and 20. The horizontal and vertical distances between the nodes as well as the number of characters used to label a node are computed automatically depending on the size of a rectangle.

4. Using the Generated Program Module

This section explains how to use the objects of the generated program module. Trees or graphs are created by successively creating their nodes. The easiest way is to call the constructor procedures *m<node_type>*. These procedures combine node creation, storage allocation, and attribute assignment. They provide a mechanism similar to record aggregates. Nested calls of constructor procedures allow programming with (ground) terms as in Prolog or LISP. In general, a node can be created by a call of one of the procedures

MakeTREE, *n<node_type>*, or *m<node_type>*.

or by invoking methods

TREE.make (*k<node_type>*), *<node_type>* (), *<node_type>* (...).

The type of a node can be retrieved by examination of the predefined tag field/member variable called *Kind/kind*. Alternatively the function/member function *TREE_IsType/isType* can be used to test whether a node has a certain type or a subtype thereof. In the procedural languages children and attributes can be accessed using two record selections. The first one states the node type and the second one gives the selector name of the desired item. In object-oriented languages children and attributes are accessed directly, possibly after applying a cast.

The following sections contain examples for the different implementation languages:

4.1. C

abstract syntax:

```
Expr      = [Pos: tPosition] <
  Binary  = Lop: Expr Rop: Expr [Operator: int] .
  Unary   = Expr [Operator] .
  IntConst = [Value] .
  RealConst = [Value: float] .
> .
```

tree construction by a term:

```
# define Plus 1
# include "TREE.h"
tTREE t;
tPosition Pos;

t = mBinary (Pos, mIntConst (Pos, 2), mIntConst (Pos, 3), Plus);
```

tree construction during parsing:

```
Expr: Expr '+' Expr {$.Tree = mBinary ($.Pos, $1.Tree, $3.Tree, Plus);} .
Expr: Expr '-' Expr {$.Tree = mUnary ($.Pos, $2.Tree, Minus);} .
Expr: IntConst {$.Tree = mIntConst ($.Pos, $1.IntValue);} .
Expr: RealConst {$.Tree = mRealConst ($.Pos, $1.RealValue);} .
```

tree construction using a statement sequence:

```
t = MakeTREE (kBinary);
t->Binary.Pos.Line      = 0;
t->Binary.Pos.Column    = 0;
t->Binary.Lop           = MakeTREE (IntConst);
t->Binary.Lop->IntConst.Pos = Pos;
t->Binary.Lop->IntConst.Value = 2;
t->Binary.Rop           = MakeTREE (IntConst);
t->Binary.Rop->IntConst.Pos = Pos;
t->Binary.Rop->IntConst.Value = 3;
t->Binary.Operator      = Plus;
```

access of tag field, children, and attributes:

```
switch (t->Kind) {
case kExpr : ... t->Expr.Pos      ...
case kBinary: ... t->Binary.Operator ...
              ... t->Binary.Lop    ...
case kUnary : ... t->Unary.Expr->Expr.Pos ...
}
```

4.2. C++

abstract syntax:

```
Expr      = [Pos: tPosition] <
  Binary  = Lop: Expr Rop: Expr [Operator: int] .
  Unary   = Expr [Operator] .
  IntConst = [Value] .
  RealConst = [Value: float] .
> .
```

tree construction by a term:

```
# define Plus 1
# include "TREE.h"
TREE o; /* create a tree object (manager) */
tTREE t; /* declare a pointer to tree nodes */
tPosition Pos;

t = o.mBinary (Pos, o.mIntConst (Pos, 2), o.mIntConst (Pos, 3), Plus);
```

tree construction during parsing:

```
Expr: Expr '+' Expr {$.Tree = o.mBinary ($.Pos, $1.Tree, $3.Tree, Plus);} .
Expr: Expr '-' Expr {$.Tree = o.mUnary ($.Pos, $2.Tree, Minus);} .
Expr: IntConst {$.Tree = o.mIntConst ($.Pos, $1.IntValue);} .
Expr: RealConst {$.Tree = o.mRealConst ($.Pos, $1.RealValue);} .
```

tree construction using a statement sequence:

```
t = o.MakeTREE (kBinary);
t->Binary.Pos.Line      = 0;
t->Binary.Pos.Column    = 0;
t->Binary.Lop           = o.MakeTREE (IntConst);
t->Binary.Lop->IntConst.Pos = Pos;
t->Binary.Lop->IntConst.Value = 2;
t->Binary.Rop           = o.MakeTREE (IntConst);
t->Binary.Rop->IntConst.Pos = Pos;
t->Binary.Rop->IntConst.Value = 3;
t->Binary.Operator      = Plus;
```

access of tag field, children, and attributes:

```
switch (t->Kind) {
case kExpr : ... t->Expr.Pos      ...
case kBinary: ... t->Binary.Operator ...
              ... t->Binary.Lop    ...
case kUnary : ... t->Unary.Expr->Expr.Pos ...
}
```

4.3. Modula-2

abstract syntax:

```
Expr      = [Pos: tPosition] <
  Binary  = Lop: Expr Rop: Expr [Operator: INTEGER] .
  Unary   = Expr [Operator] .
  IntConst = [Value] .
  RealConst = [Value: REAL] .
> .
```

tree construction by a term:

```
CONST Plus = 1;
VAR t : tTREE;
    Pos: tPosition;

t := mBinary (Pos, mIntConst (Pos, 2), mIntConst (Pos, 3), Plus);
```

tree construction during parsing:

```
Expr: Expr '+' Expr { $$ . Tree := mBinary ($2.Pos, $1.Tree, $3.Tree, Plus); } .
Expr: '-' Expr { $$ . Tree := mUnary ($1.Pos, $2.Tree, Minus); } .
Expr: IntConst { $$ . Tree := mIntConst ($1.Pos, $1.IntValue); } .
Expr: RealConst { $$ . Tree := mRealConst ($1.Pos, $1.RealValue); } .
```

tree construction using a statement sequence:

```
t := MakeTREE (Binary);
t^.Binary.Pos.Line      := 0;
t^.Binary.Pos.Column    := 0;
t^.Binary.Lop           := MakeTREE (IntConst);
t^.Binary.Lop^.IntConst.Pos := Pos;
t^.Binary.Lop^.IntConst.Value := 2;
t^.Binary.Rop           := MakeTREE (IntConst);
t^.Binary.Rop^.IntConst.Pos := Pos;
t^.Binary.Rop^.IntConst.Value := 3;
t^.Binary.Operator      := Plus;
```

access of tag field, children, and attributes:

```
CASE t^.Kind OF
| Expr : ... t^.Expr.Pos ...
| Binary: ... t^.Binary.Operator ...
          ... t^.Binary.Lop ...
| Unary : ... t^.Unary.Expr^.Expr.Pos ...
END;
```

4.4. Java

abstract syntax:

```
Expr      = [Pos: Position] <
  Binary  = Lop: Expr Rop: Expr [Operator: int] .
  Unary   = Expr [Operator] .
  IntConst = [Value] .
  RealConst = [Value: float] .
> .
```

tree construction by a term:

```
import Tree.*; // Allows IntConst instead of Tree.IntConst etc.
static final int Plus = 1;
de.cocolab.reuse.Position Pos;

Tree t = new Binary (Pos, new IntConst (Pos, 2), new IntConst (Pos, 3), Plus);
```

tree construction during parsing:

```
Expr: Expr '+' Expr { $$ = new Binary ($2.position (), $1.asExpr (), $3.asExpr (),
                                     Plus); } .
Expr: '-' Expr { $$ = new Unary ($1.position (), $2.asExpr (), Minus); } .
Expr: IntConst { $$ = new IntConst ($1.position (), $1.asIntValue ().value); } .
Expr: RealConst { $$ = new RealConst ($1.position (), $1.asRealValue ().value); } .
```

tree construction using a statement sequence:

```
Binary b = new Binary ();
b.Pos = new Position (0, 0);
b.Lop = new IntConst ();
b.Lop.Pos = Pos;
b.Lop.Value = 2;
b.Rop = new IntConst ();
b.Rop.Pos = Pos;
b.Rop.Value = 3;
b.Operator = Plus;
```

access of tag field, children, and attributes:

```
switch (t.kind) {
case Tree.Expr : Expr e = (Expr) t; ... e.Pos ...
case Tree.Binary: Binary b = (Binary) t; ... b.Operator ...
                  ... b.Lop ...
case Tree.Unary : Unary u = (Unary) t; ... u.Expr.Pos ...
}
```

5. Related Research

5.1. Variant Records

Ast specifications and variant record types like in Pascal or Modula-2 are very similar. Every node type in an *ast* specification corresponds to a single variant. In the generated code every node type is translated into a record type. All record types become members of a variant record type representing the type for the trees.

The differences are the following: *Ast* specifications are shorter than directly hand-written variant record types. *Ast* specifications are based on the formalism of context-free grammars (see section 5.3.). The generator *ast* automatically provides operations on record types which would be

simple but voluminous program by hand. The node constructor procedures allow to write record aggregates and provide dynamic storage management. The reader and writer procedures supply input and output for record types and even for complete linked data structures such as trees and graphs. Even when the target language is an object-oriented language such as Java, *ast* still provides important advantages over hand coding.

5.2. Type Extensions

Type extensions have been introduced with the language Oberon [Wir88a, Wir88b, Wir88c]. The extension mechanism of *ast* is basically the same as in Oberon. The notions extension, base type, and derived type are equivalent. Type extension is equivalent to inheritance in object-oriented languages such as C++ and Java. *Type tests* and *type guards* can be easily programmed by inspecting the tag field of a node. *Ast* does not provide assignment of subtypes to base types in the sense of value semantics or a projection, respectively. The tool can be seen as a preprocessor providing type extensions for C, C++, and Modula-2.

The second example in section 2.5. illuminates the relationship between *ast* and Oberon. The node type Stats is a base type with two fields, a child and an attribute. It is extended e. g. by the node type While with two more fields which are children.

5.3. Context-Free Grammars

As already mentioned, *ast* specifications are based on context-free grammars. *Ast* specifications extend context-free grammars by selector names for right-hand side symbols, attributes, the extension mechanism, and modules. If these features are omitted, we basically arrive at context-free grammars. This holds from the syntactic as well as from the semantic point of view. The names of the node types represent both terminal or nonterminal symbols and rule names. Node types correspond to grammar rules. The notions of derivation and derivation tree can be used similarly in both cases. The selector names can be seen as syntactic sugar and the attributes as some kind of terminal symbols. The extension mechanism is equivalent to a shorthand notation for factoring out common rule parts in combination with implicit chain rules.

Example:

ast specification:

```
Stats      = Next: Stats <
  If       = Expr Then: Stats Else: Stats .
  While    = Expr Stats .
> .
```

corresponding context-free grammar:

```
Stats      = Stats .
Stats      = Stats If .
Stats      = Stats While .
If         = Expr Stats Stats .
While     = Expr Stats .
```

In the example above, Stats corresponds to a nonterminal. There are two rules or right-hand sides for Stats which are named If and While. The latter would be regarded as nonterminals, too, if a child of types If or While would be specified.

5.4. Attribute Grammars

Attribute grammars [Knu68, Knu71] and *ast* specifications are based on context-free grammars and associate attributes with terminal and nonterminals symbols. Additionally *ast* allows attributes which are local to rules. As the structure of the tree itself is known and transparent, subtrees can be accessed or created dynamically and used as attribute values. The access of the right-hand side symbols uses the selector names for symbolic access instead of the grammar symbol with an additional subscript if needed. There is no need to map chain rules to tree nodes because of the extension mechanism offered by *ast*. Attribute evaluation is outside the scope of *ast*. This can be done either with the attribute evaluator generator *ag* [Grob] which understands *ast* specifications extended by attribute computation rules and processes the trees generated by *ast* or by hand-written programs that use an *ast* generated module. In the latter case attribute computations do not have to obey the single assignment restriction for attributes. They can assign a value to an attribute zero, one, or several times.

5.5. Interface Description Language (IDL)

The approach of *ast* is similar to the one of IDL [Lam87, NNG89]. Both specify attributed trees as well as graphs. Node types without extensions are called nodes in IDL and node types with extensions (base types) are called classes. *Ast* has simplified this to the single notion of a node type. Attributes are treated similarly in both systems. Children and attributes are both regarded as attributes, as structural and non-structural ones, with only little difference in between. Both systems allow multiple inheritance of attributes, *ast* has a separate syntax for single inheritance and uses the notion extension instead [Wir88a]. IDL knows the predefined types INTEGER, RATIONAL, BOOLEAN, STRING, SEQ OF, and SET OF. It offers special operations for the types SEQ OF and SET OF. *Ast* really has no built in types at all, it uses the ones of the target language and has a table containing the type specific operations e. g. for reading and writing. Both *ast* and IDL allow attributes of user-defined types. In *ast*, the type specific operations for predefined or user-defined types are easily expressed by macros using the target language directly. IDL offers an assertion language whereas *ast* does not. IDL provides a mechanism to modify existing specifications. The module feature of *ast* can be used to extend existing specifications. From *ast*, readers and writers are requested with simple command line options instead of complicated syntactic constructs. *Ast* does not support representation specifications, because representations are much more easily expressed using the types of the target language directly. Summarizing, we consider *ast* to have a simpler specification method and to generate more powerful features like aggregates, reversal of lists, and graph browsers.

5.6. Attribute Coupled Grammars

Attribute coupled grammars (ACG's) [Gie88] or algebraic specifications [HHK88] have only very little in common with *ast* specifications. They all view node types or rules as signatures of functions. The name of the node type plays the role of the function name and describes the result type. The types of the children and attributes correspond to the type of the function arguments. The constructor procedures generated by *ast* reflect this view best.

5.7. Object-Oriented Languages

The extension mechanism of *ast* is exactly the same as single inheritance in object-oriented languages like e. g. Simula [DMN70] or Smalltalk [Gol84]. The hierarchy introduced by the extension mechanism corresponds directly to the class hierarchy of object-oriented languages. The notions base type and super class both represent the same concept. Messages and virtual

procedures are out of the scope of *ast*. Virtual procedures might be simulated with procedure-valued attributes. Table 7 summarizes the corresponding notions of trees (*ast*), type extensions, and object-oriented programming.

5.8. Tree Grammars

Conventional tree grammars are characterized by the fact that all right-hand sides start with a terminal symbol. They are used for the description of string languages that represent trees in prefix form. *Ast* specifications describe trees which are represented by (absolute) pointers from parent to child nodes. If we shift the names of node types of *ast* specifications to the beginning of the right-hand side and interpret them as terminals we arrive at conventional tree grammars. That is exactly what is done by the *ast* tree/graph writers. They write a tree in prefix form and prepend every node with the name of its node type. That is necessary to be able to perform the read operations.

6. Hints on Specifying Abstract Syntax

- Keep the abstract syntax as short and simple as possible.
- Try to normalize by representing only the most general form.
- Normalize to the general form e. g. by adding default values.
- Normalize several concrete representations to one abstract construct.
- Map concrete to abstract syntax by disregarding the concrete syntax rules and by concentrating on the semantic structure of the abstract syntax.
- Map several concrete nonterminals to one abstract node type (e. g. Expr, Term, and Factor → Expr)
- Allow all lists to be empty regardless of the concrete syntax. Otherwise you have to process the list element at two places in exactly the same way. This causes programming overhead and violates the law of singularity: "One thing only once!"
- Operators can be represented by different node types (e. g. Plus, Minus, Mult, ...) or by one node type with an attribute describing the operator (e. g. Binary).
- Lists can be represented by separate nodes for the list and the elements (e. g. Stats and Stat) or by nodes for the elements where every node has a child that refers to the next list element (see last example in section 2.11.1.).

Table 7: Comparison of notions from the areas of trees, types, and object-oriented programming

trees	types	object-oriented programming
node type	record type	class
-	base type	superclass
-	derived type	subclass
attribute, child	record field	instance variable
tree node	record variable	object, instance
-	extension	inheritance

7. Examples

The Appendices 1 to 3 contain examples of *ast* specifications.

Appendix 1 contains the concrete syntax of *ast*'s specification language. The node types enclosed in quotes or starting with the character 't' constitute the terminals for *ast*'s parser. The extensions and the node types used for the latter describe the lexical grammar.

Appendix 2 contains the concrete syntax of a small example programming language called *MiniLAX* [GrK88]. The attributes specified are the ones a parser would evaluate during parsing. The Appendices 1 and 2 show how concrete grammars can be described with *ast*.

Appendix 3 contains an abstract syntax for *MiniLAX*. The attributes specified are input or intrinsic ones whose values would be provided by the scanner and parser. The definition follows the hints of the previous section. Terminal symbols without attributes are omitted. All binary and unary operators are expressed by two nodes having one attribute to represent the operator. To simplify things as much as possible all lists are allowed to be empty and procedure declarations as well as calls always have a parameter list. The specification tries to keep the tree as small as possible. The inheritance mechanism allows to avoid all chain rules. There are no nodes for sequences of declarations, statements, etc.. Instead every node for a declaration or a statement has a field named *Next* describing the successor entity. Except for expressions no separate nodes are used for identifiers. The information is included as attribute in the node types *Proc*, *Var*, *Formal*, and *Call*. The source position is stored only at the nodes where it might be needed during semantic analysis. The above measures not only reduce the amount of storage but they also reduce run time because less information has to be produced and processed.

8. Experiences

Ast can be used not only for abstract syntax trees in compilers but for every tree or graph like data structure. In general the data structure can serve as interface between phases within a program or between separate programs. In the latter case it would be communicated via a file using the generated reader and writer procedures.

Generated tree respectively graph modules have successfully been used in compilers e. g. for *MiniLAX* [WGS89] and *UNITY* [Bie89] as well as for a Modula to C translator [Mar90]. The modules for the internal data structure of *ast* itself and the attribute evaluator generator *ag* [Grob] have also been generated by *ast*. Moreover, the symbol table module of the Modula to C translator has been generated.

The advantage of this approach is that it saves considerably hand-coding of trivial declarations and operations. Table 8 lists the sizes (numbers of lines) of some specifications and the generated modules. Sums in the specification column are composed of the sizes for the definition of node types and for user-supplied target code. Sums in the tree module column are composed of the sizes for the definition part and for the implementation part. The reason for the large sizes of the tree modules comes from the numerous node constructor procedures and from the graph browser in the case of *ag*. These procedures proved to be very helpful for debugging purposes as they provide readable output of complex data structures. The constructor procedures allow to write record aggregates. Therefore, node creation and assignment of values to the components can be written very compact. It is even possible to write (ground) terms as in Prolog or LISP by nested calls of the constructor procedures.

Table 8: Examples of Ast Applications

application	specification	tree module
MiniLAX	56	202 + 835 = 1037
Modula-2	240	583 + 3083 = 3666
UNITY	210	207 + 962 = 1169
Ag	78 + 347 = 425	317 + 1317 = 1634
Definition table	82 + 900 = 982	399 + 1431 = 1830

9. Usage

NAME

ast - generator for abstract structure/syntax trees

SYNOPSIS

ast [-options] [-ldirectory] [files]

DESCRIPTION

Ast generates a program module to handle arbitrary attributed trees and graphs. A typical application is the abstract syntax tree in a compiler. The input *file* contains a specification which describes the structure of all possible trees or nodes respectively and the attributes of the nodes. *Ast* generates type declarations to implement the tree and several procedures for tree manipulation including ASCII and binary readers and writers (see options below). If *file* is omitted the specification is read from standard input.

OPTIONS

a	generate all except -ceh (default)	
n	generate node constructors	procedures n<node> (node)
m	generate node constructors	procedures m<node> (make)
f	generate node/tree destroyer	procedure ReleaseTREE (free)
F	generate general destroyer	procedure ReleaseTREEModule (FREE)
o	generate ASCII node writer	procedure WriteTREENode (output)
r	generate ASCII graph reader	procedure ReadTREE
w	generate ASCII graph writer	procedure WriteTREE
g	generate binary graph reader	procedure GetTREE
p	generate binary graph writer	procedure PutTREE
R	generate list reverser	procedure ReverseTREE
R	generate list iterator	procedure ForallTREE
t	generate top down traversal (reverse depth first)	procedure TraverseTREETD
b	generate bottom up traversal (depth first)	procedure TraverseTREEBU

y	generate graph copy	procedure CopyTREE
=	generate tree equality test	procedure IsEqualTREE
k	generate graph type checker	procedure CheckTREE
q	generate ASCII graph browser	procedure QueryTREE
e	generate graphic browser	procedure DrawTREE
_	generate array TREE_NodeName	
d	generate header file or definition module	
i	generate implementation part or module	
s	generate import statements	
:	generate lines not longer than 80 characters	
4	generate tree/graph description in file VIEW.TS	
6	generate # line directives	
7	touch output files only if necessary	
8	report storage consumption	
c	generate C code (default: Modula-2)	
+	generate C++ code	
J	generate Java code	
h	print help information	
ldir	dir is the directory where ast finds its data files	

FILES

if output is in C:

<module>.h	header file of the generated graph module
<module>.c	body of the generated graph module
yy<module>.h	macro file defining type specific operations
telrc.tcl	procedure definitions for procedure DrawTREE

if output is in C++:

<module>.h	header file of the generated graph module
<module>.cxx	body of the generated graph module
yy<module>.h	macro file defining type specific operations
telrc.tcl	procedure definitions for procedure DrawTREE

if output is in Modula-2:

<module>.md	definition module of the generated graph module
<module>.mi	implementation module of the generated graph module
<module>.imp	import statements

if output is in Java:

<module>.java	classes of the generated graph module
---------------	---------------------------------------

SEE ALSO

J. Grosch: "Ast - A Generator for Abstract Syntax Trees", CoCoLab Germany, Document No. 15

J. Grosch: "Tool Support for Data Structures", *Structured Programming*, 12, 31-38 (1991)

J. Grosch: "Tool Support for Data Structures", CoCoLab Germany, Document No. 17

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Appendix 1: Syntax of the Specification Language

```

RULE                               /* Ast: concrete syntax */

/* parser grammar */

Specification = <
              = TreeCodes PropPart DeclPart RulePart Modules .
              = 'MODULE' Name TreeCodes PropPart DeclPart RulePart
                'END' Name Modules .
> .
TreeCodes    = <
              = SubUnit .
              = 'TREE' SubUnit Codes .
              = 'TREE' DottedName SubUnit Codes .
> .
Codes        = <
              = .
              = Codes 'EXPORT' tTargetCode .
              = Codes 'IMPORT' tTargetCode .
              = Codes 'GLOBAL' tTargetCode .
              = Codes 'LOCAL' tTargetCode .
              = Codes 'BEGIN' tTargetCode .
              = Codes 'CLOSE' tTargetCode .
> .
SubUnit      = <
              = .
              = SubUnit 'SUBUNIT' Name .
              = SubUnit 'VIEW' Name .
> .
PropPart     = Props .

Props        = <
              = .
              = Props 'PROPERTY' Properties
              = Props 'PROPERTY' Properties 'FOR' Names
              = Props 'SELECT' Names
> .
DeclPart     = <
              = .
              = 'DECLARE' Decls .
> .
Decls        = <
              = .
              MoreNonterms = Decls Names '=' AttrDecls '.' .
              MoreTerminals = Decls Names ':' AttrDecls '.' .
> .
Names        = <
              = .
              = Names Name .
              = Names ',' .
> .
RulePart     = <
              = .
              = 'RULE' Types .
> .
Types        = <

```

```

Nonterminal = .
Terminal     = Types Name BaseType '=' AttrDecls Extensions '.' .
Abstract     = Types Name BaseType ':' AttrDecls Extensions '.' .
> .
BaseTypes    = <
              = .
              = '<' Names .
> .
Extensions   = <
              = .
              = '<' Types '>' .
> .
AttrDecl     = <
              = .
              ChildSelct = AttrDecl Name ':' Name Properties .
              ChildNoSelct = AttrDecl Name Properties .
              AttrTyped = AttrDecl '[' Name ':' Name Properties ']' .
              AttrInteger = AttrDecl '[' Name Properties ']' .
> .
Properties    = <
              = .
              = Properties 'INPUT' .
              = Properties 'OUTPUT' .
              = Properties 'SYNTHESIZED' .
              = Properties 'INHERITED' .
              = Properties 'THREAD' .
              = Properties 'REVERSE' .
              = Properties 'IGNORE' .
              = Properties 'VIRTUAL' .
> .
Modules      = <
              = .
              = Modules 'MODULE' Name TreeCodes DeclPart RulePart 'END' Name .
> .
Name         = <
              = tIdent .
              = tString .
> .
DottedName   = <
              = Name .
              = DottedName '.' Name . /* Java only */
> .

/* lexical grammar */

tIdent       : <
              = Letter .
              = tIdent Letter .
              = tIdent Digit .
              = tIdent '_' .
> .
tString      : <
              = '"' Characters '"' .
              = "'" Characters "'" .
> .
tTargetCode  : '{' Characters '}' .

```

```

Comment      : '/*' Characters '*/' .
Characters   : <
              = .
              = Characters Character .
> .

```

Appendix 2: Concrete Syntax of the Example Language MiniLAX

```

RULE
Prog          = PROGRAM tIdent ';' 'DECLARE' Decls 'BEGIN' Stats 'END' '.' .
Decl         = <
              Decl1
              Decl2
              ';' Decl .
> .
Decl         = <
              Var
              Proc0
              Proc
              'DECLARE' Decls 'BEGIN' Stats 'END' .
> .
Formals      = <
              Formals1
              Formals2
              ';' Formal .
> .
Formal       = <
              Value
              Ref
              ':' Type .
> .
Type         = <
              Int
              Real
              Bool
              Array
              '[' Lwb: tIntegerConst '..' Upb: tIntegerConst ']' OF Type .
> .
Stats        = <
              Stats1
              Stats2
              ';' Stat .
> .
Stat         = <
              Assign
              Call0
              Call
              If
              While
              Read
              Write
              '(' Expr ')' .
> .
Actuals      = <
              Expr1
              Expr2
              ',' Expr .
> .
Expr         = <
              Less
              Plus
              Times
              Not
              '(' Expr ')' .
              IConst
              RConst
              False
              True
              <
              Name
              Index
              '[' Expr ']' .
              > .
              > .
tIdent       : [Ident: tIdent] .
tIntegerConst : [Integer      ] .
tRealConst   : [Real : double] .

```

Appendix 3: Abstract Syntax of the Example Language MiniLAX

```

TREE                                /* MiniLAX: abstract syntax */
IMPORT {
# include "Idents.h"
# include "Position.h"
}

RULE

MiniLax      = Proc .
Decls       = <
  NoDecl    = .
  Decl     = Next: Decls REV [Ident: tIdent] [Pos: tPosition] <
    Proc   = Formals Decls Stats .
    Var    = Type .
  > .
> .
Formals     = <
  NoFormal  = .
  Formal   = Next: Formals REV [Ident: tIdent] [Pos: tPosition] Type .
> .
Type        = <
  Integer  = .
  Real     = .
  Boolean  = .
  Array    = Type [Lwb] [Upb] [Pos: tPosition] .
  Ref      = Type .
> .
Stats       = <
  NoStat   = .
  Stat     = Next: Stats REV <
    Assign = Adr Expr [Pos: tPosition] .
    Call   = Actuals [Ident: tIdent] [Pos: tPosition] .
    If     = Expr Then: Stats Else: Stats .
    While  = Expr Stats .
    Read   = Adr .
    Write  = Expr .
  > .
> .
Actuals     = <
  NoActual  = [Pos: tPosition] .
  Actual   = Next: Actuals REV Expr .
> .
Expr        = [Pos: tPosition] <
  Binary   = Lop: Expr Rop: Expr [Operator] .
  Unary    = Expr [Operator] .
  IntConst = [Value ] .
  RealConst = [Value: double] .
  BoolConst = [Value: rbool ] .
  Adr      = <
    Index  = Adr Expr .
    Ident  = [Ident: tIdent] .
  > .
> .

```

Appendix 4: Generated Header File for C

```

# ifndef yyTREE /* throughout replace TREE by the name of the tree module */
# define yyTREE

<import_declarations>

# define rbool char
# define NoTREE (tTREE) NULL
# define k<type_1> 1
# define k<type_2> 2
...
typedef unsigned short TREE_tKind; /* or unsigned char */
typedef unsigned short TREE_tMark;
typedef unsigned short TREE_tLabel;
typedef union TREE_Node * tTREE;
typedef void (* TREE_tProcTree) (void);

typedef tTREE t<type_1>; /* for toplevel node types, only */
typedef tTREE t<type_2>;
...

<export_declarations>

# ifndef TREE_NodeHead
# define TREE_NodeHead
# endif
typedef struct { TREE_tKind yyKind; TREE_tMark yyMark; TREE_NodeHead }
TREE_NodeHead;

typedef struct { TREE_tNodeHead yyHead;
<children_and_attributes_of_type_1> } y<type_1>;
typedef struct { TREE_tNodeHead yyHead;
<children_and_attributes_of_type_2> } y<type_2>;
...

union TREE_Node {
TREE_tKind Kind;
TREE_tNodeHead yyHead;
y<type_1> <type_1>;
y<type_2> <type_2>;
...
};

extern tTREE TREERoot;
extern unsigned long TREE_HeapUsed;
extern unsigned short TREE_NodeSize [];
extern char * TREE_NodeName [];
extern void (* Tree_Exit) (void);
extern tTREE n<type_1> (void);
extern tTREE n<type_2> (void);
...
extern tTREE m<type_1> (<input_children_and_attributes_of_type_1>);
extern tTREE m<type_2> (<input_children_and_attributes_of_type_2>);
...

extern tTREE MakeTREE (TREE_tKind Kind);
extern rbool TREE_IsType (tTREE t, TREE_tKind Kind);
extern void ReleaseTREE (tTREE t);
extern void ReleaseTREEModule (void);

```

```

extern void WriteTREENode (FILE * f, tTREE t);
extern void WriteTREE (FILE * f, tTREE t);
extern tTREE ReadTREE (FILE * f);
extern void PutTREE (FILE * f, tTREE t);
extern tTREE GetTREE (FILE * f);
extern void TraverseTREETD (tTREE t, void (* Procedure) (tTREE t));
extern void TraverseTREEBU (tTREE t, void (* Procedure) (tTREE t));
extern tTREE ReverseTREE (tTREE t);
extern void ForallTREE (tTREE t, void (* Procedure) (tTREE t));
extern tTREE CopyTREE (tTREE t);
extern rbool CheckTREE (tTREE t);
extern void QueryTREE (tTREE t);
extern void DrawTREE (tTREE t);
extern void SetDepthTREE (int Depth);
extern void SetBoxTREE (int Width, int Height);
extern rbool IsEqualTREE (tTREE t1, tTREE t2);
extern void BeginTREE (void);
extern void CloseTREE (void);

# endif

```

Appendix 5: Generated Header File for C++

```

# ifndef yyTREE /* throughout replace TREE by the name of the tree module */
# define yyTREE

<import_declarations>

# define rbool char

# define NoTREE (tTREE) 0L
# define k<type_1> 1
# define k<type_2> 2
...
typedef unsigned short TREE_tKind; /* or unsigned char */
typedef unsigned short TREE_tMark;
typedef unsigned short TREE_tLabel;
typedef union TREE_Node * tTREE;
typedef void (* TREE_tProcTree) (void);

typedef tTREE t<type_1>; /* for toplevel node types, only */
typedef tTREE t<type_2>;
...

<export_declarations>

# ifndef TREE_NodeHead
# define TREE_NodeHead
# endif
typedef struct { TREE_tKind yyKind; TREE_tMark yyMark; TREE_NodeHead }
TREE_tNodeHead;

typedef struct { TREE_tNodeHead yyHead;
<children_and_attributes_of_type_1> } y<type_1>;
typedef struct { TREE_tNodeHead yyHead;
<children_and_attributes_of_type_2> } y<type_2>;
...

union TREE_Node {
TREE_tKind Kind;
TREE_tNodeHead yyHead;
y<type_1> <type_1>;
y<type_2> <type_2>;
...
};

extern const unsigned short TREE_NodeSize [];
extern const char * const TREE_NodeName [];

# define TREE_BASE_CLASS

class TREE TREE_BASE_CLASS {
public:
tTREE TREERoot;
unsigned long TREE_HeapUsed;
void (* TREE_Exit) (void);

tTREE n<type_1> (void);
tTREE n<type_2> (void);
...

tTREE m<type_1> (<input_children_and_attributes_of_type_1>);
tTREE m<type_2> (<input_children_and_attributes_of_type_2>);
...

```

```

tTREE MakeTREE      (TREE_tKind Kind);
rbool TREE_IsType  (tTREE t, TREE_tKind Kind);
void ReleaseTREE   (tTREE t);
void ReleaseTREEModule(void);
void WriteTREENode (FILE * f, tTREE t);
void WriteTREE     (FILE * f, tTREE t);
tTREE ReadTREE    (FILE * f);
void PutTREE       (FILE * f, tTREE t);
tTREE GetTREE     (FILE * f);
void TraverseTREED (tTREE t, TREE_tProcTree Proc);
void TraverseTREEBU (tTREE t, TREE_tProcTree Proc);
tTREE ReverseTREE (tTREE t);
void ForallTREE    (tTREE t, TREE_tProcTree Proc);
tTREE CopyTREE    (tTREE t);
rbool CheckTREE   (tTREE t);
void QueryTREE    (tTREE t);
void DrawTREE     (tTREE t);
void SetDepthTREE (int Depth);
void SetBoxTREE   (int Width, int Height);
rbool IsEqualTREE (tTREE t1, tTREE t2);
void BeginTREE    (void);
void CloseTREE    (void);
TREE             (void);
~TREE            (void);
};
# endif

```

Appendix 6: Generated Definition Module for Modula-2

```

DEFINITION MODULE TREE;
IMPORT IO;      (* throughout replace TREE by the name of the tree module *)

<import_declarations>

CONST
  NoTREE      = NIL;
  <type_1>    = 1;
  <type_2>    = 2;
  ...

TYPE
  tTREE      = POINTER TO yyNode;
  tProcTree = PROCEDURE (tTREE);

  t<type_1>  = tTREE;    (* for toplevel node types, only *)
  t<type_2>  = tTREE;
  ...

<export_declarations>

TYPE
  yytNodeHead = RECORD yyKind, yyMark: SHORTCARD; END;

TYPE
  y<type_1>    = RECORD yyHead: yytNodeHead;
                    <children_and_attributes_of_type_1> END;
  y<type_2>    = RECORD yyHead: yytNodeHead;
                    <children_and_attributes_of_type_2> END;
  ...

  yyNode      = RECORD
    CASE : SHORTCARD OF
      | 0      : Kind: SHORTCARD;
      | ...   : yyHead: yytNodeHead;
      | <type_1> : <type_1>      : y<type_1>;
      | <type_2> : <type_2>      : y<type_2>;
      | ...
    END;
  END;

VAR TREERoot : tTREE;
VAR HeapUsed : LONGCARD;
VAR yyNodeSize: ARRAY [ ... ] OF SHORTCARD;
VAR yyExit   : PROC;

PROCEDURE n<type_1>      () : tTREE;
PROCEDURE n<type_2>      () : tTREE;
...
PROCEDURE m<type_1>      (<input_children_and_attributes_of_type_1>) : tTREE;
PROCEDURE m<type_2>      (<input_children_and_attributes_of_type_2>) : tTREE;
...
PROCEDURE MakeTREE      (Kind: SHORTCARD): tTREE;
PROCEDURE IsType        (Tree: tTREE; Kind: SHORTCARD): BOOLEAN;
PROCEDURE ReleaseTREE   (Tree: tTREE);
PROCEDURE ReleaseTREEModule;
PROCEDURE WriteTREENode (f: IO.tFile; Tree: tTREE);
PROCEDURE WriteTREE     (f: IO.tFile; Tree: tTREE);
PROCEDURE ReadTREE      (f: IO.tFile): tTREE;
PROCEDURE PutTREE       (f: IO.tFile; Tree: tTREE);

```

```

PROCEDURE GetTREE      (f: IO.tFile): tTREE;
PROCEDURE TraverseTREED (Tree: tTREE; Proc: tProcTree);
PROCEDURE TraverseTREEBU (Tree: tTREE; Proc: tProcTree);
PROCEDURE ReverseTREE  (Tree: tTREE): tTREE;
PROCEDURE ForallTREE   (Tree: tTREE; Proc: tProcTree);
PROCEDURE CopyTREE     (Tree: tTREE): tTREE;
PROCEDURE CheckTREE    (Tree: tTREE): BOOLEAN;
PROCEDURE QueryTREE    (Tree: tTREE);
PROCEDURE IsEqualTREE  (Tree1, Tree2: tTREE): BOOLEAN;
PROCEDURE BeginTREE;
PROCEDURE CloseTREE;
END TREE.

```

Appendix 7: Generated Declarations for Java

```

// throughout replace TREE by the name of the tree module
package <package_name>; // If the tree module is a dotted name
<import_declarations>
<global_declarations>
<local_declarations>

public class TREE implements java.io.Serializable {
    static final TREE NoTREE = null;

    /* for 'forall', 'traverseBU', 'traverseTD' */
    public static interface ProcTree {
        public void proc (TREE yyt);
    }

<export_declarations>

    /* methods available on all tree nodes */
    /* some are available as static methods taking an argument of type TREE */
    public int yyKind;
    static void writeNode (de.cocolab.reuse.CocktailWriter yyyout)
        throws java.io.IOException { ... }
    public void traverseTD (ProcTree yyyProc) { ... }
    public void traverseBU (ProcTree yyProc) { ... }
    public TREE reverse () { ... }
    public void forall (ProcTree yyProc) throws Throwable { ... }
    public boolean isType (int yyKind) { ... }
    public static boolean check (TREE yyt) throws java.io.IOException { ... }
    public void query () throws java.io.IOException { ... }
    public boolean isEqual (TREE yyt2) { ... }
    public static void write (de.cocolab.reuse.CocktailWriter yyyout)
        throws java.io.IOException { ... }
    public static TREE read (de.cocolab.reuse.CocktailReader yyyin)
        throws java.io.IOException { ... }
    public void put (java.io.OutputStream s) { ... }
    public void put (String fileName) { ... }
    public static TREE get (java.io.InputStream s) { ... }
    public static TREE get (String fileName) { ... }
    public static TREE copy (TREE yyt) { ... }
    public java.lang.Object clone () { ... }

    static final int k<type_1> = 1;
    static final int k<type_2> = 2;
    ...

    public static class <type_1> extends TREE {
        <children_and_attributes_of_type_1>
        public <type_1> () { ... }
        public <type_1> (<children_and_attributes_of_type_1>) { ... }
    }

    public static class <type_2> extends TREE {
        <children_and_attributes_of_type_1>
        public <type_2> () { ... }
        public <type_2> (<children_and_attributes_of_type_2>) { ... }
    }
    ...

    static final String [] NodeNames = {

```

```

    "NoTree", "<type_1>", "<type_2>", ... };
    public static TREE make (int yyKind) { ... }
    public static void begin () {
<begin_code>
    }
    public static void close () {
<close_code>
    }
    static { begin (); }
}

```

Appendix 8: Predefined Type Specific Operations for C

```

/* int */
# define beginint(a)
# define closeint(a)
# define readint(a)          (void) fscanf (yyf, "%d", & a);
# define writeint(a)        (void) fprintf (yyf, "%d", a);
# define getint(a)          yyGet ((char *) & a, sizeof (a));
# define putint(a)          yyPut ((char *) & a, sizeof (a));
# define copyint(a, b)
# define equalint(a, b)     (a) == (b)
/* short */
# define beginshort(a)
# define closeshort(a)
# define readshort(a)      (void) fscanf (yyf, "%hd", & a);
# define writeshort(a)     (void) fprintf (yyf, "%hd", a);
# define getshort(a)       yyGet ((char *) & a, sizeof (a));
# define putshort(a)       yyPut ((char *) & a, sizeof (a));
# define copyshort(a, b)
# define equalshort(a, b)  (a) == (b)
/* long */
# define beginlong(a)
# define closelong(a)
# define readlong(a)       (void) fscanf (yyf, "%ld", & a);
# define writelong(a)      (void) fprintf (yyf, "%ld", a);
# define getlong(a)        yyGet ((char *) & a, sizeof (a));
# define putlong(a)        yyPut ((char *) & a, sizeof (a));
# define copylong(a, b)
# define equallong(a, b)   (a) == (b)
/* unsigned */
# define beginunsigned(a)
# define closeunsigned(a)
# define readunsigned(a)   (void) fscanf (yyf, "%u", & a);
# define writeunsigned(a)  (void) fprintf (yyf, "%u", a);
# define getunsigned(a)    yyGet ((char *) & a, sizeof (a));
# define putunsigned(a)    yyPut ((char *) & a, sizeof (a));
# define copyunsigned(a, b)
# define equalunsigned(a, b) (a) == (b)
/* float */
# define beginfloat(a)
# define closefloat(a)
# define readfloat(a)      (void) fscanf (yyf, "%g", & a);
# define writefloat(a)     (void) fprintf (yyf, "%g", a);
# define getfloat(a)       yyGet ((char *) & a, sizeof (a));
# define putfloat(a)       yyPut ((char *) & a, sizeof (a));
# define copyfloat(a, b)
# define equalfloat(a, b)  (a) == (b)
/* double */
# define begindouble(a)
# define closedouble(a)
# define readdouble(a)     (void) fscanf (yyf, "%lg", & a);
# define writedouble(a)   (void) fprintf (yyf, "%lg", a);
# define getdouble(a)     yyGet ((char *) & a, sizeof (a));
# define putdouble(a)     yyPut ((char *) & a, sizeof (a));
# define copydouble(a, b)
# define equaldouble(a, b) (a) == (b)
/* rbool */

```

```

# define beginrbool(a)
# define closerbool(a)
# define readrbool(a)      a = fgetc (yyf) == 'T';
# define writerbool(a)    (void) fputc (a ? 'T' : 'F', yyf);
# define getrbool(a)      yyGet ((char *) & a, sizeof (a));
# define putrbool(a)      yyPut ((char *) & a, sizeof (a));
# define copyrbool(a, b)
# define equalrbool(a, b) (a) == (b)
/* char */
# define beginchar(a)
# define closechar(a)
# define readchar(a)      a = fgetc (yyf);
# define writechar(a)    (void) fputc (a, yyf);
# define getchar(a)      yyGet ((char *) & a, sizeof (a));
# define putchar(a)      yyPut ((char *) & a, sizeof (a));
# define copychar(a, b)
# define equalchar(a, b) (a) == (b)
/* tString */
# define begintString(a)
# define closetString(a)
# define readtString(a)
# define writetString(a)  (void) fputs (a, yyf);
# define gettString(a)
# define puttString(a)
# define copytString(a, b)
# define equaltString(a, b) strcmp (a, (b)) == 0
/* tStringRef */
# define begintStringRef(a)
# define closetStringRef(a)
# define readtStringRef(a)
# define writetStringRef(a) { char yys [1024]; \
                           (void) fgets (yys, 1024, yyf); \
                           (void) ungetc ('\n', yyf); \
                           a = PutString (yys, strlen (yys) - 1); }
# define gettStringRef(a)  WriteString (yyf, a);
# define puttStringRef(a)  { char yys [1024]; \
                           (void) fgets (yys, 1024, yyf); \
                           a = PutString (yys, strlen (yys) - 1); }
# define copytStringRef(a, b) WriteString (yyf, a); \
                             (void) fputc ('\n', yyf); }
# define equaltStringRef(a, b) (a) == (b)
/* tIdent */
# define begintIdent(a)    a = NoIdent;
# define closetIdent(a)
# define readtIdent(a)    a = yyReadIdent ();
# define writetIdent(a)  WriteIdent (yyf, a);
# define gettIdent(a)    yyGetIdent (& a);
# define puttIdent(a)    yyPutIdent (a);
# define copytIdent(a, b)
# define equaltIdent(a, b) (a) == (b)
/* tSet */
# define begintSet(a)
# define closetSet(a)
# define readtSet(a)      ReadSet (yyf, & a);
# define writetSet(a)    WriteSet (yyf, & a);
# define gettSet(a)
# define puttSet(a)

```

```

# define copytSet(a, b)
# define equaltSet(a, b)  IsEqual (& a, & b)
/* tPosition */
# define begintPosition(a) a = NoPosition;
# define closetPosition(a)
# define readtPosition(a)  ReadPosition (yyf, & a);
# define writetPosition(a) WritePosition (yyf, a);
# define gettPosition(a)   yyGet ((char *) & a, sizeof (a));
# define puttPosition(a)   yyPut ((char *) & a, sizeof (a));
# define copytPosition(a, b)
# define equaltPosition(a, b) Compare (a, b) == 0
/* NodeHead */
# define beginNodeHead(a)
# define closeNodeHead(a)
# define readNodeHead(a)
# define writeNodeHead(a)
# define getNodeHead(a)
# define putNodeHead(a)
# define copyNodeHead(a, b)
# define equalNodeHead(a, b) rtrue

```

Appendix 9: Predefined Type Specific Operations for C++

```

/* int */
# define beginint(a)
# define closeint(a)
# define readint(a)          (void) fscanf (yyf, "%d", & a);
# define writeint(a)         (void) fprintf (yyf, "%d", a);
# define getint(a)           yyGet ((char *) & a, sizeof (a));
# define putint(a)           yyPut ((char *) & a, sizeof (a));
# define copyint(a, b)
# define equalint(a, b)      (a) == (b)
/* short */
# define beginshort(a)
# define closeshort(a)
# define readshort(a)        (void) fscanf (yyf, "%hd", & a);
# define writeshort(a)       (void) fprintf (yyf, "%hd", a);
# define getshort(a)         yyGet ((char *) & a, sizeof (a));
# define putshort(a)         yyPut ((char *) & a, sizeof (a));
# define copysshort(a, b)
# define equalshort(a, b)    (a) == (b)
/* long */
# define beginlong(a)
# define closelong(a)
# define readlong(a)         (void) fscanf (yyf, "%ld", & a);
# define writelong(a)        (void) fprintf (yyf, "%ld", a);
# define getlong(a)          yyGet ((char *) & a, sizeof (a));
# define putlong(a)          yyPut ((char *) & a, sizeof (a));
# define copylong(a, b)
# define equallong(a, b)     (a) == (b)
/* unsigned */
# define beginunsigned(a)
# define closeunsigned(a)
# define readunsigned(a)     (void) fscanf (yyf, "%u", & a);
# define writeunsigned(a)    (void) fprintf (yyf, "%u", a);
# define getunsigned(a)      yyGet ((char *) & a, sizeof (a));
# define putunsigned(a)      yyPut ((char *) & a, sizeof (a));
# define copyunsigned(a, b)
# define equalunsigned(a, b) (a) == (b)
/* float */
# define beginfloat(a)
# define closefloat(a)
# define readfloat(a)        (void) fscanf (yyf, "%g", & a);
# define writefloat(a)       (void) fprintf (yyf, "%g", a);
# define getfloat(a)         yyGet ((char *) & a, sizeof (a));
# define putfloat(a)         yyPut ((char *) & a, sizeof (a));
# define copyfloat(a, b)
# define equalfloat(a, b)    (a) == (b)
/* double */
# define begindouble(a)
# define closedouble(a)
# define readdouble(a)       (void) fscanf (yyf, "%lg", & a);
# define writedouble(a)     (void) fprintf (yyf, "%lg", a);
# define getdouble(a)       yyGet ((char *) & a, sizeof (a));
# define putdouble(a)       yyPut ((char *) & a, sizeof (a));
# define copydouble(a, b)
# define equaldouble(a, b)   (a) == (b)
/* rbool */

```

```

# define beginrbool(a)
# define closerbool(a)
# define readrbool(a)       a = fgetc (yyf) == 'T';
# define writerbool(a)      (void) fputc (a ? 'T' : 'F', yyf);
# define getrbool(a)        yyGet ((char *) & a, sizeof (a));
# define putrbool(a)        yyPut ((char *) & a, sizeof (a));
# define copyrbool(a, b)    (a) == (b)
# define equalrbool(a, b)
/* char */
# define beginchar(a)
# define closechar(a)
# define readchar(a)        a = fgetc (yyf);
# define writechar(a)       (void) fputc (a, yyf);
# define getchar(a)         yyGet ((char *) & a, sizeof (a));
# define putchar(a)         yyPut ((char *) & a, sizeof (a));
# define copychar(a, b)
# define equalchar(a, b)    (a) == (b)
/* tString */
# define begintString(a)
# define closetString(a)
# define readtString(a)
# define writetString(a)    (void) fputs (a, yyf);
# define gettString(a)
# define puttString(a)
# define copytString(a, b)
# define equaltString(a, b) strcmp (a, (b)) == 0
/* tStringRef */
# define begintStringRef(a)
# define closetStringRef(a)
# define readtStringRef(a)  { char yys [1024]; \
                          (void) fgets (yys, 1024, yyf); \
                          (void) ungetc ('\n', yyf); \
                          a = String_PREFIX PutString (yys, strlen (yys) - 1); }
# define writetStringRef(a) String_PREFIX WriteString (yyf, a);
# define gettStringRef(a)   { char yys [1024]; \
                          (void) fgets (yys, 1024, yyf); \
                          a = String_PREFIX PutString (yys, strlen (yys) - 1); }
# define puttStringRef(a)   { String_PREFIX WriteString (yyf, a); \
                          (void) fputc ('\n', yyf); }
# define copytStringRef(a, b) (a) == (b)
# define equaltStringRef(a, b)
/* tIdent */
# define begintIdent(a)     a = Idents_PREFIX NoIdent;
# define closetIdent(a)
# define readtIdent(a)
# define writetIdent(a)    a = yyReadIdent ();
                          Idents_PREFIX WriteIdent (yyf, a);
# define gettIdent(a)      yyGetIdent (& a);
# define puttIdent(a)      yyPutIdent (a);
# define copytIdent(a, b)
# define equaltIdent(a, b) (a) == (b)
/* tSet */
# define begintSet(a)
# define closetSet(a)
# define readtSet(a)       ReadSet (yyf, & a);
# define writetSet(a)     WriteSet (yyf, & a);
# define gettSet(a)
# define puttSet(a)

```

```

# define copytSet(a, b)
# define equaltSet(a, b)      IsEqual (& a, & b)
/* tPosition */
# define begintPosition(a)    a = NoPosition;
# define closetPosition(a)
# define readtPosition(a)    ReadPosition (yyf, & a);
# define writetPosition(a)    WritePosition (yyf, a);
# define gettPosition(a)      yyGet ((char *) & a, sizeof (a));
# define puttPosition(a)      yyPut ((char *) & a, sizeof (a));
# define copytPosition(a, b)
# define equaltPosition(a, b) Compare (a, b) == 0
/* NodeHead */
# define beginNodeHead(a)
# define closeNodeHead(a)
# define readNodeHead(a)
# define writeNodeHead(a)
# define getNodeHead(a)
# define putNodeHead(a)
# define copyNodeHead(a, b)
# define equalNodeHead(a, b)  rtrue

```

Appendix 10: Predefined Type Specific Operations for Modula-2

```

(* INTEGER *)
# define beginINTEGER(a)
# define closeINTEGER(a)
# define readINTEGER(a)      a := IO.ReadI (yyf);
# define writeINTEGER(a)     IO.WriteI (yyf, a, 0);
# define getINTEGER(a)       yyGet (a);
# define putINTEGER(a)       yyPut (a);
# define copyINTEGER(a, b)
# define equalINTEGER(a, b)  a = b
(* SHORTINT *)
# define beginSHORTINT(a)
# define closeSHORTINT(a)
# define readSHORTINT(a)     a := IO.ReadI (yyf);
# define writeSHORTINT(a)    IO.WriteI (yyf, a, 0);
# define getSHORTINT(a)      yyGet (a);
# define putSHORTINT(a)      yyPut (a);
# define copySHORTINT(a, b)
# define equalSHORTINT(a, b) a = b
(* LONGINT *)
# define beginLONGINT(a)
# define closeLONGINT(a)
# define readLONGINT(a)      a := IO.ReadI (yyf);
# define writeLONGINT(a)     IO.WriteI (yyf, a, 0);
# define getLONGINT(a)       yyGet (a);
# define putLONGINT(a)       yyPut (a);
# define copyLONGINT(a, b)
# define equalLONGINT(a, b)  a = b
(* CARDINAL *)
# define beginCARDINAL(a)
# define closeCARDINAL(a)
# define readCARDINAL(a)     a := IO.ReadI (yyf);
# define writeCARDINAL(a)    IO.WriteCard (yyf, a, 0);
# define getCARDINAL(a)      yyGet (a);
# define putCARDINAL(a)      yyPut (a);
# define copyCARDINAL(a, b)
# define equalCARDINAL(a, b) a = b
(* SHORTCARD *)
# define beginSHORTCARD(a)
# define closeSHORTCARD(a)
# define readSHORTCARD(a)    a := IO.ReadI (yyf);
# define writeSHORTCARD(a)   IO.WriteCard (yyf, a, 0);
# define getSHORTCARD(a)     yyGet (a);
# define putSHORTCARD(a)     yyPut (a);
# define copySHORTCARD(a, b)
# define equalSHORTCARD(a, b) a = b
(* LONGCARD *)
# define beginLONGCARD(a)
# define closeLONGCARD(a)
# define readLONGCARD(a)     a := IO.ReadI (yyf);
# define writeLONGCARD(a)    IO.WriteCard (yyf, a, 0);
# define getLONGCARD(a)      yyGet (a);
# define putLONGCARD(a)      yyPut (a);
# define copyLONGCARD(a, b)
# define equalLONGCARD(a, b) a = b
(* REAL *)

```

```

# define beginREAL(a)
# define closeREAL(a)
# define readREAL(a)      a := IO.ReadR (yyf);
# define writeREAL(a)    IO.WriteR (yyf, a, 0, 6, 1);
# define getREAL(a)      yyGet (a);
# define putREAL(a)      yyPut (a);
# define copyREAL(a, b)
# define equalREAL(a, b) a = b
(* LONGREAL *)
# define beginLONGREAL(a)
# define closeLONGREAL(a)
# define readLONGREAL(a)  a := IO.ReadR (yyf);
# define writeLONGREAL(a) IO.WriteR (yyf, a, 0, 6, 1);
# define getLONGREAL(a)  yyGet (a);
# define putLONGREAL(a)  yyPut (a);
# define copyLONGREAL(a, b)
# define equalLONGREAL(a, b) a = b
(* BOOLEAN *)
# define beginBOOLEAN(a)
# define closeBOOLEAN(a)
# define readBOOLEAN(a)  a := IO.ReadB (yyf);
# define writeBOOLEAN(a) IO.WriteB (yyf, a);
# define getBOOLEAN(a)  yyGet (a);
# define putBOOLEAN(a)  yyPut (a);
# define copyBOOLEAN(a, b)
# define equalBOOLEAN(a, b) a = b
(* CHAR *)
# define beginCHAR(a)
# define closeCHAR(a)
# define readCHAR(a)     a := IO.ReadC (yyf);
# define writeCHAR(a)   IO.WriteC (yyf, a);
# define getCHAR(a)     yyGet (a);
# define putCHAR(a)     yyPut (a);
# define copyCHAR(a, b)
# define equalCHAR(a, b) a = b
(* BITSET *)
# define beginBITSET(a)
# define closeBITSET(a)
# define readBITSET(a)  yyReadHex (a);
# define writeBITSET(a) yyWriteHex (a);
# define getBITSET(a)  yyGet (a);
# define putBITSET(a)  yyPut (a);
# define copyBITSET(a, b)
# define equalBITSET(a, b) a = b
(* BYTE *)
# define beginBYTE(a)
# define closeBYTE(a)
# define readBYTE(a)   yyReadHex (a);
# define writeBYTE(a)  yyWriteHex (a);
# define getBYTE(a)    yyGet (a);
# define putBYTE(a)    yyPut (a);
# define copyBYTE(a, b)
# define equalBYTE(a, b) a = b
(* WORD *)
# define beginWORD(a)
# define closeWORD(a)
# define readWORD(a)  yyReadHex (a);

```

```

# define writeWORD(a)      yyWriteHex (a);
# define getWORD(a)       yyGet (a);
# define putWORD(a)       yyPut (a);
# define copyWORD(a, b)
# define equalWORD(a, b)  a = b
(* ADDRESS *)
# define beginADDRESS(a)
# define closeADDRESS(a)
# define readADDRESS(a)  yyReadHex (a);
# define writeADDRESS(a) yyWriteHex (a);
# define getAddress(a)  yyGet (a);
# define putADDRESS(a)  yyPut (a);
# define copyADDRESS(a, b)
# define equalADDRESS(a, b) a = b
(* tString *)
# define begintString(a)
# define closetString(a)
# define readtString(a)  Strings.ReadL (yyf, a);
# define writetString(a) Strings.WriteL (yyf, a);
# define gettString(a)  yyGet (a);
# define puttString(a)  yyPut (a);
# define copytString(a, b)
# define equaltString(a, b) Strings.IsEqual (a, b)
(* tStringRef *)
# define begintStringRef(a)
# define closetStringRef(a)
# define readtStringRef(a)
# define writetStringRef(a) StringM.WriteString (yyf, a);
# define gettStringRef(a)
# define puttStringRef(a)
# define copytStringRef(a, b)
# define equaltStringRef(a, b) a = b
(* tIdent *)
# define begintIdent(a)  a := Idents.NoIdent;
# define closetIdent(a)
# define readtIdent(a)  a := yyReadIdent ();
# define writetIdent(a) Idents.WriteIdent (yyf, a);
# define gettIdent(a)  yyGetIdent (a);
# define puttIdent(a)  yyPutIdent (a);
# define copytIdent(a, b)
# define equaltIdent(a, b) a = b
(* tText *)
# define begintText(a)
# define closetText(a)
# define readtText(a)
# define writetText(a)  Texts.WriteText (yyf, a);
# define gettText(a)
# define puttText(a)
# define copytText(a, b)
# define equaltText(a, b) FALSE
(* tSet *)
# define begintSet(a)
# define closetSet(a)
# define readtSet(a)    Sets.ReadSet (yyf, a);
# define writetSet(a)  Sets.WriteSet (yyf, a);
# define gettSet(a)
# define puttSet(a)

```

```

# define copytSet(a, b)
# define equaltSet(a, b)      Sets.IsEqual (a, b)
(* tRelation *)
# define begintRelation(a)
# define closetRelation(a)
# define readtRelation(a)    Relation.ReadRelation (yyf, a);
# define writetRelation(a)   Relation.WriteRelation (yyf, a);
# define gettRelation(a)
# define puttRelation(a)
# define copytRelation(a, b) Relation.IsEqual (a, b)
# define equaltRelation(a, b)
(* tPosition *)
# define begintPosition(a)   a := Position.NoPosition;
# define closetPosition(a)
# define readtPosition(a)   Position.ReadPosition (yyf, a);
# define writetPosition(a)  Position.WritePosition (yyf, a);
# define gettPosition(a)    yyGet (a);
# define puttPosition(a)    yyPut (a);
# define copytPosition(a, b)
# define equaltPosition(a, b) Position.Compare (a, b) = 0
(* NodeHead *)
# define beginNodeHead(a)
# define closeNodeHead(a)
# define readNodeHead(a)
# define writeNodeHead(a)
# define getNodeHead(a)
# define putNodeHead(a)
# define copyNodeHead(a, b)
# define equalNodeHead(a, b) TRUE

```

Appendix 11: Predefined Type Specific Operations for Java

```

// boolean
# define beginboolean(a)
# define closeboolean(a)
# define readboolean(a)      a = yyin.readB ();
# define writeboolean(a)    yyout.write (a);
# define getboolean(a)      **not used**
# define putboolean(a)      **not used**
# define copyboolean(a, b)  a = (b);
# define equalboolean(a, b) (a) == (b)
// byte
# define beginbyte(a)
# define closebyte(a)
# define readbyte(a)        a = (byte) yyin.readI ();
# define writebyte(a)      yyout.write ((int) a);
# define getbyte(a)        **not used**
# define putbyte(a)        **not used**
# define copybyte(a, b)    a = (b);
# define equalbyte(a, b)   (a) == (b)
// char
# define beginchar(a)
# define closechar(a)
# define readchar(a)        a = (char) yyin.read ();
# define writechar(a)      yyout.write (a);
# define getchar(a)        **not used**
# define putchar(a)        **not used**
# define copychar(a, b)    a = (b);
# define equalchar(a, b)   (a) == (b)
// double
# define begindouble(a)
# define closedouble(a)
# define readdouble(a)
# define writedouble(a)     a = Double.parseDouble (yyin.readL (). \
                           toString ());
                           yyout.write (Double.toString (a)); \
                           yyout.writeNl ();
# define getdouble(a)      **not used**
# define putdouble(a)      **not used**
# define copydouble(a, b)  a = (b);
# define equaldouble(a, b) (a) == (b)
// float
# define beginfloat(a)
# define closefloat(a)
# define readfloat(a)
# define writefloat(a)     a = yyin.readR ();
                           yyout.write (a, 0, 0, 0);
# define getfloat(a)       **not used**
# define putfloat(a)       **not used**
# define copyfloat(a, b)   a = (b);
# define equalfloat(a, b)  (a) == (b)
// int
# define beginint(a)
# define closeint(a)
# define readint(a)
# define writeint(a)       a = yyin.readI ();
                           yyout.write (a);
# define getint(a)        **not used**
# define putint(a)        **not used**
# define copyint(a, b)    a = (b);

```

```

# define equalint(a, b)      (a) == (b)
// long
# define beginlong(a)
# define closelong(a)
# define readlong(a)       a = Long.parseLong (yyin.readL ().toString ());
# define writelong(a)      yyout.write (Long.toString (a)); \
                           yyout.writeNL ();
# define getlong(a)        **not used**
# define putlong(a)        **not used**
# define copylong(a, b)    a = (b);
# define equallong(a, b)   (a) == (b)
// short
# define beginshort(a)
# define closeshort(a)
# define readshort(a)      a = (short) yyin.readI ();
# define writeshort(a)     yyout.write ((int) a);
# define getshort(a)       **not used**
# define putshort(a)       **not used**
# define copysshort(a, b)  a = (b);
# define equalshort(a, b) (a) == (b)
// Ident
# define beginIdent(a)
# define closeIdent(a)
# define readIdent(a)      a = Idents_PREFIX makeIdent (yyin.readL ());
# define writeIdent(a)     yyf.write (a);
# define getIdent(a)       **not used**
# define putIdent(a)       **not used**
# define copyIdent(a, b)   a = (b);
# define equalIdent(a, b) (a.equals (b))
// Position
# define beginPosition(a)  a = Position.NoPosition;
# define closePosition(a)
# define readPosition(a)  a = new Position (yyin);
# define writePosition(a) yyout.write (a);
# define getPosition(a)   **not used**
# define putPosition(a)   **not used**
# define copyPosition(a, b) a = (b);
# define equalPosition(a, b) (a.compareTo (b) == 0)
// NodeHead
# define beginNodeHead(a)
# define closeNodeHead(a) **not used**
# define readNodeHead(a)
# define writeNodeHead(a)
# define getNodeHead(a)   **not used**
# define putNodeHead(a)   **not used**
# define copyNodeHead(a, b)
# define equalNodeHead(a, b) true

```

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