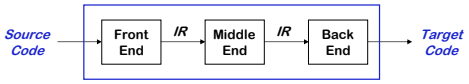
Abstract Syntax Trees

The parser's output is an abstract syntax tree (AST) representing the grammatical structure of the parsed input.

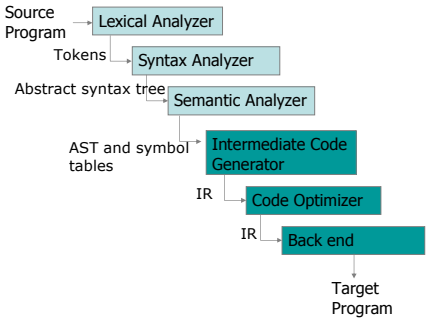
But first a digression.

Intermediate Representations



- Front end - produces an intermediate representation (IR)
- Middle end - transforms the IR into an equivalent IR that runs more efficiently (usually consists of several passes)
- Back end - transforms the IR into native code
- The IR encodes the compiler's knowledge of the program at any point in time

Typical Implementation of a Compiler



Abstract Syntax Trees

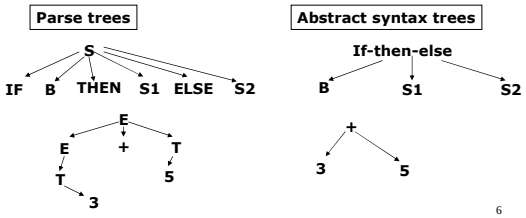
- The parser's output is an abstract syntax tree (AST) representing the grammatical structure of the parsed input
- ASTs represent only semantically meaningful aspects of input program, unlike concrete syntax trees which record the complete textual form of the input
  - There's no need to record keywords or punctuation like `()`, `;`, `else`
  - The rest of compiler only cares about the abstract structure

Concrete Syntax vs. Abstract Syntax

- Concrete syntax: what the programmer wrote => Parse Tree
- Abstract syntax: what the compiler needs => Abstract Syntax Tree

Parse trees and abstract syntax trees

- Graphically represent grammatical structure of input program
  - Parse tree: tree representation of grammar derivation
  - AST: condensed form of parse tree
    - Operators and keywords do not appear as leaves
    - Chains of single productions are collapsed



AST Class Hierarchy

- AST classes are organized into an inheritance hierarchy based on commonalities of meaning and structure
- Each "abstract non-terminal" that has multiple alternative concrete forms will have an abstract class that's the superclass of the various alternative forms
  - `Stmt` is abstract superclass of `IfStmt`, `AssignStmt`, etc.
  - `Expr` is abstract superclass of `AddExpr`, `VarExpr`, etc.
  - `Type` is abstract superclass of `IntType`, `ClassType`, etc.

7

AST Node Classes

Each node in an AST is an instance of an AST class
- `IfStmt`, `AssignStmt`, `AddExpr`, `VarDecl`, etc.

Each AST class declares its own instance variables holding its AST subtrees
- `IfStmt` has `testExpr`, `thenStmt`, and `elseStmt`
- `AssignStmt` has `lhsVar` and `rhsExpr`
- `AddExpr` has `arg1Expr` and `arg2Expr`
- `VarDecl` has `typeExpr` and `varName`

8

Notes on MiniJava Project

9

Automatic Parser Generation in MiniJava

We use the CUP tool to automatically create a parser from a specification file, `Parser/minijava.cup`

The MiniJava Makefile automatically rebuilds the parser whenever its specification file changes

A CUP file has several sections:
- introductory declarations included with the generated parser
- declarations of the terminals and nonterminals with their types
- The AST node or other value returned when finished parsing that nonterminal or terminal
- precedence declarations
- productions + actions

10

Terminal and Nonterminal Declarations

Terminal declarations we saw before:

```
/* reserved words: */
terminal CLASS, PUBLIC, STATIC, EXTENDS;
...
/* tokens with values: */
terminal String IDENTIFIER;
terminal Integer INT_LITERAL;
```

Nonterminals are similar:

```
nonterminal Program Program;
nonterminal MainClassDecl MainClassDecl;
nonterminal List/*<...>*/ ClassDecls;
nonterminal RegularClassDecl ClassDecl;
...
nonterminal List/*<Stmt>*/ Stmts;
nonterminal Stmt Stmt;
nonterminal List/*<Expr>*/ Exprs;
nonterminal List/*<Expr>*/ MoreExprs;
nonterminal Expr Expr;
nonterminal String Identifier;
```

11

Precedence Declarations

Can specify precedence and associativity of operators
- equal precedence in a single declaration
- lowest precedence textually first
- specify left, right, or nonassoc with each declaration

Examples:

```
precedence left AND_AND;
precedence nonassoc EQUALS_EQUALS,
                    EXCLAIM_EQUALS;
precedence left LESSTHAN, LESSEQUAL,
               GREATEREQUAL, GREATERTHAN;
precedence left PLUS, MINUS;
precedence left STAR, SLASH;
precedence left EXCLAIM;
precedence left PERIOD;
```

12

Productions

All of the form:

```
LHS ::=  RHS1 {: Java code 1 :}
       | RHS2 {: Java code 2 :}
       | ...
       | RHSn {: Java code n :};
```

Can label symbols in RHS with `:var` suffix to refer to its result value in Java code

- `varleft` is set to line in input where var symbol was

E.g.:

```
Expr ::= Expr:arg1 PLUS Expr:arg2
    {: RESULT = new AddExpr( arg1,arg2,arg1left);:}
    | INT_LITERAL:value{: RESULT = new IntLiteralExpr(
          value.intValue(),valueleft);:}
    | Expr:rcvr PERIOD Identifier:message OPEN_PAREN
          Exprs:args CLOSE_PAREN
    {: RESULT = new MethodCallExpr(
          rcvr,message,args,rcvrleft);:}
    | ... ;
```

13

AST Extensions For Project

New variable declarations:
- `StaticVarDecl`

New types:
- `DoubleType`
- `ArrayType`

New/changed statements:
- `IfStmt` can omit else branch
- `ForStmt`
- `BreakStmt`
- `ArrayAssignStmt`

New expressions:
- `DoubleLiteralExpr`
- `OrExpr`
- `ArrayLookupExpr`
- `ArrayLengthExpr`
- `ArrayNewExpr`

14

Extra Slides Start Here

15

Error Handling

How to handle syntax error?

Option 1: quit compilation
- + easy
- - inconvenient for programmer

Option 2: error recovery
- + try to catch as many errors as possible on one compile
- - difficult to avoid streams of spurious errors

Option 3: error correction
- + fix syntax errors as part of compilation
- - hard!!

16

Panic Mode Error Recovery

When finding a syntax error, skip tokens until reaching a "landmark"
- landmarks in MiniJava: **;**, **)**, **}**
- once a landmark is found, hope to have gotten back on track

In top-down parser, maintain set of landmark tokens as recursive descent proceeds
- landmarks selected from terminals later in production
- as parsing proceeds, set of landmarks will change, depending on the parsing context

In bottom-up parser, can add special error nonterminals, followed by landmarks
- if syntax error, then will skip tokens till seeing landmark, then reduce and continue normally

- E.g.
```
Stmt ::= ... | error ; | { error }
Expr ::= ... | ( error )
```

17