COMP 520 - Compilers

Lecture 10 (Tue Mar 1)

Contextual Analysis: Identification

- Reading
  - Chapter 5: Contextual Analysis - section 5.1 Identification (pp 136 - 150)

Sample parseProgram()

```
public Package parseProgram() {
        // start scanner
        currentToken = lexicalAnalyser.scan();
        previousToken = currentToken;

        SourcePosition start =  currentToken.posn;
        try {
                ClassDeclList cl = new ClassDeclList();
                while (currentToken.kind == TokenKind.CLASS) {
                        cl.add(parseClass());
                }
                SourcePosition end = previousToken.posn;
                if (currentToken.kind != TokenKind.EOT)
                        syntaxError("Unexpected text \"%\" after end of program",
                                        currentToken.spelling);
                return new Package(cl, new SourcePosition(start, end));
        }
        catch (SyntaxError s) { return null; }
}
```

Topics

- Identifiers
  - identifiers and what they denote
  - scopes

- Identification
  - Implementation strategies

Identifiers

- An identifier has a
  - name - a string
  - denotation – what it represents in the context in which it is used
- Examples of identifiers in Java

```
Token id = new Token(TokenKind.IDENTIFIER, “x”);
```

Identifier denotations

- Identifiers have many denotations in modern programming languages

Category	Denotation
Variable	memory address(es)
Method	executable code address
Type	interpretation of values and operations, e.g. a class name or a basetype like “int”
Classname	provides access to members of a class
Member	members of a class (or components in a record)
Namespace	provides access to a collection of externally defined identifiers, e.g. package name in import
Literal Value	e.g. true, false

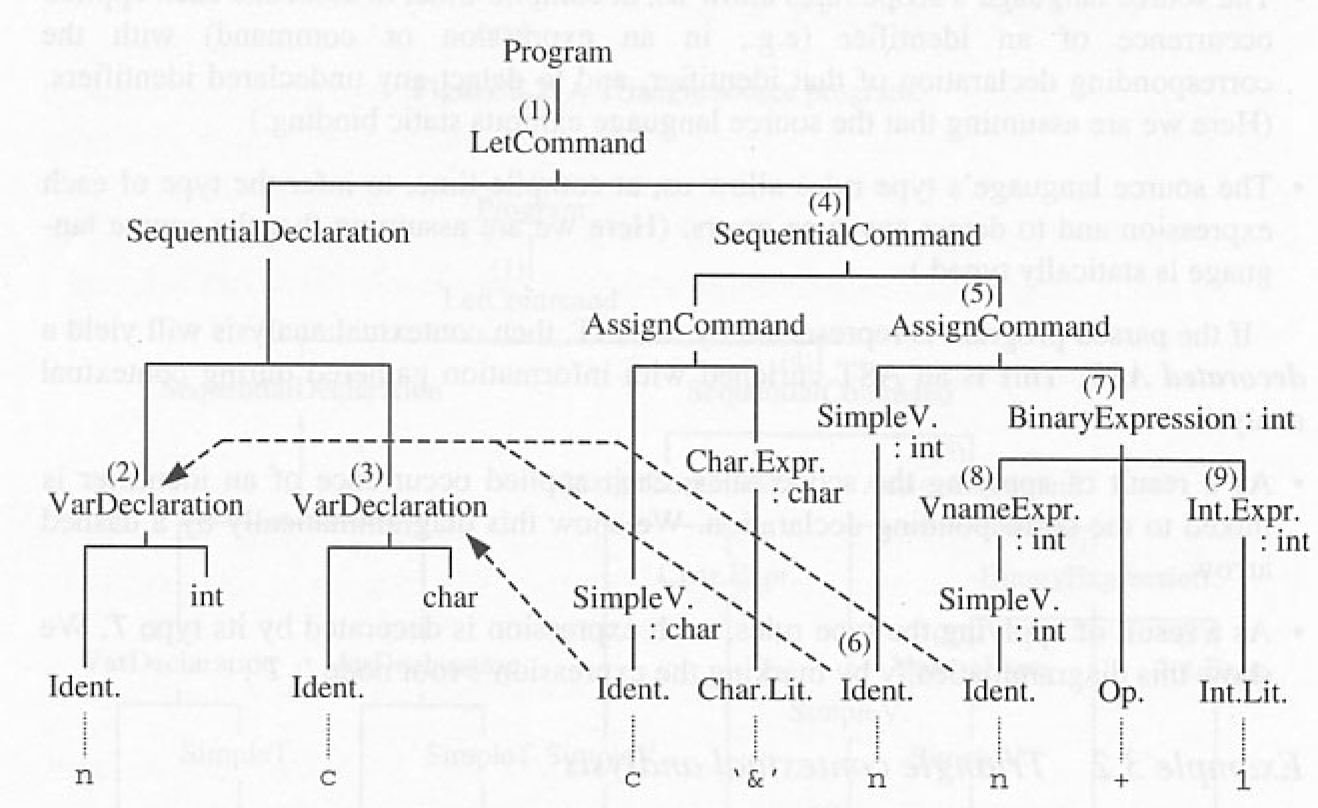
Contextual analysis: Identification

- Identifiers are
  - defined (introduced)
    - typically through declarations
    - sometimes “pre-defined” (e.g. true, false in Triangle)
  - referenced (used)
    - occurrences other than in a declaration
    - we generally call these “references”
    - our book calls these “applied occurrences”
- Identification
  - record *definitions* of identifiers and their attributes when declared
    - *attributes* describe the category and specific details of a declaration
  - relate each *reference* to the appropriate attributes
    - our book calls this “identification”
    - in modern languages this is non-trivial

Identification in the AST - Triangle

- Traverse AST
  - Record definitions in Declaration nodes
  - Link references to defining declaration

```
let
   var n: Integer;
   var c: Char
in
   begin
     c := '&';
     n := n + 1
   end
```



Scope of a declaration

- Monolithic block structure
  - All declarations are in a single global scope
    - No identifier can be declared more than once
    - .. so each reference has at most one controlling declaration

- Flat block structure (two-level scope)
  - Global scope and local scope
    - Single global scope and multiple disjoint local scopes
    - Each identifier declared at most once in global scope, and at most once in a given local scope

- Nested block structure
  - Arbitrary nesting of blocks
    - Declarations in a more deeply nested block hide those in enclosing blocks

More complex notions of scope

- An identifier may have multiple definitions
  - imports from other packages
  - class name, constructor
  - overloading
  - inheritance
  - qualified reference
  - visibility (public / private)
  - access (static / instance)

- Examples (Java)

```
int Foo = 3;

Foo id = new Foo();

Foo.method(Foo);
```

Java Identification

```
Token id = new Token(TokenKind.ID, "x")
```

- How to determine the definition that applies to a reference?
  - context
    - Java class names can only appear in some places (where?)
    - variable, function and procedure names can appear in other places
  - qualified access
    - prefix determines applicable definitions
      - e.g. System.out.println(…)
  - visibility rules
    - a subset of definitions is visible at a given program point
      - scope rules: local variables, parameters, members, classnames
      - inheritance of class or interface(s)
      - qualified references
      - accessibility: public / private / protected
  - type rules
    - overloading
      - foo(5), foo("string")

Scopes: Nested scopes in Triangle

```
let
   var a: Integer;
   var b: Boolean
in
   begin
   … a,b …
   let
      var b: Integer;
      var c: Boolean
   in
     begin
     … a,b,c …
     let var d: Integer
     in
        … a,b,c,d …;
     … a,b,c …
     end;
   … a,b …
   end
```

- The Triangle block command
  - `let` *Declaration* `in` *SingleCommand*
  - the scope of the declaration is limited to the *SingleCommand*
  - types, functions, procedures, variables can be declared
  - a declaration hides the definition of the same name in a surrounding scope
  - a use (an applied occurrence) refers to the nearest surrounding declaration

Subtleties in nested block structure

```
let
   const a ~ 3;
   const b ~ 4
in
   begin
   … a,b …
   let
      var b ~ a + 5;
      var c ~ b + 6
   in
   … a,b,c …
end
```

- Initializers in declarations
  - a variable can be given an initial value through evaluation of an expression
  - what definitions apply when the initializing expressions are evaluated?

Identification: implementation

- Identification table (a.k.a. symbol table)
  - maps identifier names to attributes
    - attributes vary greatly depending on the category of identifier
      - strategy: the attributes of an identifier are in the AST node where it is declared
      - all declaration nodes in miniJava AST are subtype of Declaration (Decl)
  - implementation
    - (auto-expanding) hashtable
      - O(n) amortized access cost for O(n) insertions and lookups
    - Java: class HashMap<String,Decl>
      - clear()
      - boolean containsKey(String id)
      - Decl put(String id , Decl decl) // associate id with decl
      - Decl get(String id) // decl or null, if id not in hashmap
      - void remove(String id) // remove current association of id, if any

Scoped Identification table

- Extends hashtable with two operations
  - openScope()
  - closeScope()
  - Get(id.spelling()) returns innermost declaration

- Implementation challenges
  - remove mappings when leaving scope
  - handling multiple declarations

Identification in Java

- parameters to the identification process
  - current package
    - access to all top-level classes
  - scoped identification table
    - enclosing variable declarations
    - enclosing parameter declarations
  - identification table for current class
    - this is scoped for nested classes
    - may be scoped to reflect inheritance
  - identification tables for other classes
    - explicit imports
    - implicit imports, e.g. same package
- in full Java, identification process returns *list* of possible definitions or error
  - type checking provides final disambiguation

Identification in miniJava

- Parameters to the identification process
  - Class declarations
    - to identify uses of class names e.g.

```
Foo x  =  ...
new Foo()
```

  - Member declarations in current class
    - to identify uses of fields or methods
  - Local declarations in current method
    - to identify uses of parameters or local variables

scoped identification table

  - Member declarations in other classes
    - to identify qualified references, e.g.

```
Foo.field
x.y.z
```

- Each Identifier occurrence in a miniJava AST has a unique declaration
  - almost always

EXAMPLE

miniJava package

```
class Foo {
    int x;

    int p(int y) {
        if (p(x)) {
            int x = 10;
            x = y;
        }
        return x;
    }
}
```

AST $\xrightarrow{2}$

$\downarrow 1$

Scoped id table

Foo
x p
y
x

```
Package
  ClassDeclList [1]
    ClassDecl
  .   "Foo" classname
  .   FieldDeclList [1]
  .   . (public) FieldDecl
  .   .   INT BaseType
  .   .   "x" fieldname
  .   MethodDeclList [1]
  .   . (public) MethodDecl
  .   .   INT BaseType
  .   .   "p" methodname
  .   .   ParameterDeclList [1]
  .   .   . ParameterDecl
  .   .   .   INT BaseType
  .   .   .   "y"parametername
```

```
  .   .   StmtList [2]
  .   .   . IfStmt
  .   .   .   CallExpr
  .   .   .     IdRef
  .   .   .       "p" Identifier
  .   .   .     ExprList + [1]
  .   .   .     . RefExpr
  .   .   .     .   IdRef
  .   .   .     .     "x" Identifier
  .   .   .   BlockStmt
  .   .   .     StatementList [2]
  .   .   .     . VarDeclStmt
  .   .   .     .   VarDecl
  .   .   .     .     INT BaseType
  .   .   .     .     "x" varname
  .   .   .     .   LiteralExpr
  .   .   .     .     "10" IntLiteral
  .   .   .     . AssignStmt
  .   .   .     .   IdRef
  .   .   .     .     "x" Identifier
  .   .   .     .   RefExpr
  .   .   .     .     IdRef
  .   .   .     .       "y" Identifier
  .   .   . ReturnStmt
  .   .   .   RefExpr
  .   .   .     IdRef
  .   .   .       "x" Identifier
```

```
class Foo {
    int x;

    int p(int y) {
        if (p(x)) {
            int x = 10;
            x = y;
        }
        return x;
    }
}
```

miniJava package

EXAMPLE

AST $\xrightarrow{2}$

$\downarrow$ 1

Scoped id table

Foo	•
x	•
p	•
y	•

```
Package
  ClassDeclList [1]
    ClassDecl
  .    "Foo" classname
  .    FieldDeclList [1]
  .    . (public) FieldDecl
  .    .    INT BaseType
  .    .    "x" fieldname
  .    MethodDeclList [1]
  .    . (public) MethodDecl
  .    .    INT BaseType
  .    .    "p" methodname
  .    .    ParameterDeclList [1]
  .    .    . ParameterDecl
  .    .    .    INT BaseType
  .    .    .    "y"parametername
```

```
.    .    StmtList [2]
.    .    . IfStmt
.    .    .    CallExpr
.    .    .      IdRef
.    .    .        "p" Identifier
.    .    .      ExprList + [1]
.    .    .      . RefExpr
.    .    .      .   IdRef
.    .    .      .     "x" Identifier
.    .    .    BlockStmt
.    .    .      StatementList [2]
.    .    .      . VarDeclStmt
.    .    .      .   VarDecl
.    .    .      .     INT BaseType
.    .    .      .     "x" varname
.    .    .      .   LiteralExpr
.    .    .      .     "10" IntLiteral
.    .    .      . AssignStmt
.    .    .      .   IdRef
.    .    .      .     "x" Identifier
.    .    .      .   RefExpr
.    .    .      .     IdRef
.    .    .      .       "y" Identifier
.    .    . ReturnStmt
.    .    .    RefExpr
.    .    .      IdRef
.    .    .        "x" Identifier
```

Logical order of Contextual analysis

1. Identification
   – check validity of declarations
     • is this declaration allowed in the current context?
   – link references to corresponding declarations
   – AST traversal order
     • top down, declarations before references

2. Type checking
   – assign types to expressions
   – check type agreement
     • operators and operands
     • assignment statements
   – AST traversal order
     • bottom up (assuming no overloading)

Contextual analysis in a single traversal

- For each node
  - *inherit* some information from parent
    - e.g. Identification table
  - traverse subtree rooted at node
  - *synthesize* some information to return to parent
    - e.g. type of expression computed by node
    - e.g. updated identification table

- Traversing the subtree rooted at a node
  - for each child in turn
    - apply contextual analysis on child
    - providing inherited data
    - receiving synthesized data

Example contextual analyses in Triangle

- Contextual analysis of Let command
  - start a new scope in identification table
  - contextual analysis of Declaration
    - updates identification table
  - contextual analysis of Command
  - remove scope in identification table

- Contextual analysis of BinaryExpression
  - contextual analysis of left expression
    - save returned type
  - contextual analysis of right expression
    - save returned type
  - look up operator argument types and result type
    - check agreement with operator