CS412/413

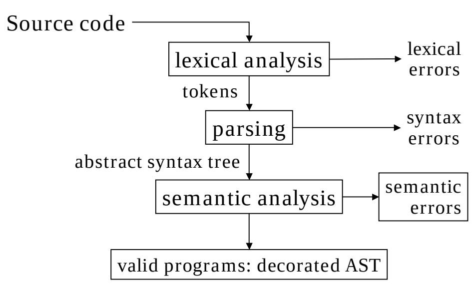
Introduction to
Compilers and Translators
Spring '00

Lecture 8: Semantic Analysis and Symbol Tables

Outline

- Type checking
- Symbol tables
- Using symbol tables for analysis

Semantic Analysis



Goals of Semantic Analysis

- Find all possible remaining errors that would make program invalid
  - undefined variables, types
  - type errors that can be caught *statically*
- Figure out useful information for later compiler phases
  - types of all expressions
  - data layout

Recursive semantic checking

- Program is tree, so...
  - recursively traverse tree, checking each component
  - traversal routine returns information about node checked

```
class Add extends Expr {
   Expr e1, e2;
   Type typeCheck() throws SemanticError {
        Type t1 = e1.typeCheck(), t2 = e2.typeCheck();
        if (t1 == Int && t2 == Int) return Int;
        else throw new TypeCheckError("type error +");
   }
```


Type-checking identifiers

```
class Id extends Expr {
   String name;
   Type typeCheck() {
        return ?
   }
}
```

- Need a *environment* that keeps track of types of all identifiers in scope: *symbol table*

Symbol table

- Can write formally as set of *identifier* : *type* pairs: { x: int, y: array[string] }

```
{
  int i, n = …;            { i: int, n: int }
  for (i = 0; i < n; i++) {
      boolean b = …
  }                        { i: int, n: int, b: boolean }
}   ?
```


Specification

- Symbol table maps identifiers to types

```
class SymTab {
  Type lookup(String id) …
  void add(String id, Type binding) …
}
```


Using the symbol table

- Symbol table is argument to all checking routines

```
class Id extends Expr {
   String name;
   Type typeCheck(SymTab s) {
      try {
         return s.lookup(name);
      } catch (NotFound exc) {
         throw new UndefinedIdentifier(this);
      }
   }
}
```


Propagation of symbol table

```
class Add extends Expr {
   Expr e1, e2;
   Type typeCheck(SymTab s) {
         Type t1 = e1.typeCheck(s),
               t2 = e2.typeCheck(s);
         if (t1 == Int && t2 == Int) return Int;
         else throw new TypeCheckError("+");
   }
```

- Same variables in scope – same symbol table used
- When do we add new entries to symbol table?

Adding entries

- Java, Iota: statement may declare new variables. { a = b; int x = 2; a = a + x }
- Suppose {$stmt_1$; $stmt_2$; $stmt_3$...} represented by AST nodes:

```
abstract class Stmt { … }
class Block { Vector/*Stmt*/ stmts; … }
```

- And declarations are a kind of statement:

```
class Decl extends Stmt {
    String id; TypeExpr typeExpr; …
```


A stab at adding entries

```
class Block { Vector stmts;
   Type typeCheck(SymTab s) { Type t;
         for (int i = 0; i < stmts.length(); i++) {
               t = stmts[i].typeCheck(s);
               if (stmts[i] instanceof Decl)
                     s.add(Decl.id, Decl.typeExpr.evaluate());
         }
         return t;
   }
}
```

Does it work?

Must be able to restore ST

```
{ int x = 5;          scope of y
  { int y = 1; }
  x = y;            // should be illegal!
}
```


Handling declarations

```
class Block { Vector stmts;
   Type typeCheck(SymTab s) { Type t;
        SymTab s1 = s.clone();
        for (int i = 0; i < stmts.length(); i++) {
            t = stmts[i].typeCheck(s1);
            if (stmts[i] instanceof Decl)
              s1.add(Decl.id, Decl.typeExpr.evaluate());
        }
        return t;
   }
}
```

Declarations added in block (to s1) don't affect code after the block

Storing Symbol Tables

- Many symbol tables constructed during checking
  - May keep track of more than just variables: type definitions, break & continue labels, ...
  - Top-level symbol table contains global variables, type & module declarations,
  - Nested scopes result in extended symbol tables containing add'l definitions for those scopes.
- Can reconstruct symbol tables, but useful to save in corresponding AST nodes to avoid recomputation

How to implement ST?

- Imperative? Three operations:

```
Object lookup(String name);
void add (String name, Object type);
SymTab clone(); // expensive?
```

- Functional? Two operations:

```
Object lookup(String name);
SymTab add (String, Object); // expensive?
```


Imperative: Linked list of tables

```
class SymTab {
   SymTab parent;
   HashMap table;
   Object lookup(String id) {
     if (table.get(id) != null) return table.get(id);
     else return parent.lookup(id); // can cache..
   }
   void add(String id, Object t)
     { table.add(id,t); }
   SymTab(Symtab p)
     { parent = p; } // =clone
}
```


Functional: Binary trees

- Discussed in Appel Ch. 5
- Implements the two-operation interface

```
Object lookup(String name);
SymTab add (String, Object);
```

  - non-destructive add so no cloning is needed
  - O(lg n) performance: clones only the path from added node to the root.

Decorating the tree

- How to remember expression type?
- One approach: record in the node

```
abstract class Expr {
    protected Type type = null;
    public Type typeCheck();
}
class Add extends Expr { Type typeCheck() {
    Type t1 = e1.typeCheck(), t2 = e2.typeCheck();
    if (t1 == Int && t2 == Int)
        { type = Int; return type; }
    else throw new TypeCheckError("+");
}
```

- Also useful to record: symbol table

Structuring Analysis

- Analysis is a traversal of AST
- Technique used in lecture: recursion using methods of AST node objects -- object-oriented style

```
class Add extends Expr {
    Type typeCheck(SymTab s) {
    Type t1 = e1.typeCheck(s),
        t2 = e2.typeCheck(s);
    if (t1 == Int && t2 == Int) return Int;
    else throw new TypeCheckError("+");
  }}
```


Constant Folding

- AST optimization: replaces constant expressions with constants they would compute
- Traverses (and modifies) AST

```
abstract class Expr {
  Expr foldConstants();
}
class Add extends Expr { Expr e1, e2;
  Expr foldConstants() {
    e1 = e1.foldConstants(); e2 = e2.foldConstants();
    if (e1 instanceof IntConst && e2 instanceof IntConst)
        return new IntConst(e1.value + e2.value);
    else return new Add(e1, e2);
  }
```


Redundancy

- There will be several more compiler phases like typeCheck and foldConstants
  - constant folding
  - translation to intermediate code
  - optimization
  - final code generation
- Object-oriented style: each phase is a method in AST node objects
- Weakness 1: code for each phase spread
- Weakness 2: traversal logic replicated

Separating Syntax, Impl.

- Can write each traversal in a *single* method

```
Type typeCheck(Node n, SymTab s) {
  if (n instanceof Add) {
      Add a = (Add) n;
      Type t1 = typeCheck(a.e1, s),
           t2 = typeCheck(a.e2, s);
      if (t1 == Int && t2 == Int) return Int;
      else throw new TypeCheckError("+");
  } else if (n instanceof Id) {
      Id id = (Id)n;
      return s.lookup(id.name); …
```

- Now, code for a given *node* spread all over!

Modularity Conflict

- Two orthogonal organizing principles: node types and phases (rows or columns)

phases →

types ↓

	typeCheck	foldConst	codeGen
Add	×	×	×
Num	×	×	×
Id	×	×	×
Stmt	×	×	×

Which is better?

- Neither completely satisfactory
- Both involve repetitive code
  - – modularity by objects (rows): different methods share basic traversal code -- boilerplate code
  - – modularity by operations (columns): lots of boilerplate:

```
if (n instanceof Add)  { Add a = (Add) n; ...}
else if (n instanceof Id)  { Id x = (Id) n; ... }
else ...
```


Visitors

- Idea: avoid repetition by providing one set of standard traversal code
- Knowledge of particular phase embedded in *visitor* object
- Standard traversal code is done by object methods, reused by every phase
- Visitor invoked at every step of traversal to allow it to do phase-specific work

A Visitor Methodology

- Class Node is superclass for all AST nodes
- NodeVisitor is superclass for all visitor classes (one visitor class per phase)

```
abstract class Node {
   public final Node visit (NodeVisitor v) {
      Node n = v.override (this);          // default: null
      if (n != null) return n;
      else {
         NodeVisitor v_ = v.enter(this);  // default: v_=v
         n = visitChildren (v_);             // visit children
         return v.leave(this, n, v_);       // default: n
      }}
   abstract Node visitChildren(NodeVisitor v);
```


Folding constants with visitors

```
public class ConstantFolder extends NodeVisitor {
  public Node leave (Node old, Node n, NodeVisitor v) {
    return n.foldConstants();
         // note: all children of n already folded
  }
}

class Node { Node foldConstants( ) { return this; } }
class BinaryExpression {
   Node foldConstants( ) { switch(op) {...} } }
class UnaryExpression {
   Node foldConstants( ) { switch(op) {...} } }
```


Summary

- Semantic analysis: traversal of AST
- Symbol tables needed to provide context during traversal
- Traversals can be modularized differently
- Visitor pattern avoids repetitive code
- Read Appel, Ch. 4 & 5
- See also: *Design Patterns*