

Winter 2006-2007 Compiler Construction T6 – semantic analysis part I scopes and symbol tables

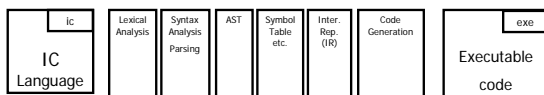
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Notes on PA1/PA2

- PA1 submissions will be returned soon
 - Use comments to fix scanner if needed
- Note correct directory structure for PAs
- Don't use CUP's **expect** switch
- Reference to numeric constant instead of symbolic names is bad programming
- Place functionality in appropriate class
- Test coverage
- TA1 fixed

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Today



- | | |
|---|--|
| <ul style="list-style-type: none"> ■ Today: <ul style="list-style-type: none"> ■ Scopes ■ Symbol tables ■ (Type table) | <ul style="list-style-type: none"> ■ Next week: <ul style="list-style-type: none"> ■ Types ■ Type-checking ■ More semantic analysis |
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Semantic analysis motivation

- Syntactically correct programs may still contain errors
 - Lexical analysis does not distinguish between different variable names (same ID token)
 - Syntax analysis does not correlate variable declaration with variable use, does not keep track of types

```
int a;
a = "hello";

int a;
b = 1;
```

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Goals of semantic analysis

- Check "correct" use of programming constructs
- Provide information for subsequent phases
- Context-sensitive – beyond context free grammars
 - Lexical analysis and syntax analysis provide relatively shallow checks of program structure
 - Semantic analysis goes deeper
- Correctness specified by semantic rules
 - Scope rules
 - Type-checking rules
 - Specific rules
- Note: semantic analysis ensures only partial correctness of programs
 - Runtime checks (pointer dereferencing, array access)

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Example of semantic rules

- A variable must be declared before used
- A variable should not be declared multiple times
- A variable should be initialized before used
- Non-void method should contain return statement along all execution paths
- **break/continue** statements allowed only in loops
- **this** keyword cannot be used in static method
- **main** method should have specific signature
- ...
- Type rules are important class of semantic rules
 - In an assignment statement, the variable and assigned expression must have the same type
 - In a condition test expression must have boolean type

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Scope and visibility

- Scope (visibility) of identifier = portion of program where identifier can be referred to
- Lexical scope = textual region in the program
 - Statement block
 - Method body
 - Class body
 - Module / package / file
 - Whole program (multiple modules)

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Scope example

```
class Foo {
  int value;
  int test() {
    int b = 3;
    return value + b;
  }
  void setValue(int c) {
    value = c;
    { int d = c;
      c = c + d;
      value = c;
    }
  }
}

class Bar extends Foo {
  int value;
  void setValue(int c) {
    value = c;
    test();
  }
}
```

Diagram illustrating scope boundaries with curly braces:

- scope of local variable `b` (enclosed in `test()`)
- scope of field `value` (enclosed in `Foo`)
- scope of formal parameter `c` (enclosed in `setValue(int c)`)
- scope of local variable in statement block `d` (enclosed in the inner block of `setValue`)
- scope of method `test` (enclosed in `test()`)
- scope of `c` (enclosed in `Bar.setValue(int c)`)
- scope of value (enclosed in `Bar.setValue(int c)`)

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Scope nesting

- Scopes may be enclosed in other scopes
`void foo() { int a; ... {int a;} }`
- Name disambiguation
- Generally scope hierarchy forms a tree
- Scope of subclass enclosed in scope of its superclass
 - Subtype relation must be acyclic

same name but different symbol

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Scope hierarchy in IC

- Global scope
 - The names of all classes defined in the program
- Class scope
 - Instance scope: all fields and methods of the class
 - Static scope: all static methods
 - Scope of subclass nested in scope of its superclass
- Method scope
 - Formal parameters and local variables in code block of body method
- Code block scope
 - Variables defined in block

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Scope rules in IC

- “When resolving an identifier at a certain point in the program, the enclosing scopes are searched for that identifier.”
- “local variables and method parameters can only be used after they are defined in one of the enclosing block or method scopes.”
- “Fields and virtual methods can be used in expressions of the form $e.f$ or $e.m()$ when e has class type C and the instance scope of C contains those fields and methods.”
- “static methods can be used in expressions of the form $C.m()$ if the static scope of C contains m .”
- ... (Section 10 in IC specification)
- How do we check these rules?

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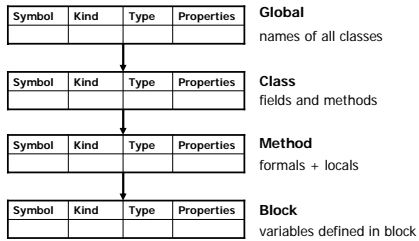
Symbol table

- An environment that stores information about identifiers
- A data structure that captures scope information
- Each entry in symbol table contains
 - The name of an identifier
 - Its kind (variable/method/field...)
 - Type
 - Additional properties, e.g. **final**, **public** (not needed for IC)
- One symbol table for each scope

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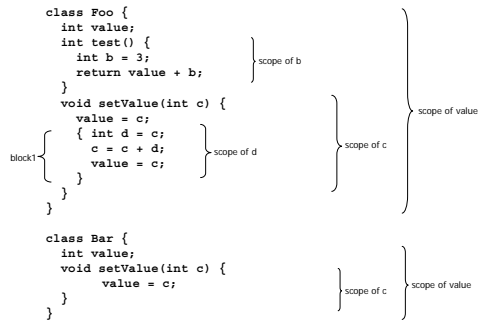
Scope nesting in IC

Scope nesting mirrored in hierarchy of symbol tables



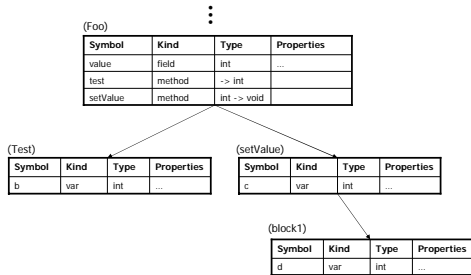
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Symbol table example



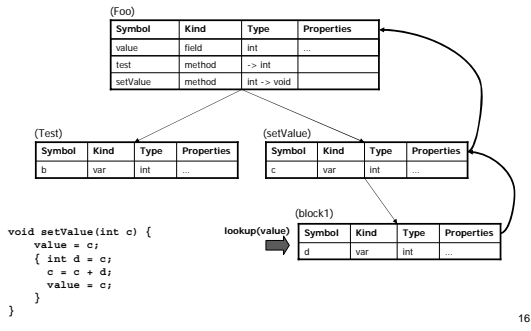
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Symbol table example cont.

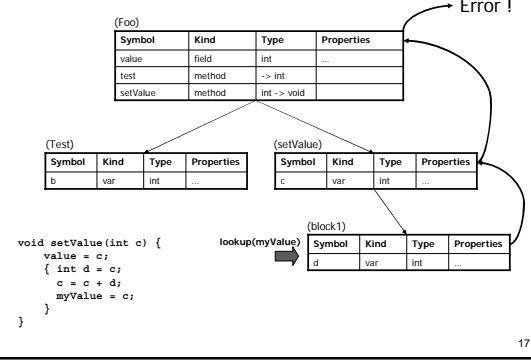


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Checking scope rules



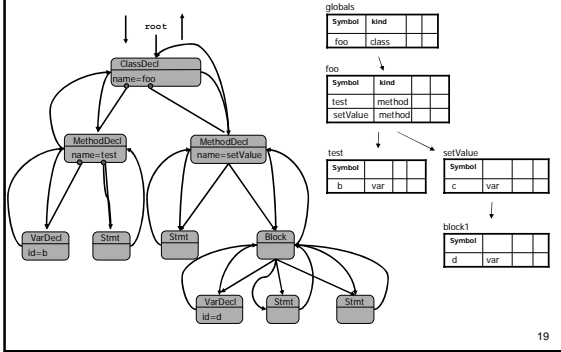
Catching semantic errors



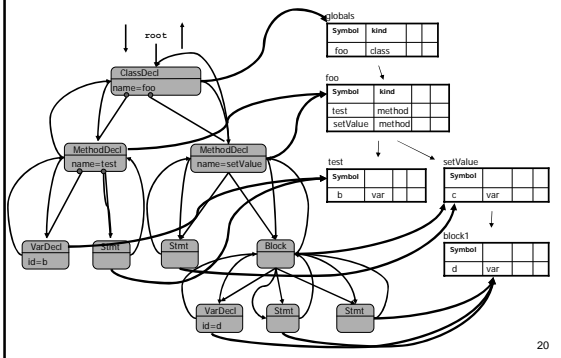
Symbol table operations

- insert
 - Insert new symbol (to current scope)
- lookup
 - Try to find a symbol in the table
 - May cause lookup in parent tables
 - Report an error when symbol not found
- How do we check illegal re-definitions?

Symbol table construction via AST traversal



Linking AST nodes to enclosing table



What's in an AST node – take 2

```

public abstract class ASTNode {
    /** line in source program */
    private int line;

    /** reference to symbol table of enclosing scope */
    private SymbolTable enclosingScope;

    /** accept visitor */
    public abstract void accept(Visitor v);

    /** accept propagating visitor */
    public abstract <D,U> U accept(PropagatingVisitor<D,U> v,D context);

    /** return line number of this AST node in program */
    public int getLine() {...}

    /** returns symbol table of enclosing scope */
    public SymbolTable enclosingScope() {...}
}

```

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Symbol table implementation

- Each table in the hierarchy could be implemented using `java.util.HashMap`
- Implement a hierarchy of symbol tables
- Can implement a class for **Symbol**
 - Use in subsequent phases instead of id name
- **HashMap** keys should obey **equals/hashcode** contracts
 - Safe when key is symbol name (`String`)

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Symbol table implementation

```
public class SymbolTable {
    /** map from String to Symbol */
    private Map<String,Symbol> entries;
    private String id;
    private SymbolTable parentSymbolTable;
    public SymbolTable(String id) {
        this.id = id;
        entries = new HashMap<String,Symbol>();
    }
    ...
}

public class Symbol {
    private String id;
    private Type type;
    private Kind kind;
    ...
}
```

(this is only a suggestion)

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Implementing table structure

- Hierarchy of symbol tables
 - Pointer to enclosing table
 - Can also keep list of sub-tables
- Symbol table key should include id and kind
 - Can implement using 2-level maps (kind->id->entry)
 - Separating table in advance according to kinds also acceptable

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Implementation option 1

```

public class SymbolTable {
    /** Map kind->(id->entry)
        Kind enum->(String->Symbol)
    **/
    private Map<Kind, Map<String,Symbol> > entries;
    private SymbolTable parent;
    ...
    public Symbol getMethod(String id) {
        Map<String,Symbol> methodEntries = entries.get(METHOD_KIND);
        return methodEntries.get(id);
    }
    public void insertMethod(String id, Type t) {
        Map<String,Symbol> methodEntries = entries.get(METHOD_KIND);
        if (methodEntries == null) {
            methodEntries = new HashMap<String,Symbol>();
            entries.put(METHOD_KIND, methodEntries);
        }
        methodEntries.put(id,new Symbol(id, t));
    }
    ...
}

```

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Implementation option 2

```

public class SymbolTable {
    /** Method Map id->entry **/
    private Map<String,Symbol> methodEntries;
    ...
    private Map<String,Symbol> variableEntries;
    ...
    private SymbolTable parent;
    public Symbol getMethod(String id, Type t) {
        return methodEntries.get(id);
    }
    ...
    public void insertMethod(String id, Type t) {
        methodEntries.put(new Symbol(id,METHOD_KIND,t);
    }
    ...
}

```

Less flexible, but acceptable

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Forward references

```

class A {
    void foo() {
        bar();
    }
    void bar() {
        ...
    }
}

```

bar used before
encountered
declaration

root

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globals

Symbol	kind		
A	class		

A

Symbol	kind		
foo	method		
bar	method		

How do we handle forward references?
Present two solutions

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Solution 1 – multiple phases

- Multiple phase solution
 - Building visitor
 - Checking visitor
- Building visitor
 - On visit to node – build corresponding symbol table
 - class, method, block (and possibly nested blocks)
 - Can maintain stack of symbol table
 - Push new table when entering scope
 - Pop when exiting scope
 - Link AST node to symbol table of corresponding scope
 - Do not perform any checks

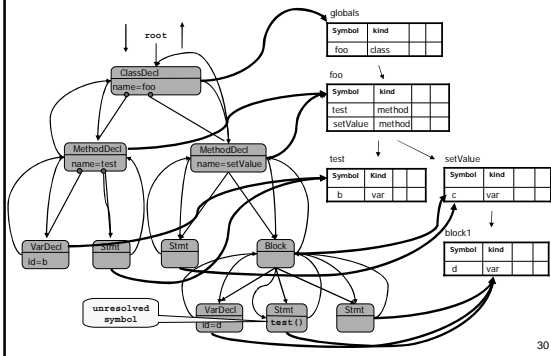
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Building and checking

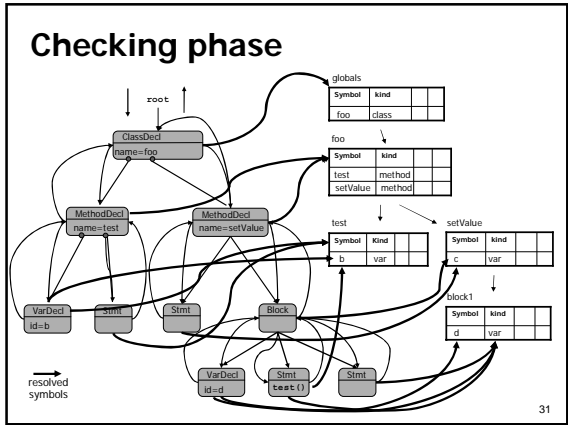
- Building visitor
 - A propagating visitor
 - Propagates reference to the symbol table of the current scope (or use table stack)
 - In some cases have to use type information (**extends**)
 - Populate tables with declarations/definitions
 - Class definitions, method definitions, field definitions, variable declarations, formal arguments
 - `class A {void foo(){int B; int[] C;}}`
- Checking visitor
 - On visit to node – perform check using symbol tables
 - Resolve identifiers
 - Look for symbol in table hierarchy

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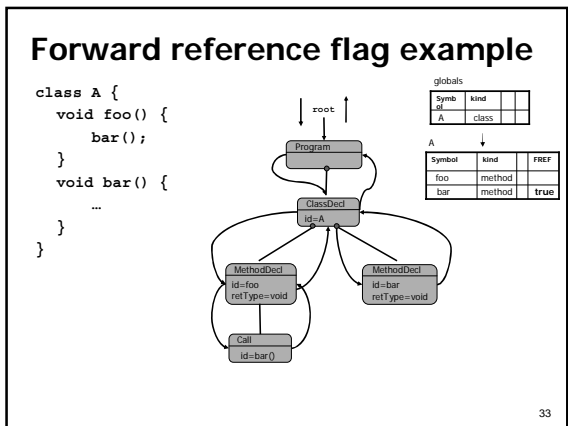
Building phase



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- ### Forward references – solution 2
- Use forward reference marker (flag)
 - Optimistically assume that symbol will be eventually defined
 - Update symbol table when symbol defined
 - Remove forward-reference marker
 - Count unresolved symbols and upon exit check that #unresolved=0
 - And/or construct some of the symbol table during parsing
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Class hierarchy

- **extends** relational should be acyclic
- Avoid creating cyclic symbol table hierarchy (infinite looping)
- Can check acyclicity in separate phase (**ClassHierarchyVisitor**)
 - Build symbol tables for classes first and check absence of cycles

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Next phase: type checking

- First, record all pre-defined types (string,int,boolean,void,null)
- Second, record all user-defined types (classes, methods, arrays)
- Store all types in table
- Now, run type-checking algorithm

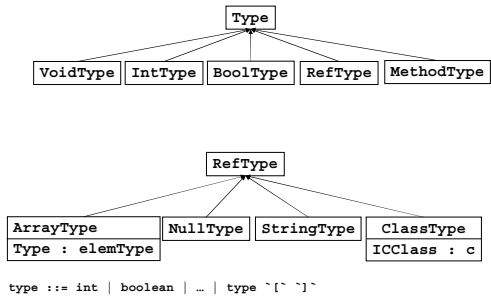
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Type table

- Keeps a single copy for each type
 - Can compare types for equality by ==
 - Records primitive types: int, bool, string, void, null
 - Initialize table with primitive types
 - User-defined types: arrays, methods, classes
- Used to record inheritance relation
 - Types should support **subTypeOf (Type t)**
- For IC enough to keep one global table
 - Static field of some class (e.g., Type)
 - In C/Java associate type table with scope

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Possible type hierarchy



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See you next week

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