SEM1: Scoping

Scoping and Symbol Tables

CMPT 379: Compilers
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Program Errors

- Program is lexically well-formed
  - Identifiers have valid names
  - Strings are properly terminated
  - No unknown characters
- Program is syntactically well-formed:
  - Package declaration have the correct structure
  - Expressions are syntactically valid
- Does this mean that the program is legal?

Example (Decaf program)

```
package test {
        var myBin bool;
        func foo() void {
                var x[0] int;
                var k int = myBin * y;
        }
        func foo() void {
        }
        func fibonacci(n int) int  {
                return foo() + fibonacci(n-1);
        }
}
```

Cannot define Array type as local variable
Cannot define Array of size 0

Variable not declared

Cannot multiply boolean value

Cannot redefine functions

Cannot add void

No main function

Goal of Semantic Analysis

- Ensure that the program has a well-defined meaning
- Verifies properties of the program that are not caught during the earlier phases
  - All variables are declared before use
  - Types are used correctly in expressions
  - Method calls have correct number and types of parameters and return value

Challenges in Semantic Analysis

- Reject all/most of the incorrect programs
- Accept all correct programs

Validity versus Correctness

```
func main () int {
    var x string;
    if (false) {
        x = 137;
    }
}
```

Not an error in an interpreted language.
Still a type error in a compiled language.
(unless the optimizer removes the statement)

Validity versus Correctness

```
func fibonacci (n int) int {
      if (n<=1) return(0);
      return fibonacci(n-1) + fibonacci(n-2);
 }
func main() int {
      print_int(fibonacci(40));
}
```

Incorrect! Should be `return(n);`

Challenges in Semantic Analysis

- Reject the largest number of incorrect programs
- Accept all correct programs
- Work fast!

Other Goals of Semantic Analysis

- Gather useful information about the program for code generation:
  - Determine what variables are meant by each identifier
  - Build an internal representation of inheritance hierarchies
  - Keep track of variables which are in scope at each program point

Implementing Semantic Analysis

- Attribute Grammars
  - Augment parsing rules to do checking during parsing
  - Single pass semantic analysis
- Recursive AST Walk
  - Construct the AST, then use recursion to explore the tree

Scoping

What’s in a Name?

- The same name (identifier) in a program may refer to fundamentally different things:
- This is perfectly legal Java code:

```
public class A {
    char A;
    A A(A A) {
        A.A = ‘A’;
        return A ((A) A);
    }
}
```

What’s in a Name?

- The same name (identifier) in a program may refer to completely different objects:
- This is perfectly legal C++ code:

```
int Awful ()  {
   int x = 137;
   {
           string x = “Scope!”
           if (float x = 0)
               double x = x;
   }
   if (x == 137) cout << “Y”;
}
```

Scope

- The scope of an entity is the set of locations in a program where that entity's name refers to that entity.
- The introduction of new variables into scope may hide older variables
- How do we keep track of what's visible?

Symbol Tables

- Symbol tables map **names** (string format) to **descriptors** (information about identifiers)
- As we run our semantic analysis, continuously update the symbol table with information about what is in scope

Symbol Tables

```
0: int x = 137;
1: int z = 42;
2: int testFunc(int x, int y){
3:   printf(“%d, %d, %d\n”, x@2, y@2, z@1);
4:   {
5:     int x, z;
6:     z@5 = y@2;
7:     x@5 = z@5;
8:     {
9:       int y = x@5;
10:      { printf(“%d, %d, %d\n”, x@5, y@9, z@5); }
11:      printf(“%d, %d, %d\n”, x@5, y@9, z@5);
12:    }
13:    printf(“%d, %d, %d\n”, x@5, y@2, z@5);
14:  }
15: }
```

Identifier	Definition Line#
x	0
z	1
x	2
y	2
x	5
z	5
y	9

Symbol Tables

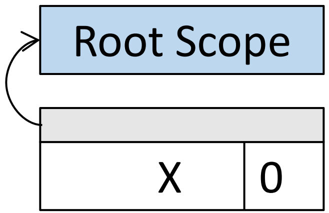
- Symbol tables map **names** (string format) to **descriptors** (information about identifiers)
- As we run our semantic analysis, continuously update the symbol table with information about what is in scope
- Typical implementation: stack
- Basic Operations:
  - Push scope: Enter a new scope
  - Pop scope: Leave a scope, discarding all declarations
  - Insert symbol: add a new identifier to the current scope
  - Lookup symbol: Given an identifier, find a descriptor

Using a Symbol Table

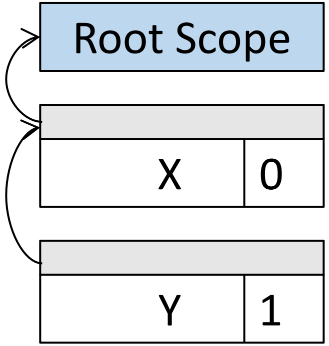
- To process a portion of the program that creates a scope (block statements, function calls, classes, etc.)
  - Enter a new scope
  - Add all variable declarations to the symbol table
  - Process the body of the block/function/class
  - Exit the scope
- Much of semantic analysis is defined over the parse tree using symbol tables

Spaghetti Stack

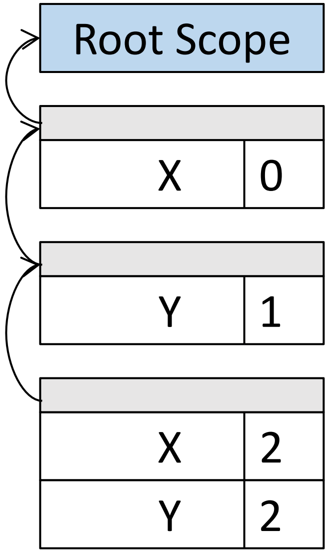
```
int x;
int y;
int testFunc(int x, int y)
{
        int w, z;
       {
              int y;
       }
       {
              int w;
       }
}
```



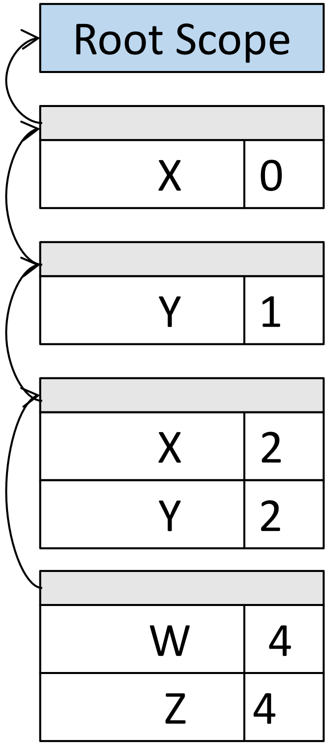
```
int x;
int y;
int testFunc(int x, int y)
{
        int w, z;
        {
                int y;
        }
        {
                int w;
        }
}
```



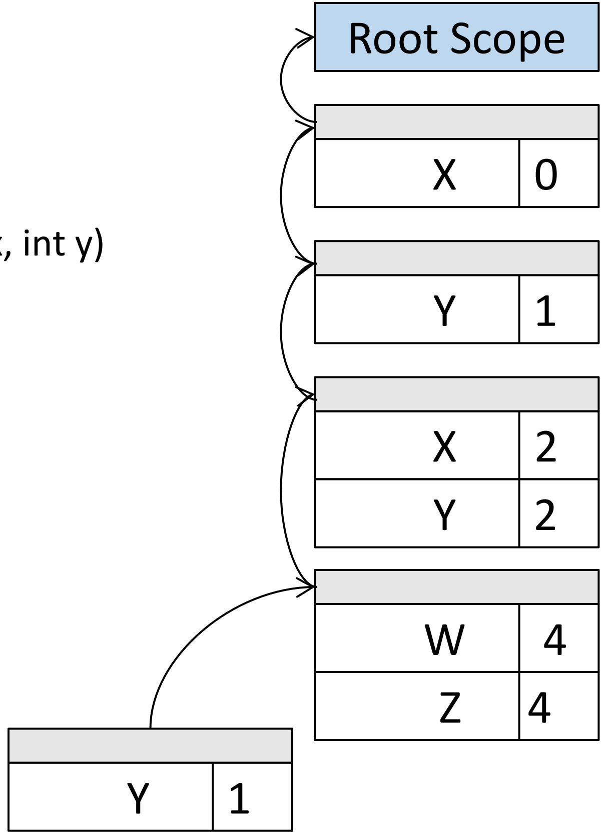
```
int x;
int y;
int testFunc(int x, int y)
{
        int w, z;
        {
                int y;
        }
        {
                int w;
        }
}
```



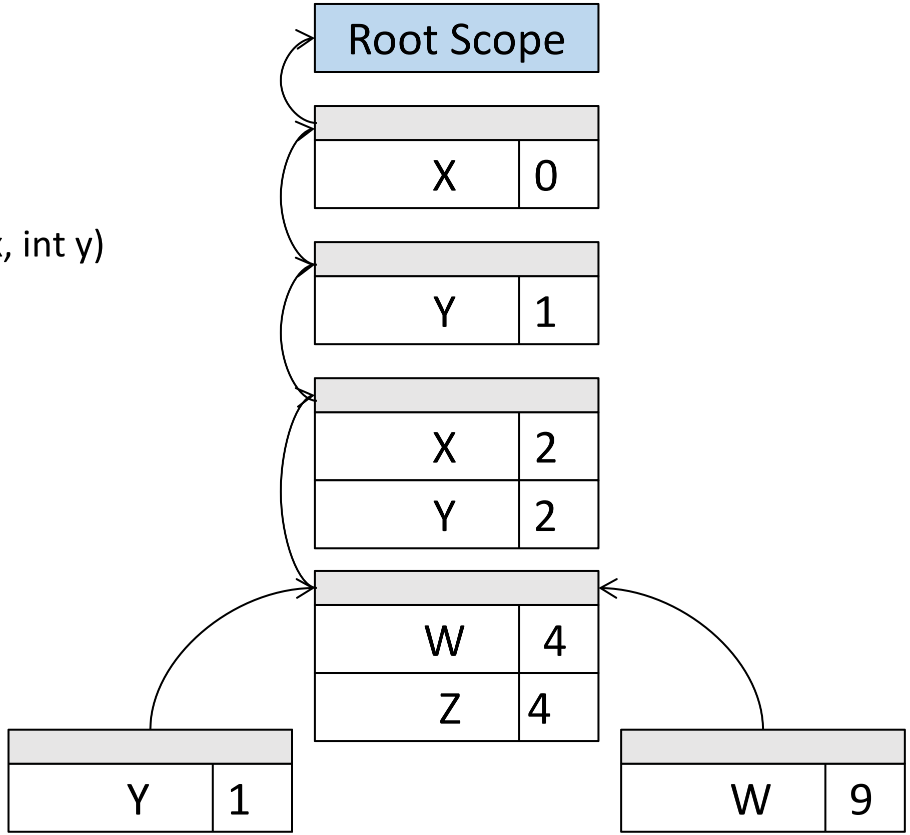
```
int x;
int y;
int testFunc(int x, int y)
{
        int w, z;
        {
                int y;
        }
        {
                int w;
        }
}
```



```
int x;
int y;
int testFunc(int x, int y)
{
        int w, z;
        {
                int y;
        }
        {
                int w;
        }
}
```



```
int x;
int y;
int testFunc(int x, int y)
{
        int w, z;
        {
                int y;
        }
        {
                int w;
        }
}
```

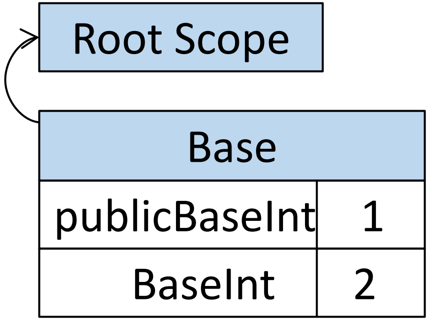


Spaghetti Stack

- Treat the symbol table as a linked structure of scopes
- Each scope stores a pointer to its parent, but not vice-versa
- From any point in the program, symbol table appears to be a stack
- This is called a spaghetti stack
- The data is stored in heap memory
- Useful for programming languages that support continuations (Scheme, Standard ML)

Scoping with Inheritance

```
public class Base {
        public int publicBaseInt = 1;
        protected int baseInt = 2;
}
```

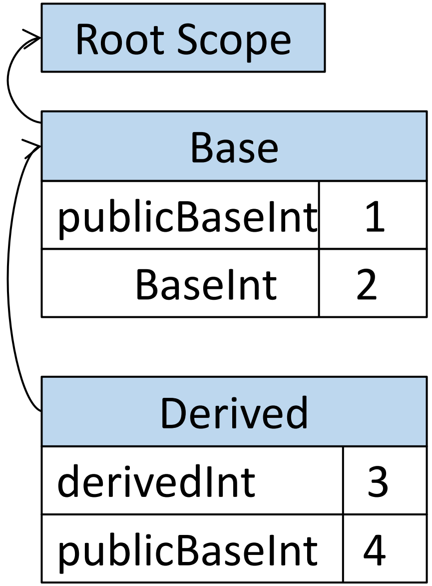


Scoping with Inheritance

```
public class Base {
        public int publicBaseInt = 1;
        protected int baseInt = 2;
}
public class Derived extends Base {
        public int derivedInt = 3;
        public int publicBaseInt = 4;

        public void doSomething () {
           System.out.println(publicBaseInt);
           System.out.println(baseInt);
           System.out.println(derivedInt);

           int publicBaseInt = 6;
           System.out.println(publicBaseInt);
        }
}
```



Scoping with Inheritance

>

```
public class Base {
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        protected int baseInt = 2;
}
public class Derived extends Base {
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        public int publicBaseInt = 4;

        public void doSomething () {
           System.out.println(publicBaseInt);
           System.out.println(baseInt);
           System.out.println(derivedInt);

           int publicBaseInt = 6;
           System.out.println(publicBaseInt);
        }
}
```
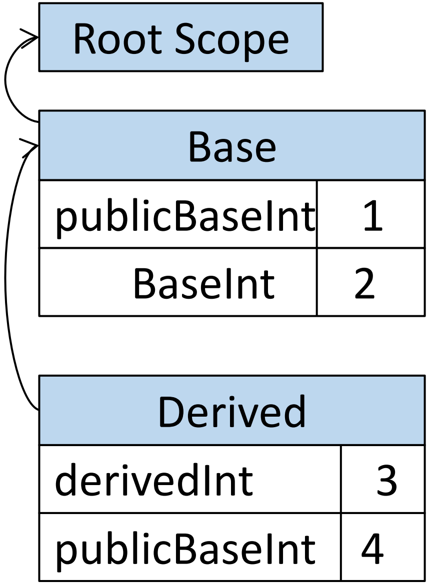



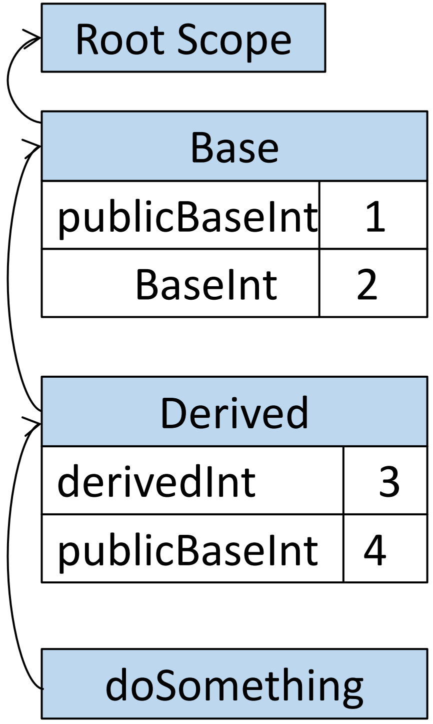
```
>
```

Scoping with Inheritance

```java
public class Base {
        public int publicBaseInt = 1;
        protected int baseInt = 2;
}
public class Derived extends Base {
        public int derivedInt = 3;
        public int publicBaseInt = 4;

        public void doSomething () {
           System.out.println(publicBaseInt);
           System.out.println(baseInt);
           System.out.println(derivedInt);

           int publicBaseInt = 6;
           System.out.println(publicBaseInt);
        }
}
```



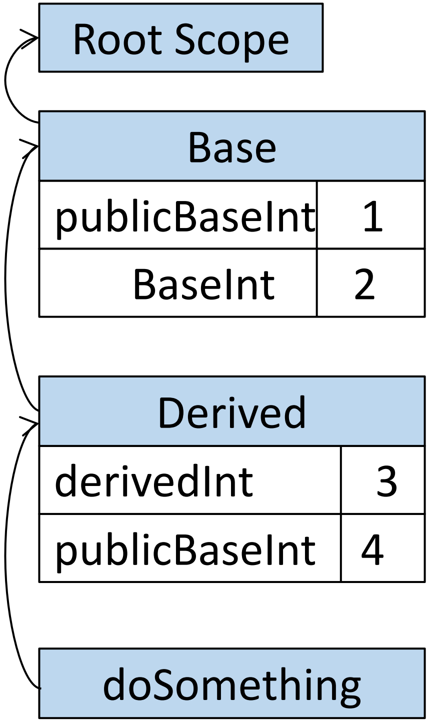
> 4

Scoping with Inheritance

```
public class Base {
        public int publicBaseInt = 1;
        protected int baseInt = 2;
}
public class Derived extends Base {
        public int derivedInt = 3;
        public int publicBaseInt = 4;

        public void doSomething () {
           System.out.println(publicBaseInt);
           System.out.println(baseInt);
           System.out.println(derivedInt);

           int publicBaseInt = 6;
           System.out.println(publicBaseInt);
        }
}
```



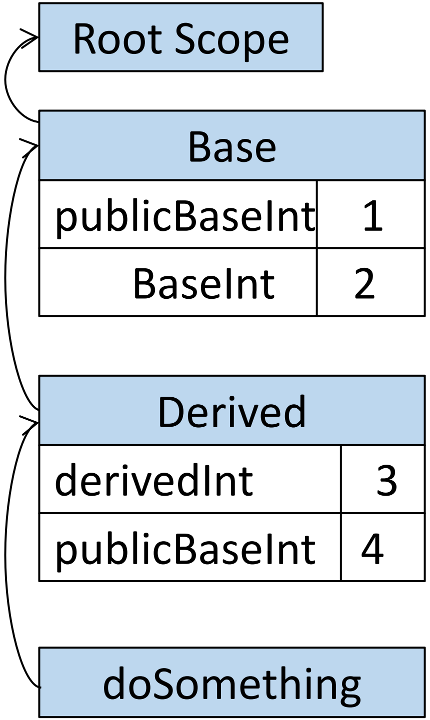
```
> 4
  2
```

Scoping with Inheritance

```
public class Base {
        public int publicBaseInt = 1;
        protected int baseInt = 2;
}
public class Derived extends Base {
        public int derivedInt = 3;
        public int publicBaseInt = 4;

        public void doSomething () {
           System.out.println(publicBaseInt);
           System.out.println(baseInt);
           System.out.println(derivedInt);

           int publicBaseInt = 6;
           System.out.println(publicBaseInt);
        }
}
```



```
> 4
  2
  3
```

Scoping with Inheritance

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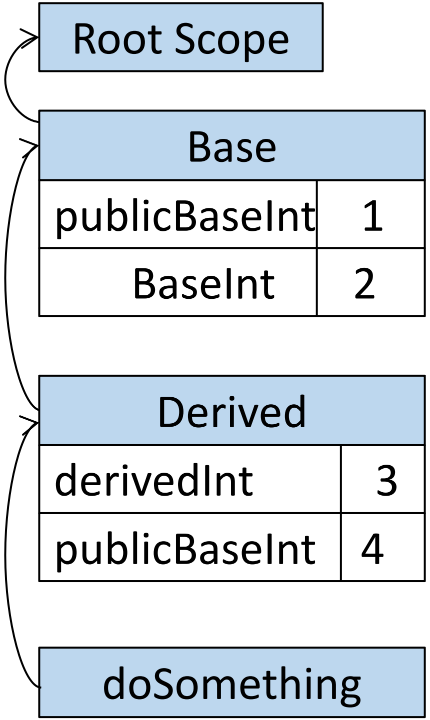
```



```
> 4
  2
  3
```

Scoping with Inheritance

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          int publicBaseInt = 6;
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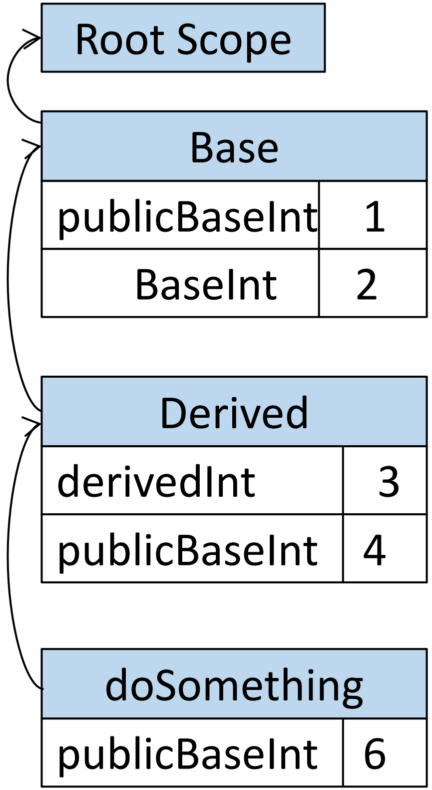
       }
}
```



Scoping with Inheritance

```
> 4
  2
  3
  6
```

```
public class Base {
        public int publicBaseInt = 1;
        protected int baseInt = 2;
}
public class Derived extends Base {
        public int derivedInt = 3;
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        public void doSomething () {
           System.out.println(publicBaseInt);
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           int publicBaseInt = 6;
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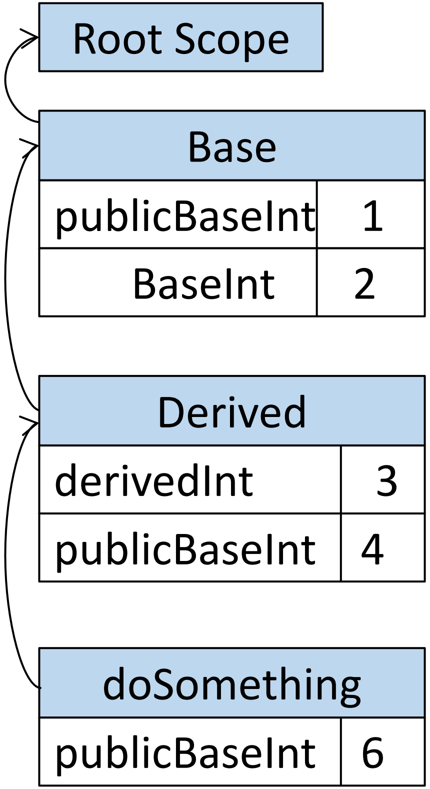
        }
}
```



Inheritance and Scoping

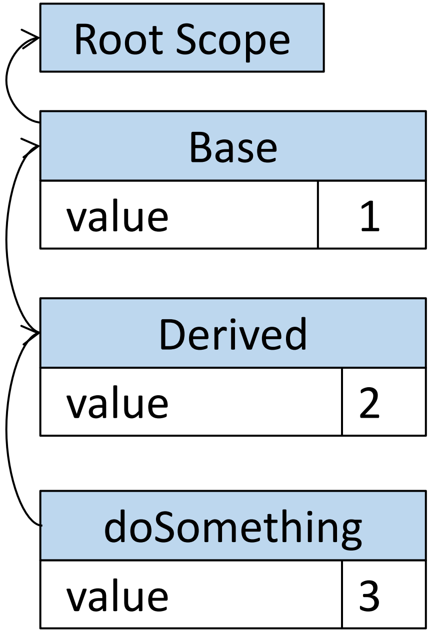
- Typically, the scope for a derived class will store a link to the scope of its base class
- Looking up a field of a class traverses the scope chain until that field is found or a semantic error is found

Explicit Disambiguation

```
public class Base {
        public int value = 1;
}
public class Derived extends Base {
        public int value = 2;

        public void doSomething () {
           int value = 3;
          System.out.println(value);
          System.out.println(this.value);
          System.out.println(super.value);

         }
}
```



Explicit Disambiguation

```
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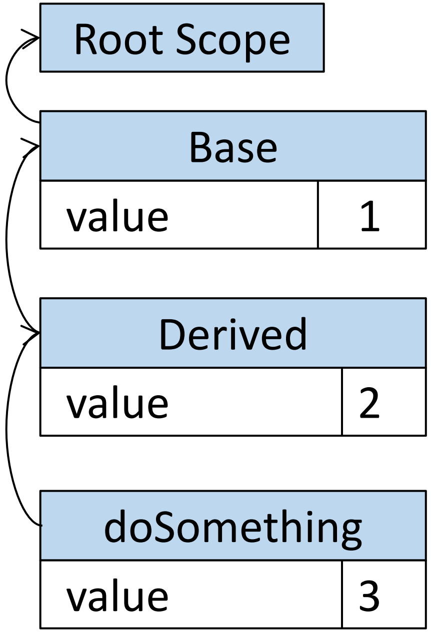
        public int value = 1;
}
public class Derived extends Base {
        public int value = 2;

        public void doSomething () {
           int value = 3;
           System.out.println(value);
           System.out.println(this.value);
           System.out.println(super.value);

         }
}
```

```
> 3
```



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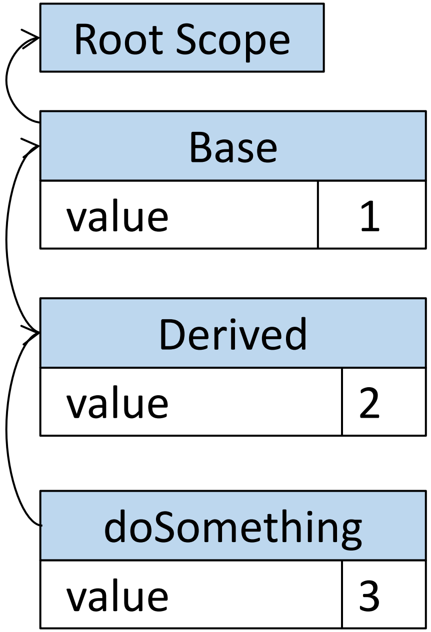
           System.out.println(value);
           System.out.println(this.value);
           System.out.println(super.value);

         }
}
```

```
> 3
  2
```



Explicit Disambiguation

```
public class Base {
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}
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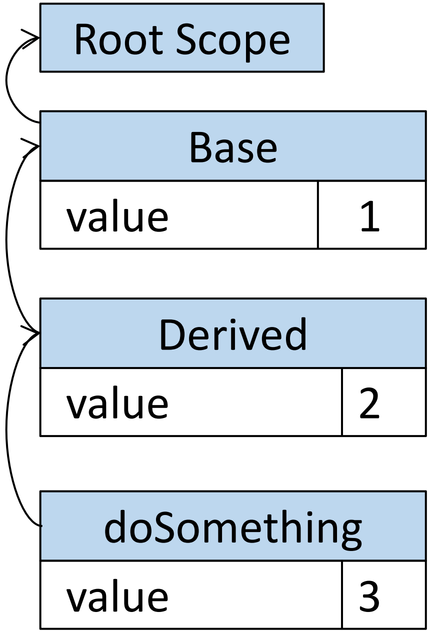
        public int value = 2;

        public void doSomething () {
            int value = 3;
           System.out.println(value);
           System.out.println(this.value);
           System.out.println(super.value);

         }
}
```

```
> 3
  2
  1
```



Explicit Disambiguation

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public class Base {
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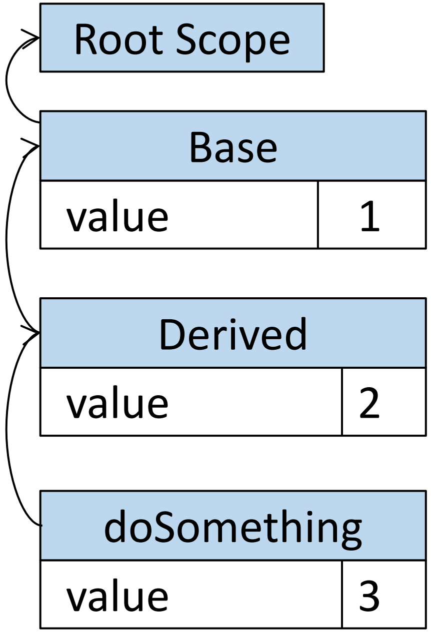
        public void doSomething () {
           int value = 3;
           System.out.println(value);
           System.out.println(this.value);
           System.out.println(super.value);

         }
}
```

```
>
```



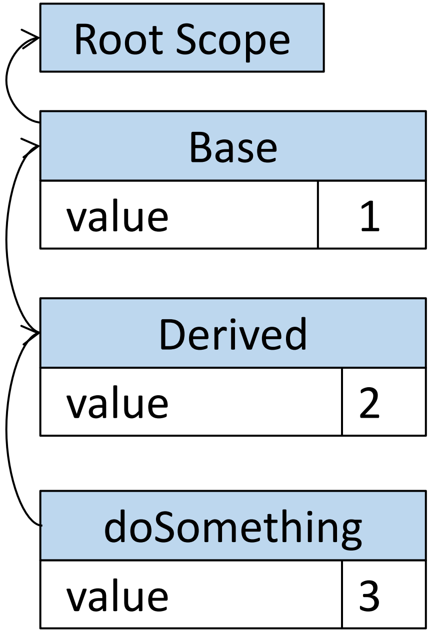
Explicit Disambiguation

```
public class Base {
        public int value = 1;
}
public class Derived extends Base {


        public void doSomething () {
           int value = 3;
           System.out.println(value);
           System.out.println(this.value);
           System.out.println(super.value);

         }
}
```

```
> 3
```



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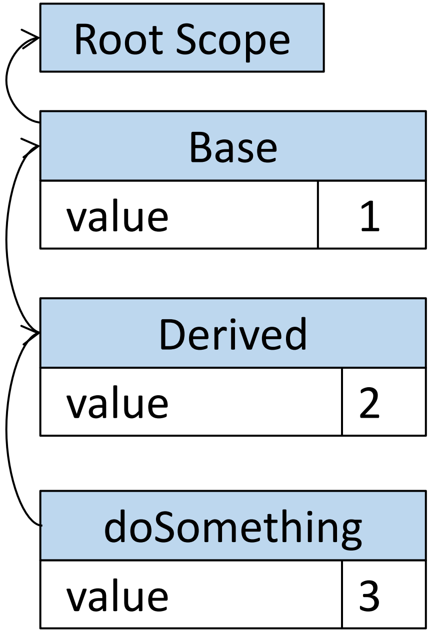
           System.out.println(value);
           System.out.println(this.value);
           System.out.println(super.value);

         }
}
```

```
> 3
  1
```



Explicit Disambiguation

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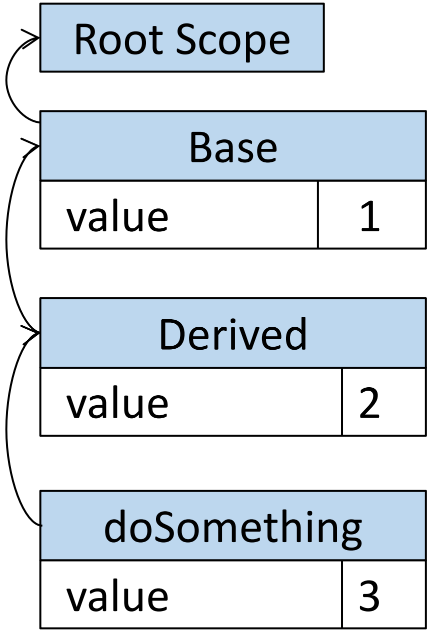
        public void doSomething () {
           int value = 3;
           System.out.println(value);
           System.out.println(this.value);
           System.out.println(super.value);

         }
}
```

```
> 3
  1
  1
```



Disambiguating Scopes

- Maintain a second table of pointers into the scope stack
- When looking up a value in a specific scope, begin the search from that scope
- Some languages allow you to jump up to any arbitrary base class (for example, C++)

Single and Multi-pass Compilers

- Predictive parsing methods always scan the input from left-to-right
- Since we only need one token of lookahead, we can do lexical analysis and parsing simultaneously in one pass over the file
- Some compilers can combine lexical analysis, parsing, semantic analysis, and code generation into same pass
  - Single pass compilers
- Other compilers rescan the input multiple times
  - Multi-pass compilers

Single and Multi-pass Compilers

- Some languages are defined to support single-pass compilers (C, C++)
- Some languages require multi-passes (Java)
- Most modern compilers uses many passes over the input program

Scoping in Multi-pass Compilers

- 1st pass: parse the input into an abstract syntax
- 2nd pass: walk the AST, gathering information about classes
- 3rd pass: walk the AST checking semantic properties and do code generation

Summary

- Semantic analysis verifies that a syntactically valid program is correctly-formed and computes additional information about the meaning of the program
- Scope checking determines what objects or classes are referred to by each name in the program.
- Scope checking is usually done with a symbol table implemented either as a stack or spaghetti stack.

Summary

- In object-oriented programs, the scope for a derived class is often placed inside of the scope of a base class.
- Some semantic analyzers operate in multiple passes in order to gain more information about the program.
- In dynamic scoping, the actual execution of a program determines what each name refers to.
- With multiple inheritance, a name may need to be searched for along multiple paths.

Extra Slides

Static and Dynamic Scoping

- The scoping we've seen so far is called static scoping and is done at compile time
  - Identifiers refer to logically related variables
- Some languages uses dynamic scoping, which is done at runtime
  - Identifiers refer to the variable with that name that is closely nested at runtime

Dynamic Scoping

```
int x = 137;
int y = 42;
void function1 () {
    print(x + y);
}
void function2 () {
    int x = 0;
    function1();
}
void function3 () {
    int y = 0;
    function2();
}
function1();
function2();
function3();
```

Symbol Table	
X	137
Y	42

```
>
```

Dynamic Scoping

```
int x = 137;
int y = 42;
void function1 () {
    print(x + y);
}
void function2 () {
    int x = 0;
    function1();
}
void function3 () {
    int y = 0;
    function2();
}
function1();
function2();
function3();
```

Symbol Table	
X	137
Y	42

```
>
```

Dynamic Scoping

```
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    int x = 0;
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}
void function3 () {
    int y = 0;
    function2();
}
function1();
function2();
function3();
```

Symbol Table	
X	137
Y	42

```
>
```

Dynamic Scoping

```
int x = 137;
int y = 42;
void function1 () {
      print(x + y);
}
void function2 () {
      int x = 0;
      function1();
}
void function3 () {
      int y = 0;
      function2();
}
function1();
function2();
function3();
```

Symbol Table	
X	137
Y	42

```
> 179
```

Dynamic Scoping

```
int x = 137;
int y = 42;
void function1 () {
    print(x + y);
}
void function2 () {
    int x = 0;
    function1();
}
void function3 () {
    int y = 0;
    function2();
}
function1();
function2();
function3();
```

Symbol Table	
X	137
Y	42

```
> 179
```

Dynamic Scoping

```
int x = 137;
int y = 42;
void function1 () {
    print(x + y);
}
void function2 () {
    int x = 0;
    function1();
}
void function3 () {
    int y = 0;
    function2();
}
function1();
function2();
function3();
```

Symbol Table	
X	137
Y	42

```
> 179
```

Dynamic Scoping

```
int x = 137;
int y = 42;
void function1 () {
    print(x + y);
}
void function2 () {
    int x = 0;
    function1();
}
void function3 () {
    int y = 0;
    function2();
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Symbol Table	
X	137
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> 179
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Dynamic Scoping

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Dynamic Scoping in Practice

- Examples: Perl
- Often implemented by preserving symbol table at runtime
- Often less efficient than static scoping
  - Compiler cannot hardcode location of variables
  - Names must be resolved at runtime