Lecture 16: Static Semantics Overview[1]

- Lexical analysis
  - Produces tokens
  - Detects & eliminates illegal tokens
- Parsing
  - Produces trees
  - Detects & eliminates ill-formed parse trees
- Static semantic analysis ⟸ *we are here*
  - Produces *decorated tree* with additional information attached
  - Detects & eliminates remaining static errors

[1] From material by R. Bodik and P. Hilfinger

Static vs. Dynamic

- We use the term *static* to describe properties that the compiler can determine without considering any particular execution.
  - E.g., in

    ```
    def f(x) : x + 1
    ```

    Both uses of x refer to same variable
- Dynamic properties are those that depend on particular executions in general.
  - E.g., will `x = x/y` cause an arithmetic exception?
- Actually, distinction is not that simple. E.g., after

  ```
  x = 3
  y = x + 2
  ```

  compiler *could* deduce that x and y are integers.
- But languages often designed to require that we treat variables only according to explicitly declared types, because deductions are difficult or impossible in general.

Typical Tasks of the Semantic Analyzer

- Find the declaration that defines each identifier instance
- Determine the static types of expressions
- Perform re-organizations of the AST that were inconvenient in parser, or required semantic information
- Detect errors and fix to allow further processing

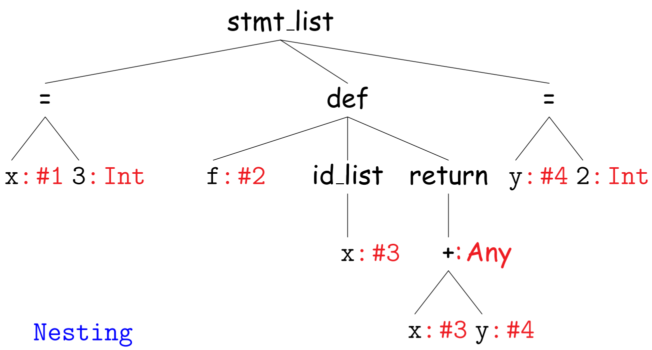
Typical Semantic Errors: Java, C++

- Multiple declarations: a variable should be declared (in the same region) at most once
- Undeclared variable: a variable should not be used without being declared.
- Type mismatch: e.g., type of the left-hand side of an assignment should match the type of the right-hand side.
- Wrong arguments: methods should be called with the right number and types of arguments.
- Definite-assignment check (Java): conservative check that simple variables assigned to before use.

Output from Static Semantic Analysis

Input is AST; output is an *annotated tree:* identifiers decorated with declarations, other expressions with type information.

```
x = 3
def f (x):
   return x+y
y = 2
```




```
    Id  Type     Nesting
#1: x,  Any,      0
#2: f,  Any->Any, 0
#3: x,  Any,      1
#4: y,  Any,      0
```


Output from Static Semantic Analysis (II)

- Analysis has added objects we'll call *symbol entries* to hold information about instances of identifiers.
- In this example, `#1: x, Any, 0` denotes an entry for something named 'x' occurring at the outer lexical level (level 0) and having static type Any.
- For other expressions, we annotate with static type information.

Output from Static Semantic Analysis: Classes

- In Python (dynamically typed), can write

```
class A(object):
   def f(self): return self.x

a1 = A(); a2 = A()   # Create two As
a1.x = 3; print a1.x # OK
print a2.x           # Error; there is no x
```

  so can't say much about attributes (fields) of A.
- In Java, C, C++ (statically typed), analogous program is illegal, even without second print (the class definition itself is illegal).
- So in statically typed languages, symbol entries for classes would contain dictionaries mapping attribute names to types.

Scope Rules: Binding Names to Symbol Entries

- *Scope of a declaration:* section of text or program execution in which declaration applies
- *Declarative region:* section of text or program execution that bounds scopes of declarations (we'll say "*region*" for short).
- If scope of a declaration defined entirely according to its position in source text of a program, we say language is *statically scoped.*
- If scope of a declaration depends on what statements get executed during a particular run of the program, we say language has *dynamically scoped.*

Scope Rules: Name⟹Declaration is Many-to-One

- In most languages, can declare the same name multiple times, if its declarations
  - occur in different declarative regions, or
  - involve different kinds of names.
  - Examples from Java?, C++?

Scope Rules: Nesting

- Most statically scoped languages (including C, C++, Java) use:

  Algol scope rule: Where multiple declarations might apply, choose the one defined in the *innermost* (most deeply nested) declarative region.

- Often expressed as "inner declarations *hide* outer ones."
- Variations on this: Java disallows attempts to hide local variables and parameters.

Scope Rules: Declarative Regions

- Languages differ in their definitions of declarative regions.
- In Java, variable declaration's effect stops at the closing '}', that is, each function body is a declarative region.
- What others?
- In Python, function header and body make up a declarative region, as does a lambda expression. But nothing smaller. Just one `x` in this program:

```
def f(x):
   x = 3
   L = [x for x in xrange(0,10)]
```


Scope Rules: Use Before Definition

- Languages have taken various decisions on where scopes start.
- In Java, C++, scope of a member (field or method) includes the entire class (textual uses may precede declaration).
- But scope of a local variable starts at its declaration.
- As for non-member and class declarations in C++: must write

```
extern int f(int);  // Forward declarations
class C;
int x = f(3)        // Would be illegal w/o forward decls.
void g(C* x) {
   ...
}

int f (int x) { ... }  // Full definitions
class C { ... }
```

Scope Rules: Overloading

- In Java or C++ (not Python or C), can use the same name for more than one method, as long as the number or types of parameters are unique.

```
int add(int a, int b);         float add(float a, float b);
```

- The declaration applies to the *signature*—name + argument types—not just name.
- But return type not part of signature, so this won't work:

```
int add (int a, int b);        float add (int a, int b)
```

- In Ada, it will, because the return type *is* part of signature.

Dynamic Scoping

- Original Lisp, APL, Snobol use *dynamic scoping,* rather than static:

  Use of a variable refers to most recently executed, and still active, declaration of that variable.

- Makes static determination of declaration generally impossible.
- Example:

```
void main() { f1(); f2(); }
void f1() { int x = 10; g(); }
void f2() { String x = "hello"; f3();g(); }
void f3() { double x = 30.5; }
void g() { print(x); }
```

- With static scoping, illegal.
- With dynamic scoping, prints "10" and "hello"

Explicit vs. Implicit Declaration

- Java, C++ require explicit declarations of things.
- C is lenient: if you write `foo(3)` with no declaration of `foo` in scope, C will supply one.
- Python implicitly declares variables you assign to in a function to be local variables.
- Fortran implicitly declares any variables you use, and gives them a type depending on their first letter.
- But in all these cases, there *is* a declaration as far as the compiler is concerned.

So How Do We Annotate with Declarations?

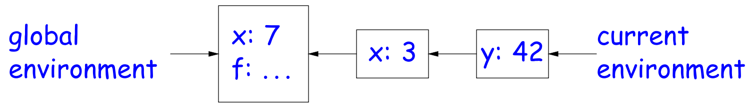
- Idea is to recursively navigate the AST,
  - in effect executing the program in simplified fashion,
  - extracting information that isn't data dependent.
- You saw it in CS61A (sort of).

Environment Diagrams and Symbol Entries

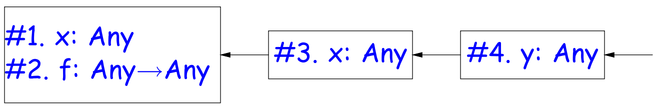
- In Scheme, executing

```
(set! x 7)
(define (f x) (let ((y (+ x 39))) (+ x y)))
(f 3)
```

would eventually give this environment at `(+ x y)`:



- Now abstract away values in favor of static type info:



- and voila! A data structure for mapping names to current declarations: a *block-structured symbol table*.