

Lecture 10: Static Semantics Overview¹

Administrivia

- If you're interested, there's a workshop on writing just-in-time compilers using LLVM on Oct. 2nd in the Woz, from 8-10pm.
- First in-class test 10 October.

¹From material by R. Bodik and P. Hilfinger
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Overview

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

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

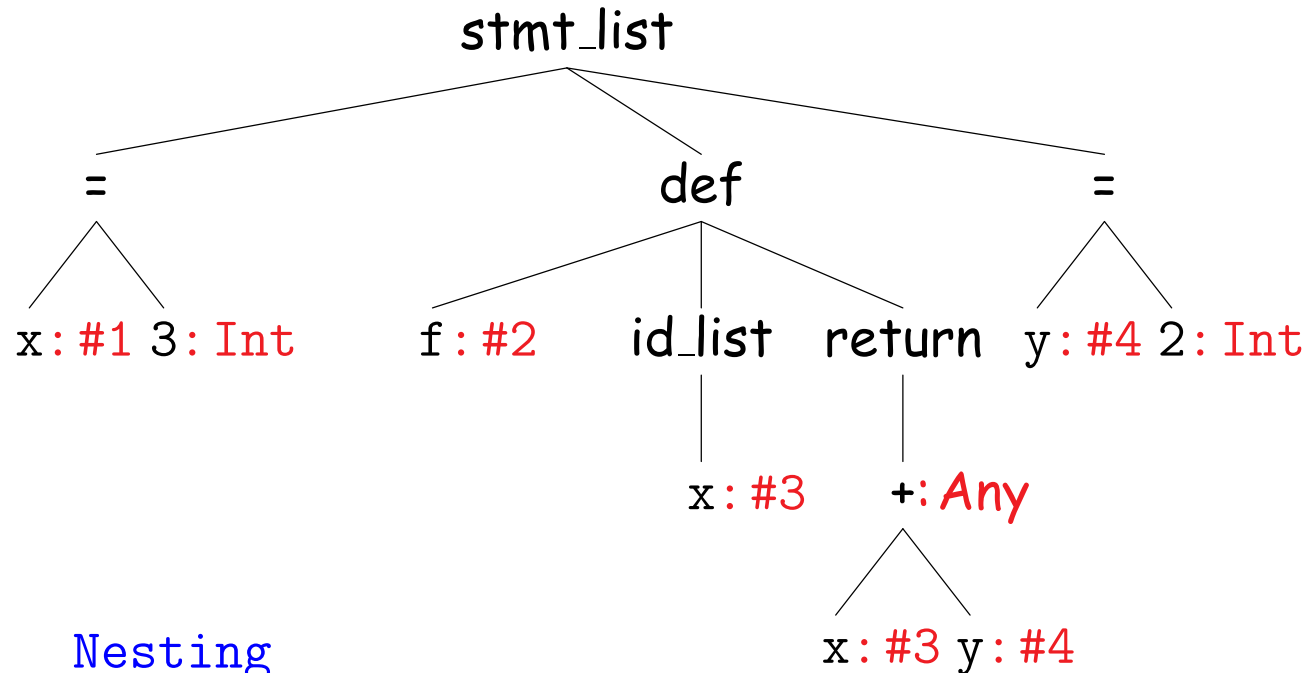
Input is AST; output is an *annotated tree*: identifiers decorated with declarations, other expressions with type information.

```
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 $\implies$ 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?

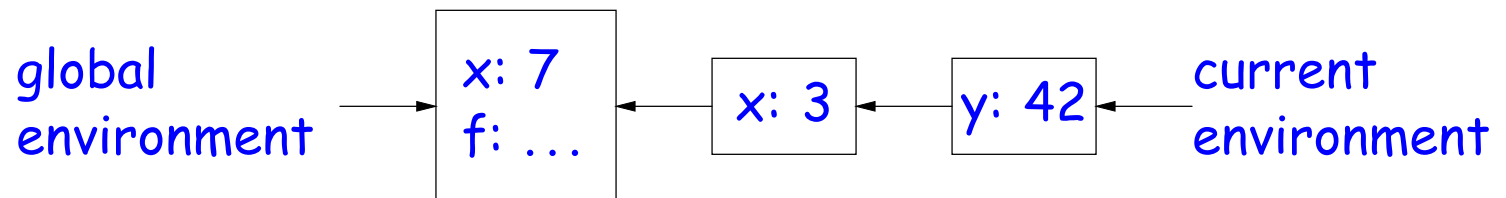
- Idea is to recursively navigate the AST,
  - in effect executing the program in simplified fashion,
  - extracting information that isn't data dependent.
- You saw it in CS61A (sort of).

# Environment Diagrams and Symbol Entries

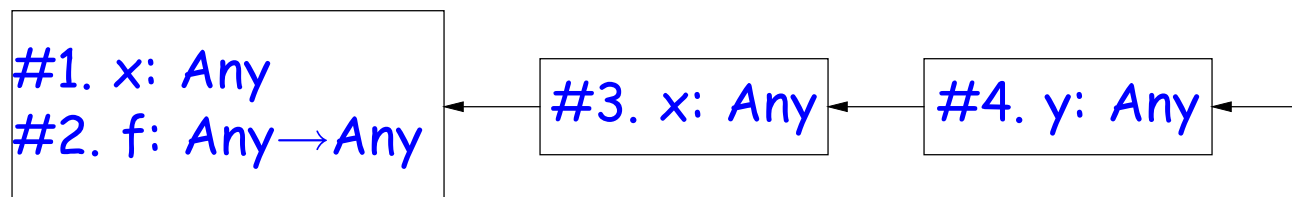
- In Scheme, executing

```
(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*.