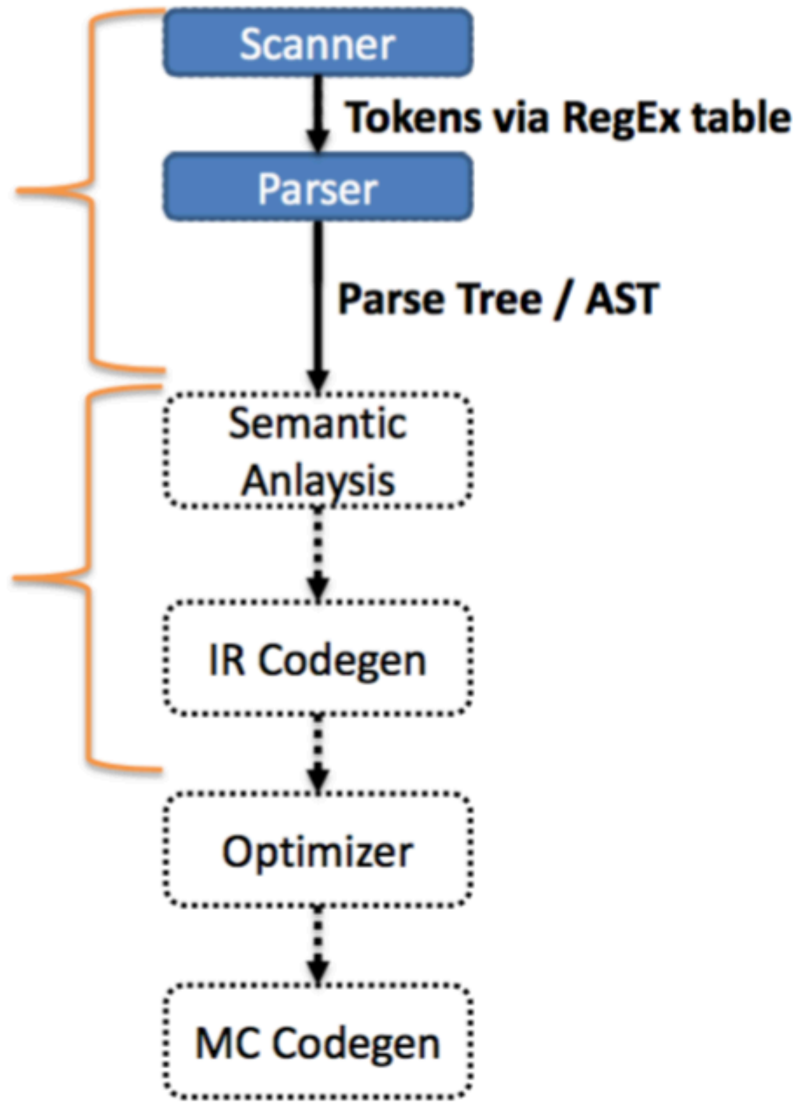
CS536

Semantic Analysis Introduction with Emphasis on Name Analysis

Where we are at

- So far, we've only defined the structure of a program—aka the syntax
- We are now diving into the semantics of the program



Semantics: The Meaning of a Program

- The parser can guarantee that the program is structurally correct
- The parser does not guarantee that the program makes sense:
  - `void var;`
  - Undeclared variables
  - Ill-typed statements

```
int doubleRainbow;
doubleRainbow = true;
```

Static Semantic Analysis

- Two phases
  - Name analysis (aka name resolution)
    - For each scope
      - Process declarations, add them to symbol table
      - Process statements, update IDs to point to their entry
  - Type analysis
    - Process statements
      - Use symbol table info to determine the type of each expression

Why do we need this phase?

- Code generation
  - Different operations use different instructions:
    - Consistent variable access
    - Integer addition vs floating point addition
    - Operator overloading
- Optimization
  - Symbol table knows where a variable is used
    - Can remove dead code
    - Can weaken the type (e.g., int -> bool)
    - NOTE: pointers can make this occasionally impossible
- Error checking

Semantic Error Analysis

- For non-trivial programming languages, we run into fundamental undecidability problems
  - Halting?
  - Crashes?
- Sometimes practical feasibility as well
  - Thread interleavings
  - Interprocedural dataflow

Catch Obvious Errors

- We may not be able to guarantee the absence of errors
- We can at least catch some, though
  - Undeclared identifiers
  - Multiply declared identifiers
  - Ill-typedness

Name analysis

- Associating ids with their uses
- Need to bind names before we can type uses
  - What definitions do we need about identifiers?
    - Symbol table
  - How do we bind definitions and uses together?
    - scope

Symbol table entries

- A table that binds a name to information we need
- Information typically needed in an entry
  - Kind (struct, variable, function, class)
  - Type (int, int $\times$ string $\rightarrow$ bool, struct)
  - Nesting level
  - Runtime location (where it's stored in memory)

Symbol table operations

- Insert entry
- Lookup
- Add new table
- Remove/forget a table

When should we use these operations?

Scope: the lifetime of a name

- Block of code in which a name is visible/valid
  - No scope

    Assembly / FORTRAN
  - static / most deeply nested scope

    Should be familiar – C / Java / C++

```
void func(){
   int a;
}

void soul(int b){
    if (b){
        int c = 2;
    }
}
```

Many decisions related to scope!!

Static vs Dynamic Scope

- Static
  - Correspondence between a variable use / decl is known at compile time
- Dynamic
  - Correspondence determined at runtime

```
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);
}
```

Exercises

```
class animal {
  // methods
  void attack(int animal) {
     for (int animal=0; animal<10; animal++) { // not okay for animal
         int attack;
     }
  }

  int attack(int x) {// not okay for attack, already declared as void type method with the same param
     for (int attack=0; attack<10; attack++) {
        int animal;
     }
  }

  void animal() { }

  // fields
  double attack;
  int attack; //not okay for attack, already declared as a field
  int animal;
}
```

What uses/decl are OK in this Java code?

Exercises

```
void main() {
  int x = 0;
  f1();
  g();
  f2();
}

void f1() {
  int x = 10;
  g();
}

void f2() {
  int x = 20;
  f1();
  g();
}

void g() {
  print(x);
}
```

x=10
x=0
x=10
x=20

What does this return, assuming dynamic scoping?

Variable shadowing

- Do we allow names to be reused in nesting relations?
- What about when the kinds are different?

```
void smoothJazz(int a){
   int a;
   if (a){
       int a;
       if (a){
           int a;
       }
   }
}
```

```
void hardRock(int a){
    int hardRock;
}
```

Overloading

- Same name different type

```
int techno(int a){
}

bool techno(int a){
}

bool techno(bool a){
}
bool techno(bool a, bool b){
}
```

Forward references

- Use of a name before it is filled out in the symbol table

```
void country(){
    western();
}

void western(){
    country();
}
```

- Requires two passes over the program
  - 1 to fill symbol table, 1 to use it

Example

```
int1 k=10, 2x=20;

void3 foo(int k)4 {
    int5 a = 2x;
    int6 x = 4k;
    int7 b = 6x;
    while (...) {
        int 8x;
        if 8(x ==4 k) {
            int9 k, 10y;
           9k =10y = 8x;
        }
        if 8(x ==4 k) {
            int11 x = 10y;   Error
        }
    }
}
```

Determine which uses correspond to which decl

Example

```
int (1)k=10, (2)x=20;

void (3)foo(int (4)k) {
    int (5)a = x(2);
    int (6)x = k(4);
    int (7)b = x(6);
    while (...) {
       int  (8)x;
       if (x(8) == k(4)) {
          int (9)k, (10)y;
          k(9) = y(10) = x(8);
       }
       if (x(8) == k(4)) {
          int (11)x = y(ERROR);
       }
    }
}
```

Determine which uses correspond to which decl

Name analysis for YES

- Time to make some decisions
  - What scoping rules will we allow?
  - What info does a YES compiler need in its symbol table?
  - Relevant for P4

YES: A statically scoped language

- YES is designed for ease of symbol table use
  - global scope + nested scopes
  - All declarations are made at the top of a scope
  - Declarations can always be removed from table at end of scope

```
int a;
void fun(){
    int b;
    int c;
    int d;
    b = 0;
    if (b == 0){
        int d;
    }
    c = b;
    d = b + c;
}
```

YES: Nesting

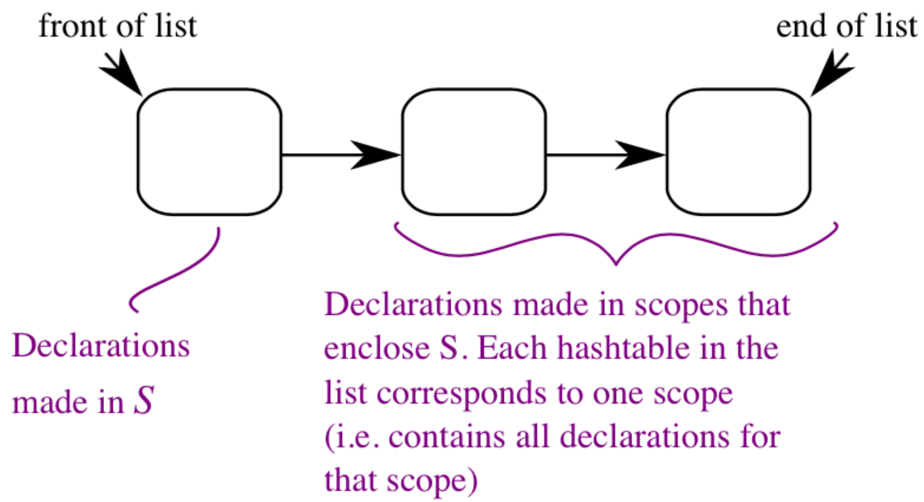
- Like Java or C, we'll use most deeply nested scope to determine binding
  - Shadowing
    - Variable shadowing allowed
    - Struct definition shadowing allowed

```
int a;
void fun(){
    int b;
    b = 0;
    if (b == 0){
        int b;
        b = 1;
    }
    c = b;
}
```

YES: Symbol table implementation

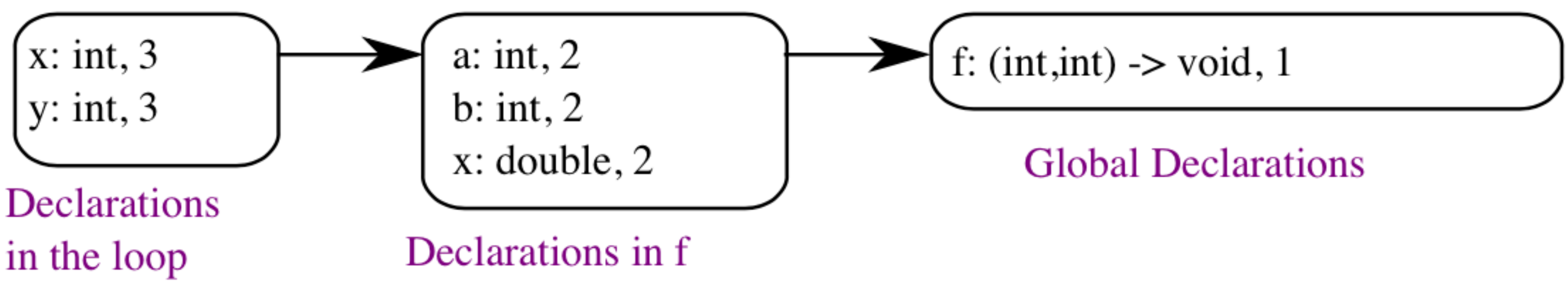
- We want the symbol table to efficiently add an entry when we need it, remove it when we're done with it
- We'll go with a list of hashmaps
  - This makes sense since we expect to remove a lot of names from scope at once

Example




```
void f(int a, int b) {
   double x;
   while (...) {
      int x, y;
      ...
   }

void g() {
   f();
}
```



YES: Symbol kinds

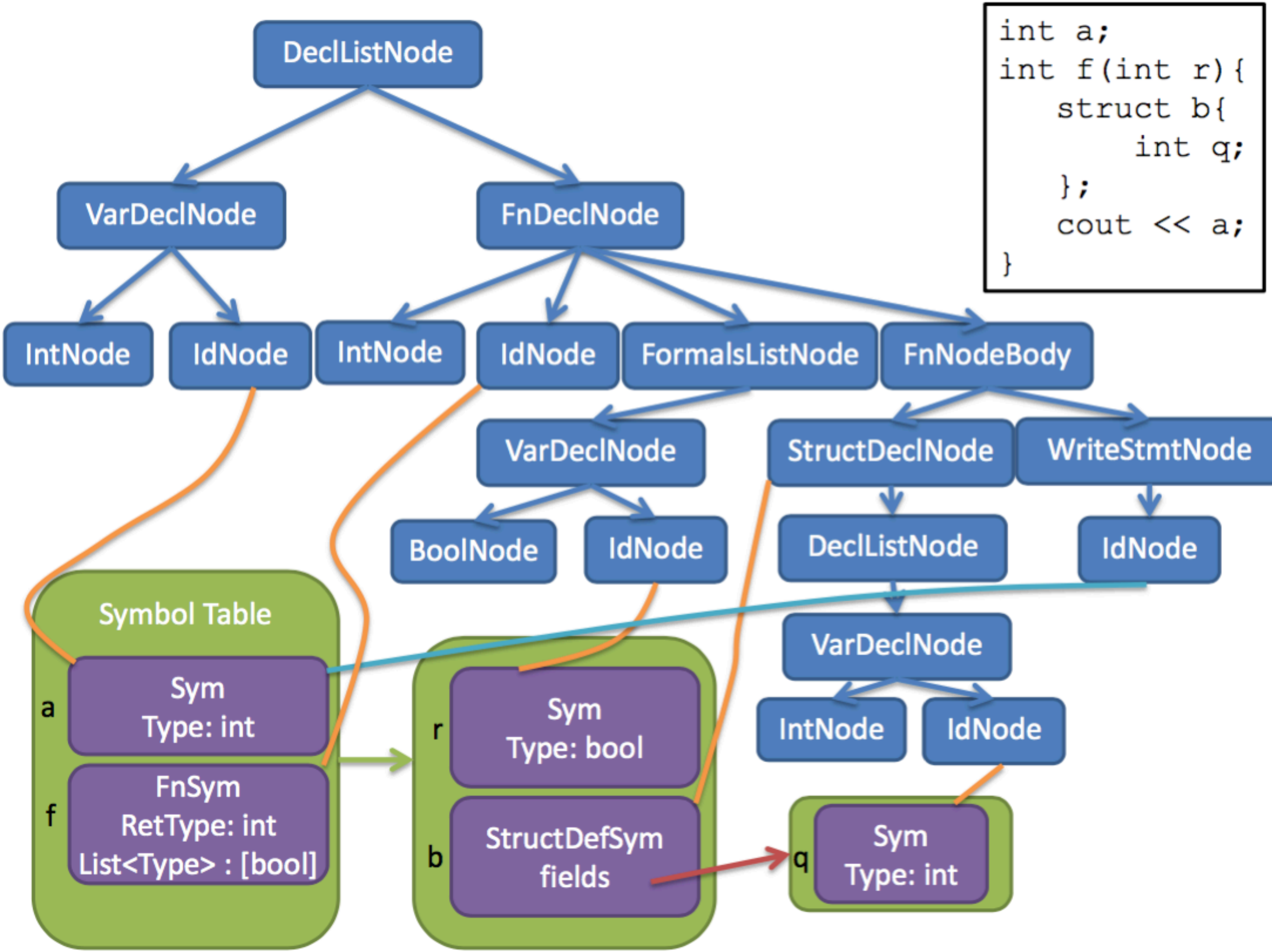
- Identifier types
  - Variables
    - Carries a name, primitive type
  - Function declarations
    - Carries a name, return type, list of param types
  - Struct definitions
    - Carries a name, list of fields (types with names), size

YES: Sym class implementation

- There are many ways to implement your symbols
- Here’s one suggestion
  – Sym class for variable definitions
  – FnSym subclass for function declarations
  – StructDefSym for struct type definitions
    - Contains it’s OWN symbol table for it’s field definitions
  – StructSym for when you want an instance of a struct

Implementing name analysis with an AST

- At this point, we're basically done with the Parse Tree
- Walk the AST, much like the unparse() method
  - Augment AST nodes with a link to the relevant name in the symbol table
  - Build new entries into the symbol table when a declaration is encountered


int a;
int f(int r){
struct b{
int q;
};
cout << a;
}
DeclListNode
VarDeclNode
FnDeclNode
IntNode
IdNode
IntNode
IdNode
FormalsListNode
FnNodeBody
VarDeclNode
StructDeclNode
WriteStmtNode
BoolNode
IdNode
DeclListNode
IdNode
VarDeclNode
IntNode
IdNode
Symbol Table
a
Sym
Type: int
f
FnSym
RetType: int
List<Type> : [bool]
r
Sym
Type: bool
b
StructDefSym
fields
q
Sym
Type: int