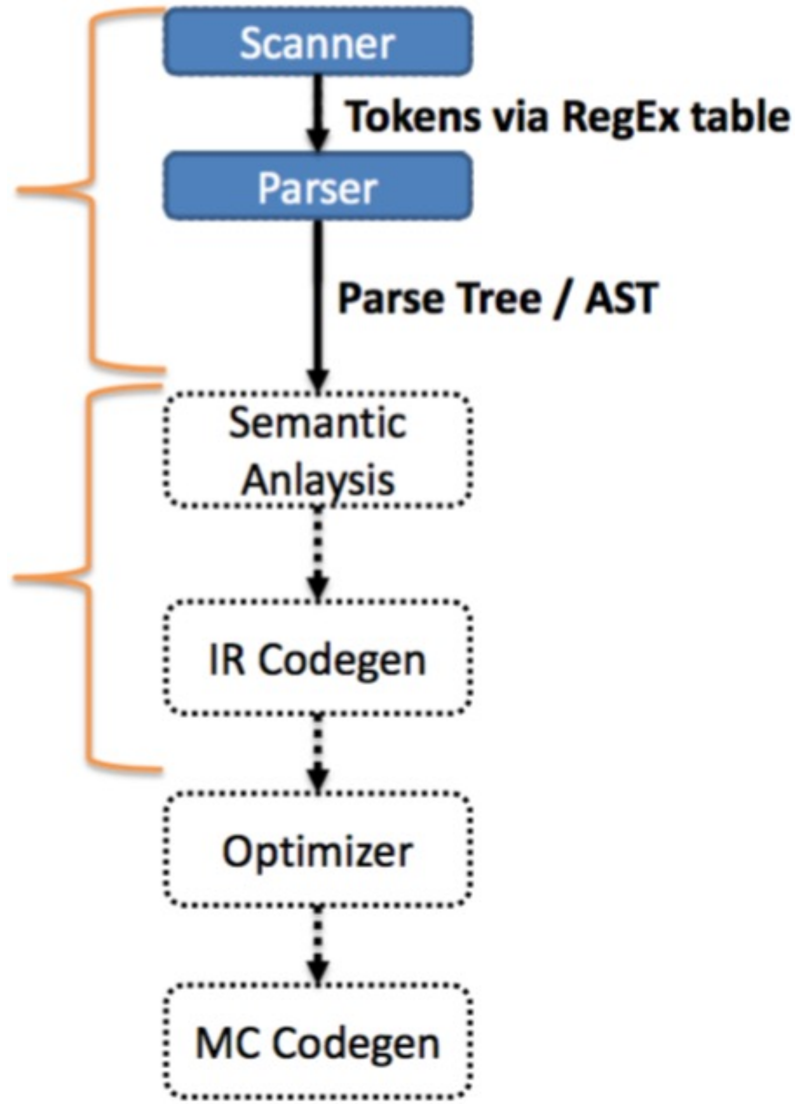
Semantic Analysis with Emphasis on Name Analysis

You'll need this for P4

Where we are at

So far, we've only defined the structure of a program—a.k.a. 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:

- Undeclared variables
- Ill-typed statements

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

Static Semantic Analysis

Two phases

- Name analysis (a.k.a. name resolution)
  - For each scope
    - Process declarations, insert them into the symbol table
    - Process statements, update IdNodes to point to the appropriate symbol-table entry
- Type analysis
  - Process statements
    - Use symbol-table info to determine the type of each expression (and sub-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 entry serves to identify which variable is used
  - Can help in removing dead code (with some further analysis)
  - NOTE: pointers can make these tasks hard

Error checking

Semantic Error Analysis

For non-trivial programming languages, we run into fundamental undecidability problems

- Does the program halt?
- Can the program crash?

Even with simplifying assumptions, sometimes infeasible in practice, as well

- Combinations of thread interleavings
- Inter-procedural dataflow

Catch Obvious Errors

We cannot guarantee the absence of errors …

… but we can at least catch some:

- Undeclared identifiers
- Multiply declared identifiers
- Ill-typed terms

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

(Structured) dictionary that binds a name to information that we need

What information do you think we need?

- Kind (struct, variable, function, class)
- Type (int, int × string → bool, struct)
- Nesting level
- Runtime location (where it is stored in memory)

Symbol-Table Operations

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

When do you think we use these operations?

Scope: The Lifetime of a Name

Block of code in which a name is visible/valid

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

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

No scope

- Assembly / FORTRAN

Static / most-nested scope

- Should be familiar – C / Java / C++

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++) {
         int attack;
     }
  }

  int attack(int x) {
     for (int attack=0; attack<10; attack++) {
        int animal;
     }
  }

  void animal() { }

  // fields
  double attack;
  int attack;
  int animal;
}
```

What uses and declarations 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);
}
```

What does this print, 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 added to symbol table

How do we implement it?

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

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

Requires two passes over the program

– 1 to fill symbol table, 1 to use it

Example

```
int k=10, x=20;

void foo(int k) {
    int a = x;
    int x = k;
    int b = x;
    while (...) {
       int x;
        if (x == k) {
           int k, y;
           k = y = x;
        }
        if (x == k) {
           int x = y;
        }
    }
}
```

Determine which uses correspond to which declarations

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 declarations

Name Analysis for b

Time to make some decisions

- What scoping rules will we allow?
- What info does a b compiler need in its symbol table?
- Relevant for P4

b: A Statically Scoped Language

b 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;
}
```

b: Nesting

Like Java or C, we'll use most deeply nested scope to determine binding

- Shadowing
  - Variable shadowing allowed

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

b: Symbol-Table Implementation

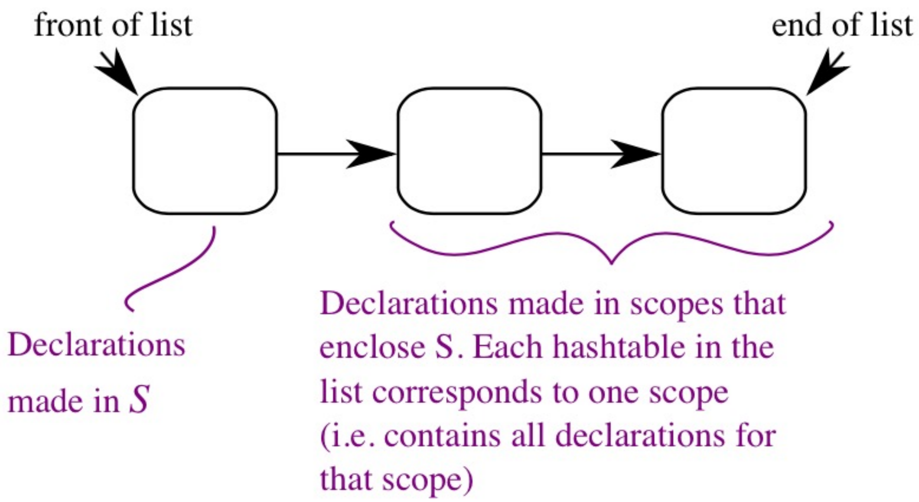
We want a symbol-table implementation for which we can

- add an entry efficiently when we need to
- remove an entry when we are done with it

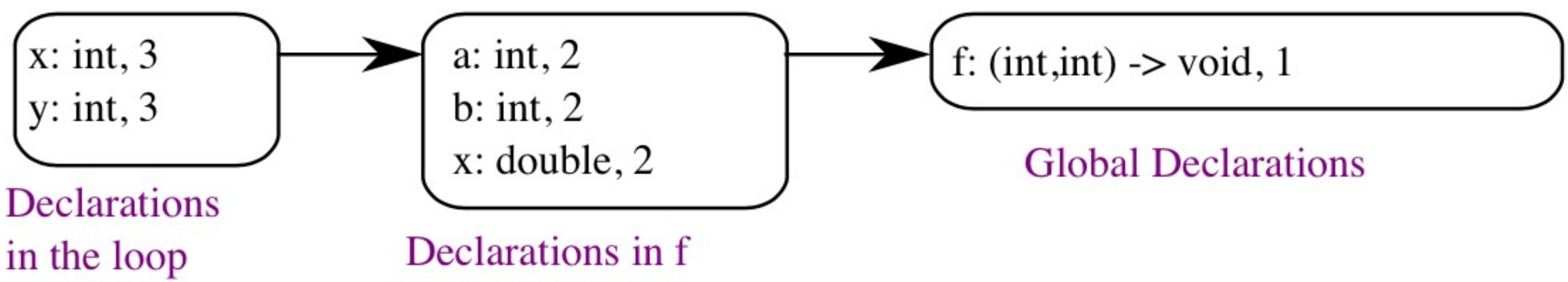
We will use a list of hashmaps

- sensible because we expect to remove a lot of names from a scope at once
- you did most of this in P1

Example




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



b: Symbol Kinds

Symbol kinds (= types of identifiers)

- Variable
  - Carries a name, primitive type
- Function declaration
  - Carries a name, return type, list of parameter types
- Struct definition
  - Carries a name, list of fields (types with names), size

b: Implementation of Class Sym

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 its field definitions
- StructSym for when you want an instance of a struct

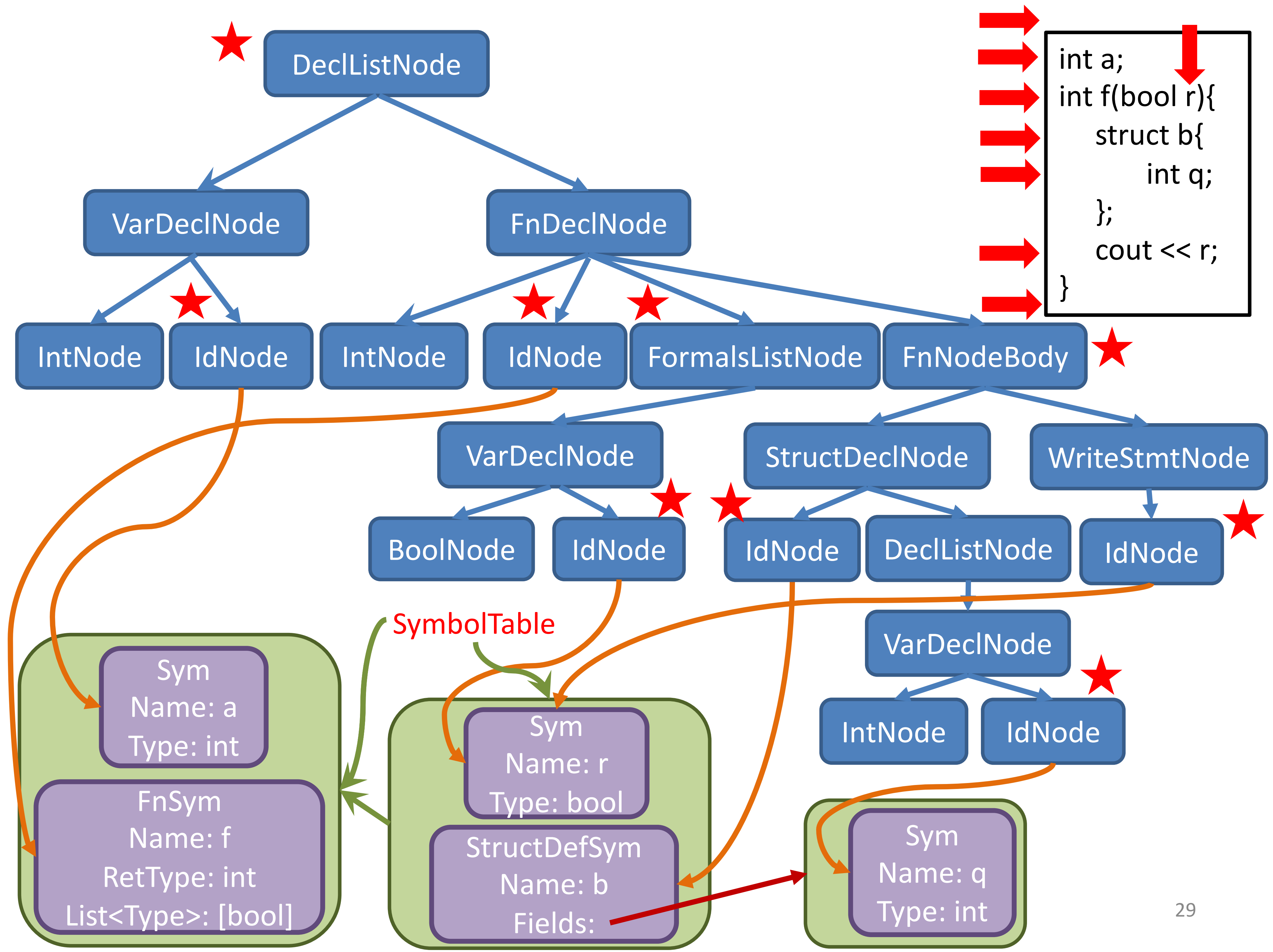
Implementing Name Analysis with an AST

At this point, we are done with the parse tree (which never existed to begin with ☺)

- All subsequent processing done on the <u>AST + symbol table</u>

Walk the AST, much like the unparse() method

- Augment AST nodes where names are used (both declarations and uses) with a link to the relevant object in the symbol table
- Put new entries into the symbol table when a declaration is encountered


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