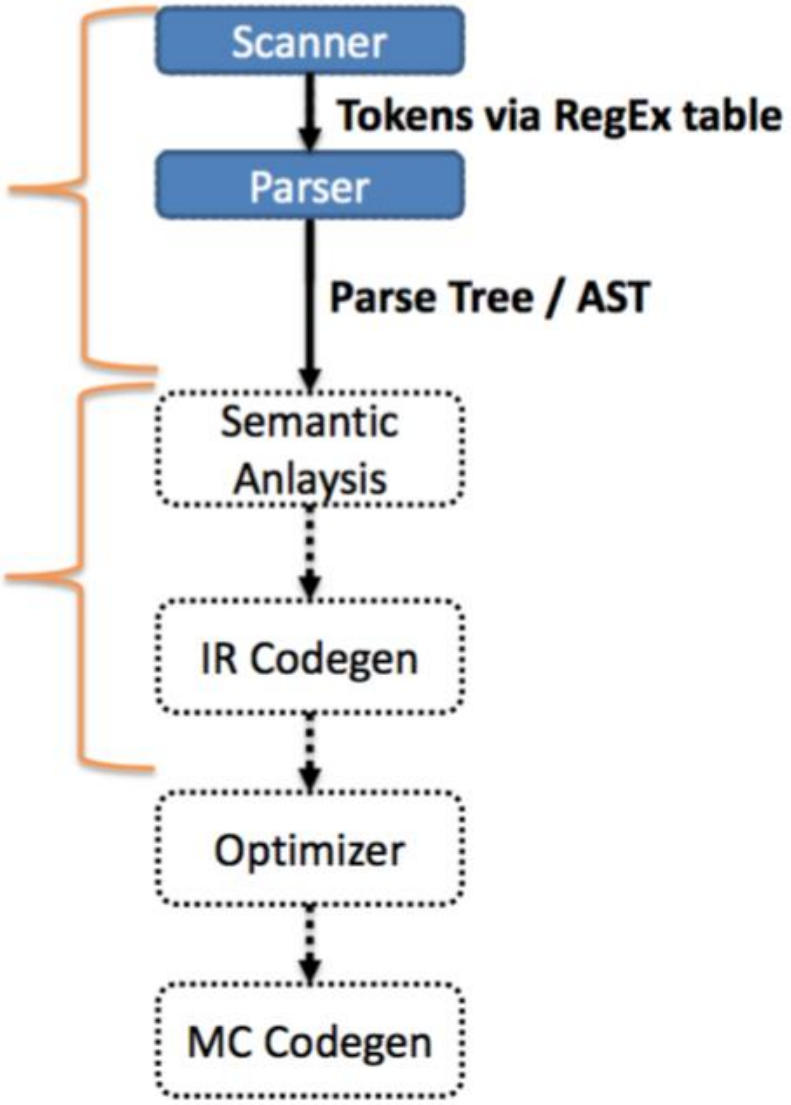
Introduction to Compiler Design

Lesson 11:

Semantic Analysis – Name Analysis

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:
  - `void var;`
  - 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)
    - Can weaken the type (e.g., bool → int)
    - 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++

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);
}
```

Example

```
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?

Example

```
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 and 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 C--

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

C--, a Statically Scoped Language

- C-- 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;
}
```

C-- 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;
}
```

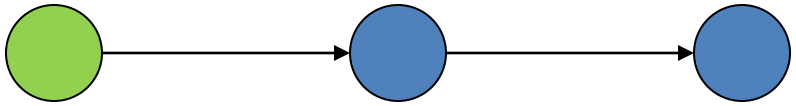
C-- Symbol Table Implementation

- 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 hash tables
  - sensible because we expect to remove a lot of names from a scope at once

C-- Symbol Table

- Entries in Table
  - Symbol Name
  - Type
  - Nesting Level of declaration

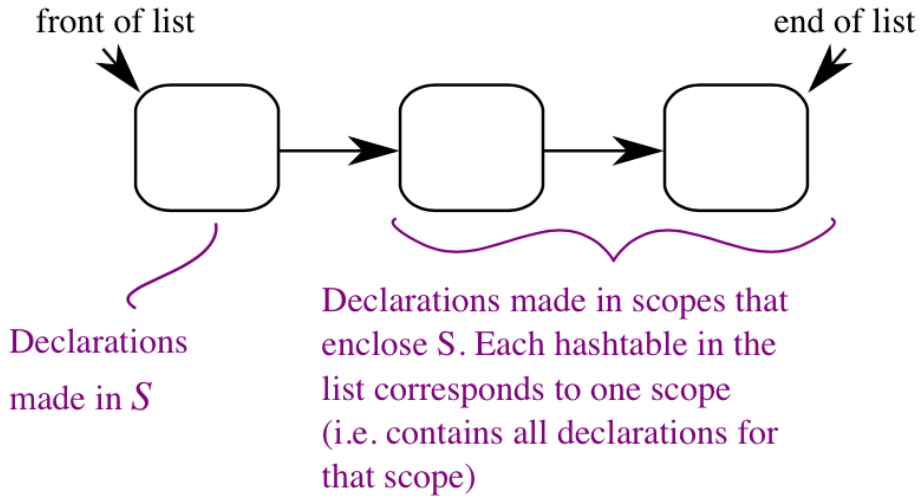
- Use List of Hashtables



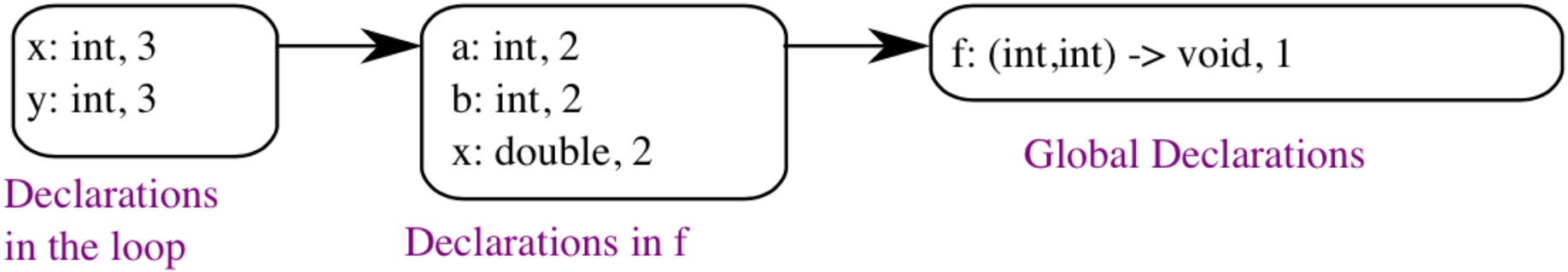
Declarations in S

Declarations made in scopes that enclose S

Example




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



C-- Symbol Kinds

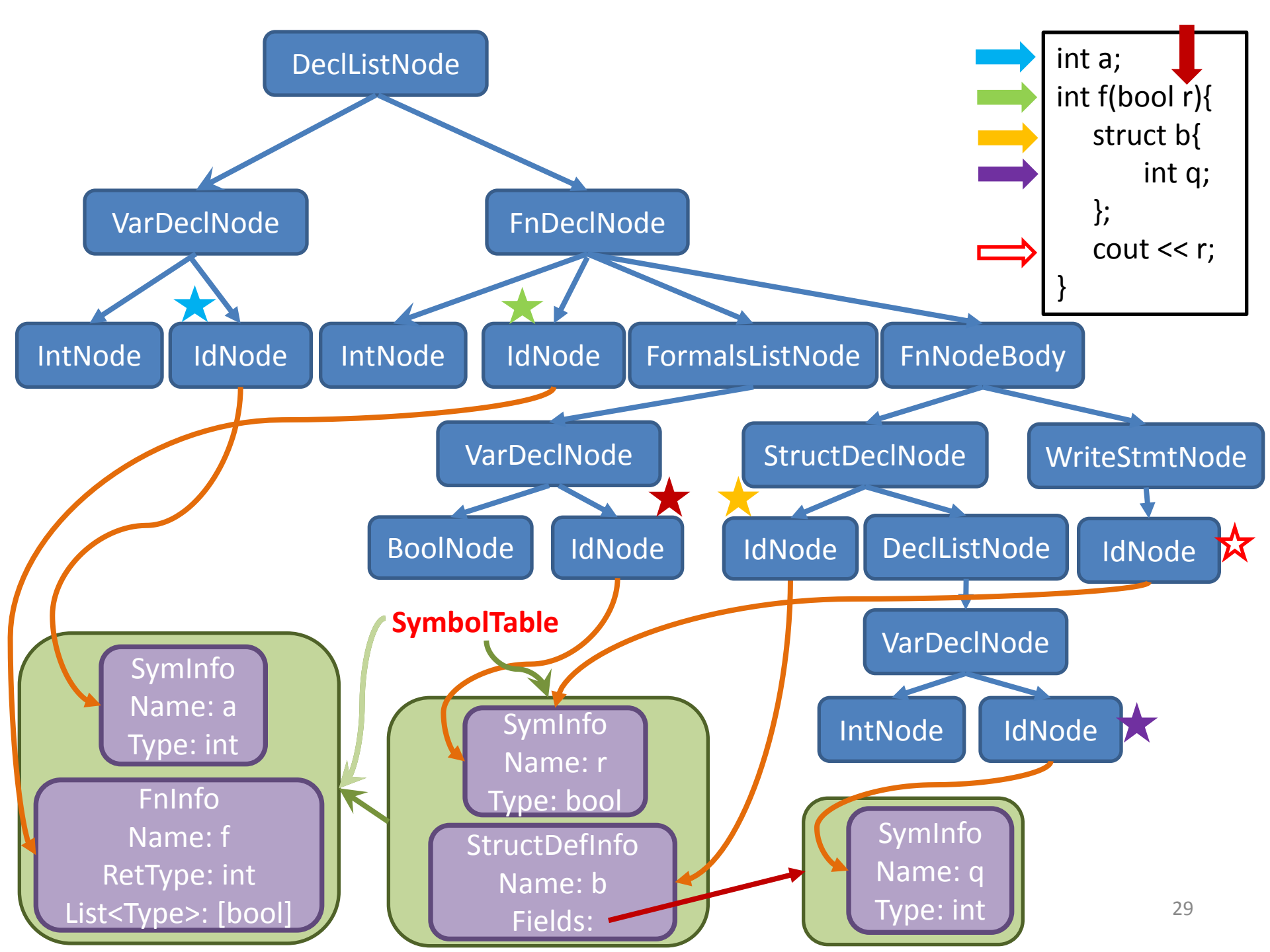
- Symbol kinds (= types of identifiers)
  - Variable
    - Carries a name, primitive type
  - Function declaration
    - Carries a name, return type, list of parameter types
  - Struct definition
    - Carries a name, list of fields (types with names), size

C-- Implementation of Class `SymInfo`

- There are many ways to implement your symbols
- Here's one way
  - `SymInfo` class for variable definitions
  - `FnInfo` subclass for function declarations
  - `StructDefInfo` for **struct** type definitions
    - Contains it's OWN symbol table for its field definitions
  - `StructInfo` 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
  - All subsequent processing will be done on the AST + symbol table
- Walk the AST
  - 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


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