Semantic Analysis
with Emphasis on Name Analysis

You’ll need this for P4
We’ll get back to Parsing next week
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++
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

```java
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);
}
```
What uses and declarations are OK in this Java code?
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);
}
Variable Shadowing

Do we allow names to be reused in nesting relations?

What about when the kinds are different?

```c
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

```c
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?

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

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

Requires two passes over the program

– 1 to fill symbol table, 1 to use it
Example

```c
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;  // Determine which uses correspond to which declarations
        }
        if (x == k) {
            int x = y;
        }
    }
}
```
Example

```c
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 moo

Time to make some decisions

– What scoping rules will we allow?
– What info does a moo compiler need in its symbol table?
– Relevant for P4
moo: A Statically Scoped Language

moo 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

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

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

- Shadowing
  - Variable shadowing allowed
  - Struct-definition shadowing allowed

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

x: int, 3
y: int, 3
Declarations in the loop

a: int, 2
b: int, 2
Declarations in f

f: (int,int) -> void, 1
Global Declarations
moo: 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
moo: 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 AST + symbol table

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;
}