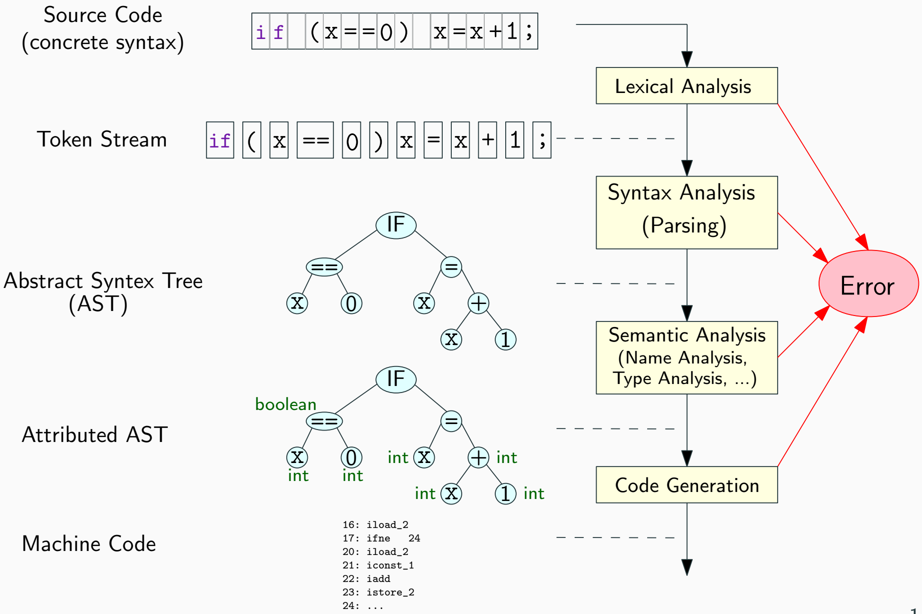
CSCI 742 - Compiler Construction

Lecture 19
Introduction to Name Analysis
Instructor: Hossein Hojjat

February 28, 2018

Compiler Phases



Parser

- Task of a parser:
  find a derivation of a string in a context-free grammar
- CYK recognizes languages defined by context-free grammars
  - Standard version operates only on Chomsky Normal Form (CNF)
  - cubic time $O(n^3)$
- Restricted forms of CFG can be parsed in linear time:
  - LL (left to right, left-most derivation)
  - LR (left to right, reverse right-most derivation)
- Simple top-down parser: LL(1)
  - Basic recursive-descent implementation
- More powerful parser: LR(1), bottom-up
- An efficiency hack on top of LR(1): LALR(1)

What to expect next?

- Is “x” an array, integer or a function? Is it declared?
- Is the expression “x + z” type-consistent?
- In “x[i]”, is “x” an array? Does it have the correct number of dimensions?
- Where can “x” be stored? (register, local, global, heap, static)
- How many arguments does “f()” take? What about “printf ()” ?

Error detection at different phases

- File input: file does not exist
- Lexer: unknown token, string not closed before end of file, ...
- Parser: syntax error - unexpected token, cannot parse given input string, ...
- Name analyzer: unknown identifier, ...
- Type analyzer: applying function to arguments of wrong type, ...
- Data-flow analyzer: division by zero, loop runs forever, ...

Error detection at different phases

- File input: file does not exist
- Lexer: unknown token, string not closed before end of file, ...
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- **Name analyzer: unknown identifier, ...**
- Type analyzer: applying function to arguments of wrong type, ...
- Data-flow analyzer: division by zero, loop runs forever, ...

Problems detected by Name Analysis

- a class is defined more than once:

  ```
  class A {...} class B {...} class A {...}
  ```

- a variable is defined more than once:

  ```
  int x; int y; int x;
  ```

- a field member is overridden (forbidden in eMiniJava)

  ```
  class A {int x; ...}
  class B extends A {int x; ...}
  ```

- a method is overloaded (forbidden in eMiniJava)

  ```
  class A { void f(B x) {} void f(C x) {} ... }
  ```

- a method argument is shadowed by a local variable declaration (forbidden in Java)

  ```
  void f (int x) { int x; ...}
  ```

- two method arguments have the same name (forbidden in many languages)

  ```
  void f (int x, int y, int x) { ... }
  ```

Problems detected by Name Analysis

- a class name is used as a symbol (as parent class or type, for instance) but is not declared:

  ```
  class A extends Undeclared {}
  ```

- an identifier is used as a variable but is not declared:

  ```
  int inc (int x, int amount)
    {return x + ammount; }
  ```

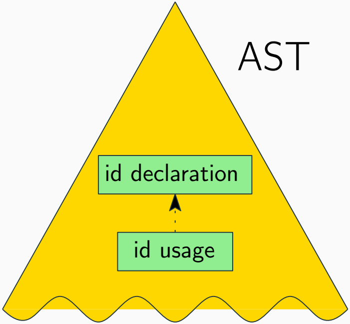
- the inheritance graph has a cycle:

  ```
  class A extends B {}
  class B extends C {}
  class C extends A
  ```

Identifier Definition

- **Property:** "Each identifier needs to be declared before usage"
- To check such a property we need "context" information:
  the environment where a command executes in
- In theory we can use context-sensitive grammars to specify this
- In practice we use context-free grammars to specify valid syntax and identify invalid programs using other mechanisms
  - Those mechanisms enforce language properties that cannot be expressed with a CFG
- In order to check the property, we need to find the declaration of each usage of an identifier

Identifier Definition




```
bool b;
  ⋮
if (b) x = x + 1;
```

- **Name Analysis:** making sense of trees; converting them into graphs: connect identifier uses and declarations

Identifier Mapping

- To make name analysis efficient and clean,
  we associate mapping from each identifier to the symbol that the identifier represents
- We use Map data structures to maintain this mapping
- The rules that specify how declarations are used to construct such maps are given by "scoping" rules of the programming language

Showing Good Errors with Syntax Trees

- Suppose we have undeclared variable "`x`" in a program of 100K lines
- Which error message would you prefer to see from the compiler?

- An occurrence of variable "`x`" not declared (which variable? where?)
- An occurrence of variable "`x`" in procedure `P` not declared
- Variable "`x`" undeclared at line 612, column 21
  (and IDE points you there) ✓

Showing Good Errors with Syntax Trees

- How to emit those good error messages if we only have a syntax trees?
- Abstract syntax tree nodes store positions within file
- For identifier nodes: allows reporting variable uses
- Variable "x" in line 612, column 21 undeclared
- For other nodes, supports useful for type errors, e.g. could report for `(x + y) * (!b)`
  - Type error in line 13,
  - expression in line 13, column 11-14, has type `bool`, expected `int` instead

Showing Good Errors with Syntax Trees

Constructing trees with positions:

- Lexer records positions for tokens
- Each subtree in AST corresponds to some parse tree,
  so it has first and last token
- Get positions from those tokens
- Save these positions in the constructed tree

It is important to save information for leaves

- Information for other nodes can often be approximated using information in the leaves

Scopes

- **Scope:** The region where an identifier is visible is referred to as the scope of the identifier
- Here identifier refers to function or variable name
- It is only legal to refer to the identifier within its scope
- **Static** property: compiler decides the issue at compile time
- **Dynamic** property: an issue that requires a decision at run-time
- We will study static and dynamic scoping

Scopes

```
class Example {
  boolean x;
  int y;
  int z;
  int compute(int y, int z) {
    int x = 3;
    return   x + y + z;
  }
  public void main() {
    int res;
    x = true;
    int y = 10;
    z = 5;
    res = compute(z-1, z+1);
    System.out.println(res);
  }
}
```

- Draw an arrow from occurrence of each identifier to the point of its declaration

Scopes

```
class Example {
  boolean x;
  int y;
  int z;
  int compute(int y, int z) {
    int x = 3;
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    System.out.println(res);
  }
}
```

- Draw an arrow from occurrence of each identifier to the point of its declaration
- Name analysis:
  Computes those arrows

Name Analysis Implementation

- For each declaration of identifier, identify where the identifier refers to
- Name analysis:
  - maps, partial functions (math)
  - environments (PL theory)
  - symbol table (implementation)
- Report some simple semantic errors
- We usually introduce symbols for things denoted by identifiers
- Symbol tables map identifiers to symbols

Static Scoping

```
class World {
  int sum;
  int value;
  void add() {
    sum = sum + value;
    value = 0;
  }
  void main() {
    sum = 0;
    value = 10;
    add();
    if (sum % 3 == 1) {
      int value;
      value = 1;
      add();
      println("inner value = " + value);
      println("sum = " + sum);
    }
    println("outer value = " + value);
  }
}
```

- Static Scoping:
  Identifier refers to the symbol that was declared "closest" to the place in program structure (thus "static")
- We will assume static scoping unless otherwise specified

Static Scoping

```
class World {
  int sum;
  int value;
  void add() {
    sum = sum + value;
    value = 0;
  }
  void main() {
    sum = 0;
    value = 10;
    add();
    if (sum % 3 == 1) {
      int value;
      value = 1;
      add();
      println("inner value = " + value);  1
      println("sum = " + sum);  10
    }
    println("outer value = " + value);  0
  }
}
```

- Static Scoping:
  Identifier refers to the symbol that was declared "closest" to the place in program structure (thus "static")
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Static Scoping

```
class World {
  int sum;
  int value;
  void add() {
    sum = sum + value;
    value = 0;
  }
  void main() {
    sum = 0;
    value = 10;
    add();
    if (sum % 3 == 1) {
      int value1;
      value1 = 1;
      add(); // cannot change value1
      println("inner value = " + value1);  1
      println("sum = " + sum);  10
    }
    println("outer value = " + value);  0
  }
}
```

- Static Scoping:
  Identifier refers to the symbol that was declared “closest” to the place in program structure (thus “static”)
- We will assume static scoping unless otherwise specified
- Property of static scoping: Given the entire program, we can rename variables to avoid any shadowing (make all vars unique)

Dynamic Scoping

```
class World {
  int sum;
  int value;
  void add() {
    sum = sum + value;
    value = 0;
  }
  void main() {
    sum = 0;
    value = 10;
    add();
    if (sum % 3 == 1) {
      int value;
      value = 1;
      add();
      println("inner value = " + value); 0
      println("sum = " + sum); 11
    }
    println("outer value = " + value); 0
  }
}
```

- Symbol refers to the variable that was most recently declared within program execution
- Views variable declarations as executable statements that establish which symbol is considered to be the "current one"
  - Used in old LISP interpreters
- Translation to normal code: access through a dynamic environment

Dynamic vs. Static Scoping

- Dynamic Scoping Implementation:
  - Each time a function is called its local variables are pushed on a stack
  - When a reference to a variable is made, the stack is searched top-down for the variable name
- Static scoping is almost universally accepted in modern programming language design
- It is usually easier to reason about and easier to compile
- Static scoping makes reasoning about modular codes easier: binding structure can be understood in isolation

Exercise

Determine the output of the following program assuming static and dynamic scoping. Explain the difference, if there is any.

```
class MyClass{
  int x = 5;
  public int foo(int z) {
    return x + z;
  }
  public int bar(int y) {
    int x = 1;
    int z = 2;
    return foo(y);
  }
  public void main(){
    int x = 7;
    println(foo(bar(3)));
  }
}
```