CMSC 330: Organization of Programming Languages

Type Systems,
Names & Binding

Topics Covered Thus Far

- Programming languages
  - Ruby
  - OCaml
- Syntax specification
  - Regular expressions
  - Context free grammars
- Implementation
  - Finite automata (scanners)
  - Recursive descent parsers

Language Features Covered Thus Far

- Ruby
  - Implicit declarations { x = 1 }
  - Dynamic typing { x = 1 ; x = “foo” }
- OCaml
  - Functional programming add 1 (add 2 3)
  - Type inference let x = x+1 (x : int)
  - Higher-order functions let rec x = fun y -> x y
  - Static (lexical) scoping let x = let x = …
  - Parametric polymorphism let x y = y (‘a -> ‘a)
  - Modules module foo struct … end

Programming Languages Revisited

- Characteristics
  - Artificial language for precisely describing algorithms
  - Used to control behavior of machine / computer
  - Defined by its syntax & semantics
- Syntax
  - Combination of meaningful text symbols
    - Examples: if, while, let, =, ==, &&, +
- Semantics
  - Meaning associated with syntactic construct
    - Examples: x = 1 vs. x == 1

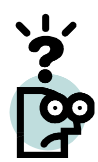
Comparing Programming Languages

- Syntax
  - Differences usually superficial
    - C / Java　　if (x == 1) { … } else { … }
    - Ruby　　if x == 1 … else … end
    - OCaml　　if (x = 1) then … else …
  - Can cope with differences easily with experience
    - Though may be annoying initially
  - You should be able to learn new syntax quickly
    - Just keep language manual / examples handy

Comparing Prog. Languages (cont.)

- Semantics
  - Differences may be major / minor / subtle

	Physical Equality	Structural Equality
Java	a == b	a.equals(b)
C	a == b	*a == *b
Ruby	a.equal?(b)	a == b
OCaml	a == b	a = b



  - Explaining these differences a major goal for 330
  - Will be covering different features in upcoming lectures

Programming Language Features

- Paradigm
  - Imperative
  - Object oriented
  - Functional
  - Logical
- Higher-order functions
  - Closures
- Declarations
  - Explicit
  - Implicit
- Type system
  - Typed vs. untyped
  - Static vs. dynamic
  - Weak vs. strong (type safe)

Programming Language Features (cont.)

- Names & binding
  - Namespaces
  - Static (lexical) scopes
  - Dynamic scopes
- Parameter passing
  - Call by value
  - Call by reference
  - Call by name
    - Eager vs. lazy evaluation
- Polymorphism
  - Ad-hoc
    - Subtype
    - Overloading
  - Parametric
    - Generics
- Parallelism
  - Multithreading
  - Message passing

Explicit vs. Implicit Declarations

- Explicit declarations
  - Variables must be declared before used
  - Examples
    - C, C++, Java, OCaml
- Implicit declarations
  - Variables do not need to be declared
  - Examples
    - Ruby

Type System Overview

- Typed vs. untyped
- Static vs. dynamic
- Type safety
  - Weak (not type safe) vs. strong (type safe)

Type vs. Untyped Languages

- Typed language
  - Operations are only valid for specified types
    - 2 * 3 = 6
    - “foo” * “bar” = undefined
  - Helps catch program errors
    - Either at compile or run time
- Untyped language
  - All operations are valid for all values
  - Treat all values as sequences of 0’s and 1’s
  - Example
    - Assembly languages, FORTH

Static vs. Dynamic Types

- Static types
  - Before program is run
    - Type of all expressions are determined
      - Usually by compiler
    - Disallowed operations cause compile-time error
- Static types may be manifest or inferred
  - Manifest – specified in text (at variable declaration)
    - C, C++, Java, C#
  - Inferred – compiler determines type based on usage
    - ML, OCaml

Static vs. Dynamic Types (cont.)

- Dynamic types
  - While program is running
    - Type of all expressions determined
      - Values maintain tag indicating type
    - Disallowed operations cause run-time exception
- Dynamic types are not manifest (obviously)
  - Examples
    - Ruby, Python, Javascript, Lisp

Type Safety

- Determined by extent programming language allows type errors
- Language should only allow operations on values that are permitted by their type
  - Non-type safe code example
    - printf("%d", 3.12)   // Allows float to be printed as int
- Definitions
  - Type safe language → strong type system
  - Non-type safe language → weak type system

Weak vs. Strong Typing

- Weak typing
  - Allows one type to be treated as another or provides (many) implicit casts
  - Example (int treated as bool)
    - C
      ```
      int i = 1 ;
      if (i)                  // checks for 0
         printf("%d", i);
      ```
    - Ruby
      ```
      i = 1
      if i                    // checks for nil
         puts i
      end;
      ```
  - Example languages
    - C, C++, Ruby, Perl, Javascript

Weak vs. Strong Typing (cont.)

- Strong typing
  - Prevents one type from being treated as another (also known as type safe)
  - Example (int not treated as bool)
    - Java
      ```
      int i = 1 ;
      if (i)                  // error, not bool
         System.out.println(i);
      ```
    - OCaml
      ```
      let i = 1 in
         if i then            // error, not bool
            print_int i
      ```
  - Example languages
    - Java (rare exceptions), OCaml

Weak/Strong vs. Static/Dynamic Types

- How do these properties interact?
  - Weak/strong & static/dynamic are orthogonal
  - Some literature confuse strong & static type
- Strong / static types
  - More work for programmer
  - Catches more errors at compile time
- Weak / dynamic types
  - Less work for programmer
  - More errors occur at run time

Names & Binding Overview

- Order of bindings
- Namespaces
- Static (lexical) scopes
- Dynamic scopes

Names and Binding

- Programs use names to refer to things
  - E.g., in x = x + 1, x refers to a variable
- A binding is an association between a name and what it refers to
  - int x; /* x is bound to a stack location containing an int */
  - int f (int) { ... } /* f is bound to a function */
  - class C { ... } /* C is bound to a class */
  - let x = e1 in e2 (* x is bound to e1 *)

Name Restrictions

- Languages often have various restrictions on names to make scanning and parsing easier
  - Names cannot be the same as keywords in the language
  - OCaml function names must be lowercase
  - OCaml type constructor and module names must be uppercase
  - Names cannot include special characters like ; , : etc
    - Usually names are upper- and lowercase letters, digits, and _ (where the first character can't be a digit)
    - Some languages also allow more symbols like ! or -

Names and Scopes

- Good names are a precious commodity
  - They help document your code
  - They make it easy to remember what names correspond to what entities
- We want to be able to reuse names in different, non-overlapping regions of the code

Names and Scopes (cont.)

- A scope is the region of a program where a binding is active
  - The same name in a different scope can refer to a different binding (refer to a different program object)
- A name is in scope if it's bound to something within the particular scope we're referring to

Example

```
void w(int i) {
  ...
}

void x(float j) {
  ...
}

void y(float i) {
  ...
}

void z(void) {
   int j;
   char *i;
   ...
}
```

- i is in scope
  - in the body of w, the body of y, and after the declaration of j in z
  - but all those i's are different
- j is in scope
  - in the body of x and z

Ordering of Bindings

- Languages make various choices for when declarations of things are in scope

Order of Bindings – OCaml

- let x = e1 in e2 – x is bound to e1 in scope of e2
- let rec x = e1 in e2 – x is bound in e1 and in e2

```
let x = 3 in
  let y = x + 3 in...    (* x is in scope here *)
```

```
let x = 3 + x in ...     (* error, x not in scope *)
```

```
let rec length = function
      [] -> 0
   | (h::t) -> 1 + (length t)   (* ok, length in scope *)
in ...
```


Order of Bindings – C

- All declarations are in scope from the declaration onward

```
int i;
int j = i;   /* ok, i is in scope */
i = 3;       /* also ok */
```

```
void f(...) { ... }

int i;
int j = j + 3;    /* error */
f(...);           /* ok, f declared */
```

```
f(...);  /* may be error; need prototype (or oldstyle C) */

void f(...) { ... }
```

Order of Bindings – Java

- Declarations are in scope from the declaration onward, except for methods and fields, which are in scope throughout the class

```
class C {
  void f(){
    ...g()...    // OK
  }

  void g(){
    ...
  }
}
```


Shadowing Names

- Shadowing is rebinding a name in an inner scope to have a different meaning
  - May or may not be allowed by the language

C

```
int i;

void f(float i) {

  {
    char *i = NULL;
    ...
  }

}
```

OCaml

```
let g = 3;;
let g x = x + 3;;
```

Java

```
void h(int i) {
  {
    float i; // not allowed
    ...
  }
}
```

Namespaces

- Languages have a "top-level" or outermost scope
  - Many things go in this scope; hard to control collisions
- Common solution seems to be to add a hierarchy
  - OCaml: Modules
    - List.hd, String.length, etc.
    - open to add names into current scope
  - Java: Packages
    - java.lang.String, java.awt.Point, etc.
    - import to add names into current scope
  - C++: Namespaces
    - namespace f { class g { ... } }, f::g b, etc.
    - using namespace to add names to current scope

Static Scope Recall

- In static scoping, a name refers to its closest binding, going from inner to outer scope in the program text
  - Languages like C, C++, Java, Ruby, and OCaml are statically scoped

```
int i;

{
  int j;

  {
    float i;

    j = (int) i;
  }
}
```

Free and Bound Variables

- The bound variables of a scope are those names that are declared in it
- If a variable is not bound in a scope, it is free
  - The bindings of variables which are free in a scope are inherited from declarations of those variables in outer scopes in static scoping

j is bound in scope 1

j is free in scope 2

```
{ /* 1 */
  int j;

  { /* 2 */
    float i;

    j = (int) i;
  }
}
```

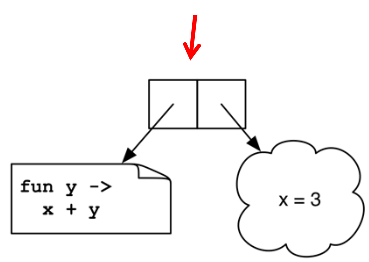
i is bound in scope 2

Static Scoping and Nested Functions

- Closures needed when
  - Nested function declarations
  - Static scoping
  - Returning a function from function call (upwards funargs)

```
let add x = (fun y -> x + y)
```

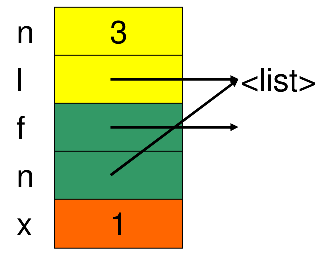
`(add 3) 4 → <closure> 4 → 3 + 4 → 7`



Dynamic Scope

- In a language with dynamic scoping, a name refers to its closest binding at runtime

```
let map (f, n) = match n with
  [] -> []
| (h::t) -> (f h)::(map (f, t))
let addN (n, l) =
  let add x = n + x in
  map (add, l)
addN (3, [1; 2; 3])
```



- Value of n in add
  - Dynamic scope: reads it off the stack (n = <list>)
  - Static scope: lexical binding (n = param n to addN)

Static vs. Dynamic Scope

Static scoping

- Local understanding of function behavior
- Know at compile-time what each name refers to
- A little more work to implement (keep a link to the lexical nesting scope in stack frame)

Dynamic scoping

- Can be hard to understand behavior of functions
- Requires finding name bindings at runtime
- Easier to implement (keep a global table of stacks of variable/value bindings)