EECS 490 – Lecture 6

Functions and Introduction to Scheme

Announcements

- Project 1 due **today** at 8pm
- Homework 2 due Friday 9/29 at 8pm
- Project 2 due Friday 10/6 at 8pm

() (3) (x 3) #(. . .) (3 . 4)

Scheme Syntax

(y (3 4))

- From R5RS spec:

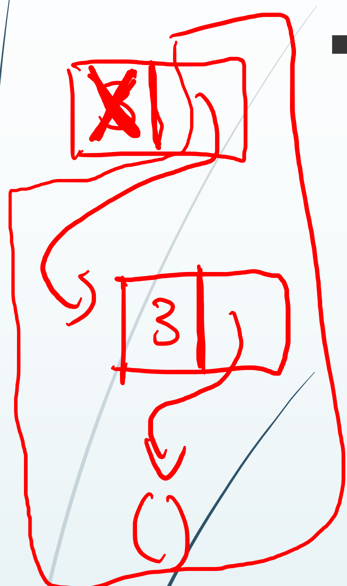
  ⟨datum⟩ → ⟨simple datum⟩ | ⟨compound datum⟩

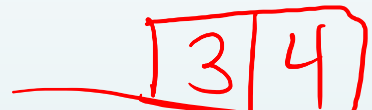
  ⟨compound datum⟩ → ⟨list⟩ | ⟨vector⟩

  ⟨list⟩ → (⟨datum⟩*) | (⟨datum⟩+ . ⟨datum⟩) | ⟨abbreviation⟩

  ⟨abbreviation⟩ → ⟨abbrev prefix⟩ ⟨datum⟩

  ⟨abbrev prefix⟩ → ' | ` | , | ,@





(1 2 . 3)

car
cdr

- List can be
  - Zero or more datums in parentheses
  - Parentheses containing one or more datums, a period, and a single datum
  - A quotation character followed by a datum

(1 . 2 3)

(car '(x 3)) → x

(cdr '(x 3)) → (3)

(quote (x 3))
'(x 3)

Scheme Syntax

(define x 3)

- From R5RS spec:

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  ⟨abbrev prefix⟩ → ’ | ‘ | , | ,@

datum

compound datum

list

(datum datum datum)

simple datum simple datum :

define identifier identifier number

x 3

foo(a);

Vexing Parse

- In languages with complex syntax, such as C++, ambiguity cannot be avoided in the grammar
  - External rules are specified to disambiguate fragments

```
struct foo {
  foo() {
    cout << "foo::foo()" << endl;
  }
  foo(int x) {
    cout << "foo::foo(" << x << ")" << endl;
  }
  void operator=(int x) {
    cout << "foo::operator=(" << x << ")" << endl;
  }
};

int a = 3, b = 4;

int main() {
  foo(a);    // equivalent to foo a;
  foo(b) = 3;   // equivalent to foo b = 3;
}
```

C++ disambiguates in favor of declarations

Names can be parenthesized in declarations

```
foo::foo()
foo::foo(3)
```

foo()

void baz(int(x));

Most Vexing Parse

void baz(int);

void baz(int());

- A most vexing example:

```
struct bar {
  bar(foo f) {
    cout << "bar::bar(foo)" << endl;
  }
};

bar c(foo()); // equivalent to bar c(foo);
```

Nothing printed

C++ disambiguates in favor of function declarations

string s();

- Clang warning:

```
foo.cpp:28:8: warning: parentheses were disambiguated as a function
declaration
      [-Wvexing-parse]
  bar c(foo()); // equivalent to bar c(foo);
       ^~~~~~~
foo.cpp:28:9: note: add a pair of parentheses to declare a variable
  bar c(foo()); // equivalent to bar c(foo);
        ^
        (    )
```

bar c = foo();

~~auto c = foo();~~

bar c((foo()));

auto c = bar(foo());

bar

Agenda

- Keyword and Default Arguments
- Variadic Functions
- Parameter Passing
- Introduction to Scheme

Keyword Arguments

- In most languages, names are not specified for arguments when calling a function
  - Arguments are bound to parameters in order

```
void foo(int x, int y);
foo(3, 4);
```

- Some languages allow arguments to be passed to specific parameters, allowing them to be given in a different order and serving as documentation

```
def foo(x, y):
    print(x, y)

>>> foo(y = 3, x = 4)
4 3
```

foo(4 , x=3)

~~foo(y=3 ,4)~~

Arguments in Swift

- Swift and Objective-C require argument names for most arguments, as well as that they are passed in the same order as the parameters

```
func greet(name: String, withGreeting: String) {
  print(withGreeting + " " + name)
}
greet(name: "world", withGreeting: "hello")
```

- Functions can specify separate internal and external names for a parameter

- Argument names used in function-overload resolution

```
func foo(a: Int) { ... }
func foo(b: Int) { ... }
foo(a: 3)
```

Default Arguments

- Some languages allow a function definition or declaration to provide a default argument for a parameter
- Allow a function to be called without an argument value for the parameter

```
void foo(int x, int y = 0);
foo(3);  // equivalent to foo(3, 0)
foo(3, 4);
```

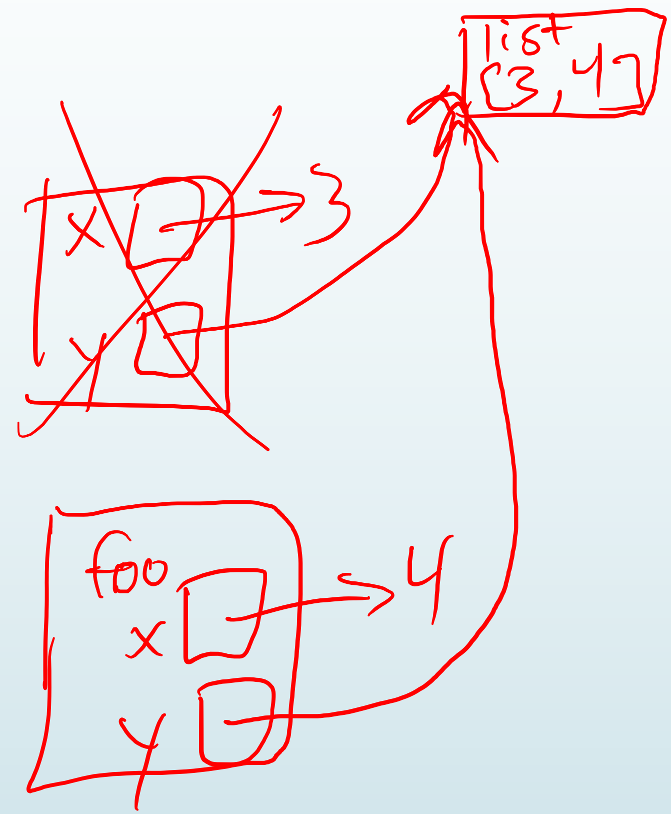
- Parameters with default arguments generally have to be at the end of the parameter list
- Evaluation rules
  - Evaluated in definition environment in most languages
  - Most languages evaluate default argument each time the function is called

Python Default Arguments

- Python differs from most languages in that the default argument is evaluated only once at definition time

```
def foo(x, y = []):
    y.append(x)
    print(y)

>>> foo(3)
[3]
>>> foo(4)
[3, 4]
```



C/C++ Default Arguments

- Default arguments can be provided in any declaration of a function, including its definition
- Multiple visible declarations may not provide a default argument for the same parameter, even if it is the same
- The set of default arguments is the union of all visible declarations in the same scope

```
int foo(int x, int y = 4);
int foo(int x = 3, int y) {
  return x + y;
}
```

- C++ templates also can have default arguments

Overloading as Alternative

- Some languages, such as Java, rely on function overloading to provide the same behavior as default arguments

```
static void foo(int x, int y) {
  System.out.println(x + y);
}

static void foo(int x) {
  foo(x, 0);
}
```

"Default" argument of `0`

Variadic Functions

- Functions that can be called with a variable number of arguments, also referred to as *varargs*
- Arguments often packed into a container such as a tuple or array
- Arguments may be required to be of the same type, or can be of different types
- Example in Java:

String[]

```
static void print_all(String... args) {
  for (String s : args) {
    System.out.println(s);
  }
}

print_all("hello", "world");
```

All Strings, packaged into array

Java also allows an array to be passed into a variadic parameter.

Varargs in Python

- Python allows both variadic simple arguments as well as keyword arguments
- Simple variadic arguments packaged into tuple
- Variadic keyword arguments packaged into `dict`

```
def print_args(*args, **kwargs):
    print(args)
    print(kwargs)

>>> print_args(3, 4, x = 5, y = 6)
(3, 4)
{'x': 5, 'y': 6}
```

Unpacking Sequences and Dictionaries

- Python has operators for unpacking sequences and dictionaries

- Can be used where a value list is required

```
>>> print_args(*[3, 4], **{ 'x': 5, 'y': 6})
(3, 4)
{'x': 5, 'y': 6}
```

3, 4, x=5, y=6

Unpacks sequence

Unpacks dictionary

Varargs in C/C++

- C and C++ provide a varargs mechanism that is low level and can be unsafe

```
#include <stdarg.h>
int sum(int count, ...) {
  va_list args;
  int total = 0;
  int i;
  va_start(args, count);
  for (i = 0; i < count; i++) {
    total += va_arg(args, int);
  }
  va_end(args);
  return total;
}
```

Relies on caller to pass correct count

Relies on caller to pass right types

Enables format string attacks in functions like `printf()`.

Parameter Passing

- Arguments and parameters are a means of communication between a function and its caller
- A parameter may be used only for input, only for output, or for both
- Semantics of parameters determined by *call mode* of function
  - Call by value
  - Call by reference
  - Call by result
  - Call by value-result
  - Call by name

Call by Value

- A parameter represents a new variable in the frame of a function invocation
- Argument value is copied to parameter variable
- Parameter can only be used for input

y $\boxed{3}$

```
void foo(int x) {
  x++;
  cout << x << endl;
}
```

foo

x $\boxed{\cancel{3}}$ 4

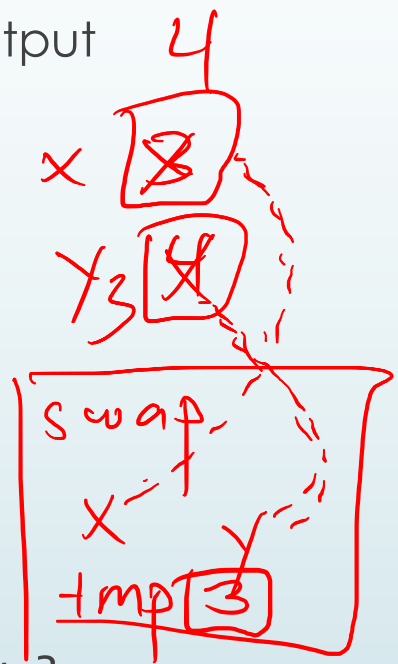
```
int y = 3;
foo(y);                  // prints 4
cout << y << endl;    // prints 3
```

Call by Reference

- Requires l-value as argument[1]
- Parameter name is bound to argument object
- Parameter can be used for input and output
- No separate storage for parameter

```
void swap(int &x, int &y) {
  int tmp = x;
  x = y;
  y = tmp;
}

int x = 3, y = 4;
swap(x, y);        // x now 4, y now 3
```



[1]In C++, const l-value references can bind to r-values

Simulating Call by Reference

- Pointers can be used to simulate call by reference

- However, function is still call by value, since parameters correspond to new pointer variables

```
void swap(int *x, int *y) {
  int tmp = *x;
  *x = *y;
  *y = tmp;
}

int x = 3, y = 4;
swap(&x, &y);      // x now 4, y now 3
```

Call by Result

- Argument must be l-value
- Parameter is a new variable with its own storage
- Parameter is **not** initialized with argument value
- Upon return of the function, parameter value is copied to argument object
- Can only be used for output

```
void foo(result int x) {
  x = 3;
  ...
  x++;     // x is now 4
}

int y = 5;
foo(y);    // y is now 4
```

This is not C++! C++ does not have call by result.

Call by Value-Result

- Combination of call by value and call by result
- Argument must be l-value
- Parameter is a new variable with storage, initialized with argument value
- Upon return, value of parameter is copied to argument object

```
int foo(v/r int x, v/r int y) {
  x++;
  return x - y;
}

int z = 3;
print(foo(z, z));    // prints 1
```

Again, not C++! Final value of `z` depends on whether it is copied from first or second parameter in the given language

Call by Name

- Any expression provided as argument
- Parameter name is replaced by argument expression everywhere in the body
- Expression computed whenever it is encountered in body

```
void foo(name int x) {
  print(x);  // becomes print(++y)
  print(x);  // becomes print(++y)
}

int y = 3;
foo(++y);  // prints 4, then 5; y is now 5
```

Thunks

- In call by name, expression must be computed in its own environment

```
void bar(name int x) {
  int y = 3;
  print(x + y);  // becomes print(y + 1 + y)
}

int y = 1;
bar(y + 1);       // should print 5, not 7
```

- This is accomplished with a *thunk*, a compiler-generated local function that packages the expression with its environment

Python is Call by Value

- Call by value is most common mode, followed by call by reference
- Python and Java are not call by reference
  - They combine call by value with reference semantics
  - This is sometimes called "call by object reference"

```
def swap(x, y):
    tmp = x
    x = y
    y = tmp

>>> x, y = 1, 2
>>> swap(x, y)
>>> x, y
(1, 2)
```

x and y are new variables with their own storage

Break Time!

- We'll start again in five minutes.

Running Scheme

- We recommend Racket
  - https://download.racket-lang.org/
  - Includes DrRacket IDE and command-line `plt-r5rs` interpreter
- Online interpreter for simple examples
  - https://repl.it/languages/scheme
- Be aware that most interpreters are not fully R5RS compliant, so we recommend sticking to Racket for homework/project development

Call Expressions

- Everything is an expression in Scheme
- Simple expressions: literals, names
- Compound expressions consist of a parenthesized list
- Call expressions:

```
(function arg1 arg2 ... argN)
```

- Examples:

```
(+ 3 4)
(+ (* 3 5) (- 10 6))
(quotient 10 2)
```

Integer division

Order of evaluation of subexpressions is not defined

Conditionals

- Special forms have their own evaluation rules
- Conditional evaluates test, then evaluates *then* expression if true, otherwise the *else* expression if provided

```
(if <test> <then_expr> <else_expr>)
```

- Value of whole expression is value of then or else expression
  - If test is false and no else expression, then value is unspecified
- Only `#f` is a false value, all other values are true

Definitions and Blocks

- Variables can be defined in the current frame using `define`

  ```
  (define <name> <expr>)
  ```

- In standard Scheme, this can only be at the top level or at the beginning of a block
  - We won't require this to be enforced in the project

- Blocks can be introduced with `let`

  ```
  (let ((<name1> <expr1>) ... (<nameN> <exprN>))
    <body_expr1> <body_expr2> ... <body_exprN>)
  ```

`let` can be considered syntactic sugar for `lambda` definition and application.

Functions

- Functions can also be defined using `define`

```
(define (<name> <param1> ... <paramN>)
   <body_expr1> ... <body_exprN>)
```

- Anonymous functions can be defined using `lambda`

```
(lambda (<param1> ... <paramN>)
   <body_expr1> ... <body_exprN>)
```

- Then the `define` form is equivalent to

```
(define (lambda (<param1> ... <paramN>)
                <body_expr1> ... <body_exprN>)
   <name>)
```

Pairs

- Pairs are a fundamental mechanism for combining data

- Construct pair using `cons`

```
> (define x (cons 1 2))
> x
(1 . 2)
```

Dot denotes pair where the second is not a list

- Access the first and second with `car` and `cdr`

```
> (car x)
1
> (cdr x)
2
```

Lists

- A list is a sequence of pairs terminated by an empty list

- An empty list is denoted by `'()`, and in our implementation, by the non-standard **`nil`**

```
> (define y (cons 1 (cons 2 (cons 3 '()))))
> y
(1 2 3)
> (car y)
1
> (cdr y)
(2 3)
> (cdr (cdr (cdr y)))
()
```

Also `(cdddr y)` in standard Scheme

Symbolic Data

- In Scheme, both code and data share the same representation

- Quotation specifies that what follows should be treated as data and not evaluated

```
> (define x 3)
> x
3
> 'x
x
> '(hello world)
(hello world)
```

Equivalent to `(quote x)`

The `eval` procedure can be used to evaluate symbolic data.