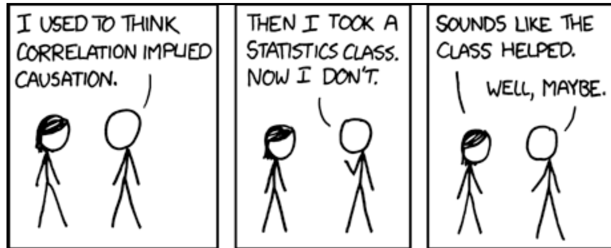


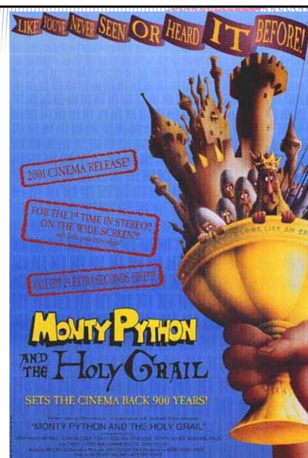
Objects & Python Interpreters

One-Slide Summary

- **Object-Oriented Programming** encapsulates state and methods together into objects. This hides implementation details (cf. inheritance) while allowing methods to operate on many types of input.
- **Python** and **Java** are both universal, imperative, object-oriented languages but differ several ways including treatment of whitespace and typing.
- Building an **interpreter** is a fundamental idea in computing. **Eval** and **Apply** are **mutually recursive**.
- We can write a Java program that acts as an interpreter for programs written in **MiniPython**, a simplified version of the **Python** language.

Outline

- Object Lessons
- Ali G
- Interpreters
- Eval
- Apply



Who was the first object-oriented programmer?

"So, by a vote of 8 to 2 we have decided to skip the Industrial Revolution completely, and go right into the Electronic Age."

By the word operation, we mean any process which alters the mutual relation of two or more things, be this relation of what kind it may. This is the most general definition, and would include all subjects in the universe. Again, it might act upon other things besides number, were objects found whose mutual fundamental relations could be expressed by those of the abstract science of operations, and which should be also susceptible of adaptations to the action of the operating notation and mechanism of the engine... Supposing, for instance, that the fundamental relations of pitched sounds in the science of harmony and of musical composition were susceptible of such expression and adaptations, the engine might compose elaborate and scientific pieces of music of any degree of complexity or extent.

Ada, Countess of Lovelace, around 1843

Implementing Interpreters

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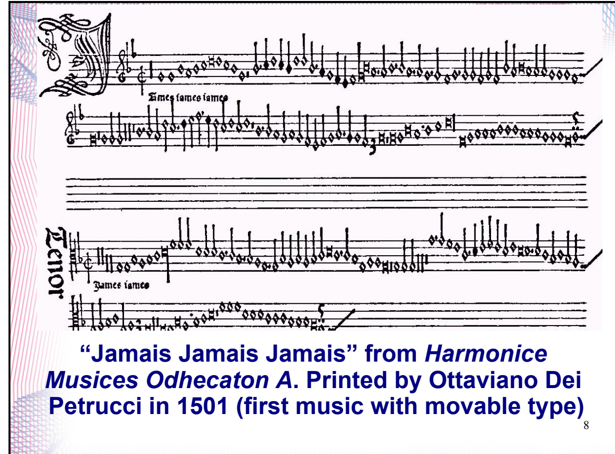
MIND YOUR HEAD

Learn Languages: Expand Minds

Languages change the way we think.

The more languages you know, the more different ways you have of thinking about (and solving) problems.



"Jamais Jamais Jamais" from *Harmonice Musices Odhecaton A*. Printed by Ottaviano Dei Petrucci in 1501 (first music with movable type)

Music with Movable Type?

- *Odhecaton*: secular songs published in 1501 Venice
  - First book of music ever printed using movable type,
  - Hugely influential both in publishing in general, and in dissemination of the Franco-Flemish musical style.
  - Seeing business potential, in 1498 Petrucci had obtained an exclusive 20-year license for all printing activities related to music anywhere in the Venetian Republic.
  - He printed two parts on the right-hand side of a page, and two parts on the left: four singers or instrumentalists could read from the same sheet.
  - Petrucci's publication not only revolutionized music distribution, it contributed to making the Franco-Flemish style the international musical language of Europe for the next century.

"Jamais Jamais Jamais" from *Harmonice Musices Odhecaton A.* (1501)

J S Bach, "Coffee Cantata", BWV 211 (1732)
www.npj.com/homepage/teritowe/jsbhand.html

Computability in Theory and Practice

(Intellectual Computability Discussion on TV Video) (I hope this works!)

Ali G Problem

- **Input:** a list of 2 numbers with up to d digits each
- **Output:** the product of the 2 numbers

Is it computable?

Yes – a straightforward algorithm solves it. Using elementary multiplication techniques it is $O(d^2)$

Can *real* computers solve it?

Microsoft Excel - AliG

File Edit View Insert Format Tools Data Window Help — Why can't Excel multiply?

C6 =PRODUCT(C1:C5)

	A	B	C
1	999999999	999999999	999999999
2	99	99	99
3	99	99	99
4		99	99
5			99
6	9800999990199	970298999029701	96059600903940400

Sheet1 / Sheet2 / Sheet3 — Ready

```
Python 2.6.5 (r265:79063, Apr 16 2010, 13:57:41)
[GCC 4.4.3] on linux2
Type "help", "copyright", "credits" or "license" for more information.
>>> (999999999 * 99 * 99)
9800999990199
>>> (999999999 * 99 * 99 * 99)
970298999029701
>>> (999999999 * 99 * 99 * 99 * 99)
96059600903940399
>>>
```

Ali G was Right!

- Theory assumes ideal computers:
  - Unlimited, perfect memory
  - Unlimited (finite) time
- Real computers have:
  - Limited memory, time, power outages, flaky programming languages, etc.
  - There are many computable problems we cannot solve with real computer: the actual inputs ***do*** matter (in practice, but not in theory!)

Liberal Arts Trivia: Biology

- This family of non-venomous serpents contains the longest snake in the world. They have teeth, heat-sensing organs, and ambush prey. They kill by a process of constriction: sufficient pressure is applied to the prey to prevent it from inhaling, and the prey succumbs to asphyxiation and is swallowed whole.

Liberal Arts Trivia: Chemistry

- This element is a ductile metal with very high thermal and electrical conductivity. When pure and fresh it has a pinkish or peachy color, but it turns green with age (oxidation). It has played a significant role in the history of humanity. In the Roman era it was usually mined on Cyprus; hence the provenance of its modern name (Cyprium to Cuprum).

Implementing Interpreters

I READ THIS LIBRARY BOOK YOU GOT ME.
WHAT DID YOU THINK OF IT?
IT REALLY MADE ME SEE THINGS DIFFERENTLY. IT'S GIVEN ME A LOT TO THINK ABOUT.
I'M GLAD YOU ENJOYED IT.
IT'S COMPLICATING MY LIFE. DON'T GET ME ANY MORE.

Inventing a Language

- Design the grammar
  - What strings are in the language?
  - Use BNF to describe all the strings in the language
- Make up the evaluation rules
  - Describe what everything the grammar can produce means
- Build an evaluator
  - A procedure that evaluates expressions in the language

Is this an exaggeration?

(SICP, p. 360)

It is no exaggeration to regard this as the most fundamental idea in programming:

The evaluator, which determines the meaning of expressions in the programming language, is *just another program*.

To appreciate this point is to change our images of ourselves as programmers. We come to see ourselves as designers of languages, rather than only users of languages designed by others.

Environmental Model of Evaluation

- To **evaluate** an expression, **evaluate** all the subexpressions and **apply** the value of the first subexpression to the values of the other subexpressions.
- To **apply** a procedure to a set of arguments (**evalCall** in PS7), evaluate the body of the function in a new environment.
  - To construct this environment, make a **new** frame with an environment pointer that is the environment of the procedure that contains places with the formal parameters bound to the arguments.

Eval and Apply are defined in terms of each other.

The Plan – Front End

- We are given a string like "((5 + 6) - 10)"
- First, we remove whitespace and **parse** it according to our MiniPython grammar.
- We will represent MiniPython expressions internally as either
  - Primitive elements, like "5" or "+"
  - String ArrayLists representing functions and arguments, like {"-", {"+", "5", "6"}, "10"}
  - (Plus some other details in PS7.)

The Plan – Back End

- So now we have Java representations of MiniPython expressions, such as:
  - "123" # 123
  - ["-", ["+", "5", "6"], "10"] # ((5 + 6) - 10)
- We want to **evaluate** such expressions. We will write a method, **meval**(), that does this.
  - **meval**("123") = 123
- We'll also write **evalCall()** to apply functions created by def.
  - **evalCall**(["pow", "2", "4"]) = 16

Evaluation and Environments

- Recall the Environment Model for Python
  - Go back to Class 13 or Book Chapter 9 if not!
- Let's think about some **meval** inputs and outputs together:
  - **meval**("12") = 12
  - **meval**("x") = ??
- So meval will need an **environment**:
  - **meval**("12",env) = 12
  - **meval**("x",env) = *value-of-x-in-env*

meval Basics

- So we might try to write **meval** by cases:

```
public static Object meval(Object expr, Environment env){
    if (isPrimitive(expr))          // “3”, “x”, etc.
        return evalPrimitive(expr, env);

    if (isIfStatement(expr))        // [if, [<,x,2],...]
        return evalIf(expr, env);

    if (isCall(expr))               // [pow, 2, 4]
        return evalCall(expr, env);
}
```


meval Basics

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    if (isPrimitive(expr))          // “3”, “x”, etc.
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        return evalIf(expr, env);

    if (isCall(expr))               // [pow, 2, 4]
        return evalCall(expr, env);
}
```

What does this look like in real Java?

meval Basics

- So we might try to write **meval** by cases:

```
public static Object meval(Object expr, Environment env){
  if(expr instanceof ArrayList<?>) {
    ArrayList<Object> exp = (ArrayList<Object>) expr;
    Object operation = exp.get(0);
    if (operation.equals(“if”)) { // [if, [<,x,2],...]
      return evalIf(exp,env);
    } else if (operation.equals(“callE”) {// [pow, 2, 4]
      return evalCall(exp,env);
    }
  } else {
     return evalPrimative(expr,env); // “3”, “x”, etc.
}
```


meval Basics

- So we might try to write **meval** by cases:

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public static Object meval(Object expr, Environment env){
  if(expr instanceof ArrayList<?>) {
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      return evalIf(exp,env);
    } else if (operation.equals(“callE”) {// [pow, 2, 4]
      return evalCall(exp,env);
    }
  } else {
     return evalPrimative(expr,env); // “3”, “x”, etc.
}
```


Tracing Simple Evaluations

System.out.println(Parser.parse(“55”));

55 // or very close

Evaluation Trace:

meval(“55”, env)

evalPrimative(“55”)

55

What about something more complicated like (5 + 6)?

Parses to {“+”, “5”, “6”}

meval Basics

- So we might try to write **meval** by cases:

```
public static Object meval(Object expr, Environment env){
  if(expr instanceof ArrayList<?>) {
    ArrayList<Object> exp = (ArrayList<Object>) expr;
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    if (operation.equals(“if”)) { // [if, [<,x,2],...]
      return evalIf(exp,env);
    } else if (operation.equals(“callE”) {// [pow, 2, 4]
      return evalCall(exp,env);
    }
  } else {
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}
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      return evalIf(exp,env);
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      return evalCall(exp,env);
    }
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meval Basics

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    } else if (operation.equals("callE") {// [pow, 2, 4]
      return evalCall(exp,env);
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    Object operation = exp.get(0);
    if (operation.equals("if")) { // [if, [<,x,2],...]
      return evalIf(exp,env);
    } else if (operation.equals("callE") {// [pow, 2, 4]
      return evalCall(exp,env);
    }
  } else {
     return evalPrimative(expr,env); // "3", "x", etc.
  }
```

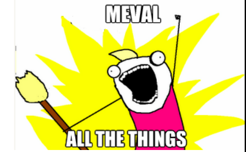

meval Basics

- So we might try to write **meval** by cases:

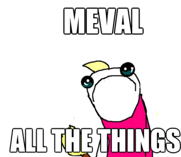
```
public static Object meval(Object expr, Environment env){
  if(expr instanceof ArrayList<?>) {
    ArrayList<Object> exp = (ArrayList<Object>) expr;
    Object operation = exp.get(0);

  // What other expressions are there?
  // Brainstorm now!

  } else {
     return evalPrimative(expr,env); // "3", "x", etc.
  }
```




```
   else if (operation.equals("def")) {
     return evalDef(expr,env);
   } else if (operation.equals("if")) {
     return evalIf(expr, env);
   } else if (operation.equals("return")) {
     return evalReturn(expr,env);
   } else if (operation.equals("assign")) {
     return evalAssign(expr,env);
   } else if (operation.equals("print")) {
     return evalPrint(expr,env);
   } else if (operation.equals("callS")) {
     evalCall(expr,env); return null;
   } else if (operation.equals("while")) {
     return evalWhile(expr,env);
   } else if (operation.equals("callE")) {
     return evalCall(expr,env);
   } else if (operation.equals("get")) {
     return evalGetLstElt(expr,env);
   } else if (operation.equals("list")) {
     return evalList(expr,env);
   } else if (operation.equals("sizeof")) {
     return evalSize(expr,env);
   } else if (operation.equals("==")) {
     return evalEquals(expr,env);
  } … // also *, /, >, <, and <=
```



Liberal Arts Trivia: Philosophy

- In the philosophy of mind, *this* is used to describe views in which the mind and matter are two ontologically separate categories. In *this*, neither mind nor matter can be reduced to each other in any way. *This* is typically opposed to reductive materialism. A well-known example of this is attributed to Descartes, holding that the mind is a nonphysical substance.

Liberal Arts Trivia: Chemistry

- This exothermic chemical process involves the rapid oxidation of a fuel material, releasing light, heat and various reaction products. Fuels of interest often include organic compounds and hydrocarbons. Slower oxidation processes, like rusting, are not part of this process.

Liberal Arts Trivia: Statistics

- A t-test is a statistical hypothesis test in which the test statistic has a *This* distribution if the null hypothesis is true. The *This* distribution arises when estimating the mean of a normally distributed population when the sample size is small. It was first published by William Gosset in 1908 while he worked at a Guinness Brewery in Dublin. The brewery forbade the publication of research by its staff members (!), so he published the paper under a pseudonym.


```
  else if (operation.equals("def")) {
    return evalDef(expr,env);
  } else if (operation.equals("if")) {
    return evalIf(expr, env);
  } else if (operation.equals("return")) {
    return evalReturn(expr,env);
  } else if (operation.equals("assign")) {
    return evalAssign(expr,env);
  } else if (operation.equals("print")) {
    return evalPrint(expr,env);
  } else if (operation.equals("callS")) {
    evalCall(expr,env); return null;
  } else if (operation.equals("while")) {
    return evalWhile(expr,env);
  } else if (operation.equals("callE")) {
    return evalCall(expr,env);
  } else if (operation.equals("get")) {
    return evalGetLstElt(expr,env);
  } else if (operation.equals("list")) {
    return evalList(expr,env);
  } else if (operation.equals("sizeof")) {
    return evalSize(expr,env);
  } else if (operation.equals("==")) {
    return evalEquals(expr,env);
} … // also *, /, >, <, and <=
```

evalCall basics

Let's think about mapply input and output together:

- meval(['+', '1', '2']) = 3
- meval(parse("(def add2(x): return x + 2); add2(5)")) = 7
- meval(['sqrt', '4']) = 2

So we'll have separate handling for

- **Primitive** procedures
- Procedures made with **def**
  - Have parameters ("x") and bodies ("+ x 2")
  - May live in the environment ("sqrt")

Applying Primitives

How about: (5 + 6) ?

- The expression parses like this: ["+", "5", "6"]

Applying Primitives

How about: (5 + 6) ? =

- The expression parses like this: ["+", "5", "6"]

Recall from the eval slide:

```
} else if (operation.equals("+")) {
  return evalPlus(expr,env);
}
```

Applying Primitives

```
public static Object evalAdd(ArrayList<Object> exp, Environment env) {
  Object v1 = Evaluator.meval(exp.get(1),env);
  Object v2 = Evaluator.meval(exp.get(2),env);
  if (v1 instanceof Integer && v2 instanceof Integer) {
    return (Integer)v1+(Integer)v2;
  } else if(v1 instanceof ArrayList<?> && v2 instanceof ArrayList<?>) {
    ArrayList<Object> list1 = (ArrayList<Object>) v1;
    ArrayList<Object> list2 = (ArrayList<Object>) v2;
    ArrayList<Object> new_list = (ArrayList<Object>) list1.clone();
    new_list.addAll(list2);
    return new_list;
   }
   throw new EvalError("Cannot add " + v1 + " and " + v2);
}
```

Applying Primitives

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public static Object evalAdd(ArrayList<Object> exp, Environment env) {
  Object v1 = Evaluator.meval(exp.get(1),env);
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    ArrayList<Object> new_list = (ArrayList<Object>) list1.clone();
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  } else if(v1 instanceof ArrayList<?> && v2 instanceof ArrayList<?>) {
    ArrayList<Object> list1 = (ArrayList<Object>) v1;
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    ArrayList<Object> new_list = (ArrayList<Object>) list1.clone();
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    return new_list;

    throw new EvalError("Cannot add " + v1 + " and " + v2);
}
```

Applying Primitives

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public static Object evalAdd(ArrayList<Object> exp, Environment env) {
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    return new_list;
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```

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Applying Primitives

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    ArrayList<Object> list2 = (ArrayList<Object>) v2;
    ArrayList<Object> new_list = (ArrayList<Object>) list1.clone();
    new_list.addAll(list2);
    return new_list;
   }
   throw new EvalError("Cannot add " + v1 + " and " + v2);
}
```

Tracing

How about: (5 + x) ? // Where the env sets x=6

The expression parses like this: [+, 5, x]

meval([+, 5, x], env)
 evalAdd([+, 5, x], env)
  v1 = **meval**(5, env)
   evalPrimative(5, env) returns 5
  v2 = **meval**(x, env)
   evalPrimative(x, env) returns 6
  return v1 + v2

Tracing

How about: (5 + x) ? // Where the env sets x=6

The expression parses like this: [+, 5, x]

meval([+, 5, x], env)
 evalAdd([+, 5, x], env)
  v1 = **meval**(5, env)
   evalPrimative(5, env) returns 5
  v2 = **meval**(x, env)
   evalPrimative(x, env) returns 6
  return v1 + v2

Question: What about (5 + 6) - 10 ?

More Tracing

The expression parses as: [-, [+, 5, 6], 10]

meval([-, [+, 5, 6], 10], env)	
evalSub([-, [+, 5, 6], 10], env)	-
v1 = **meval**([+, 5, 6], env)	
evalAdd([+, 5, 6], env)	+
v1 = **meval**(5,env)	
evalPrimative(5, env) returns 5	5
v2 = **meval**(6,env)	
evalPrimative(6, env) returns 6	6
returns v1 + v2 // 5 + 6	
v2 = **meval**(10, env)	10
evalPrimitive(10, env) returns 10	
returns v1 – v2 // 11 – 10	1

evalCall basics

- **meval**() already covers **primitive** operations
  - **meval**({"+", "1", "2"}) // returns 3
  - Also works for -,/,*,>,<,etc.
- But we need still need to handle arguments passed to programmer-defined functions with **def:**

```
def add2(x):
    return x + 2
add2(5)
```

- **meval**({"callE", "add2", "5"}, env) // returns 7
  - add2 has arguments ("x") and a body ({return {"+", "x", "2"] }})

Implementing evalCall

```
public static Object evalCall(ArrayList<Object> exp, Environment env) {
  // Look up the defined procedure in the environment
  Procedure proc = ((Procedure)env.lookupVar((String)exp.get(1));

  // Get the formal argument values passed to the function
  ArrayList<Object> passedArgs = (ArrayList<Object>) exp.get(2);

  // Get the expected argument names from the procedure
  ArrayList<String> expectedArgNames = proc.args;

  // Create a new environment with the procedure's env as the parent
  Environment newEnv = new Environment(proc.env);

  // Evaluate then bind each argument value to the argument name
  for (int i = 0; i < passedArgs.size(); i++)
   newEnv.addVar(expectedArgNames.get(i),meval(passedArgs.get(i),env));

  // Evaluate the function body with the new environment
  return meval(proc.body, new_env);
}
```

Implementing evalCall

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public static Object evalCall(ArrayList<Object> exp, Environment env) {
  // Look up the defined procedure in the environment
  Procedure proc = ((Procedure)env.lookupVar((String)exp.get(1));
}
```

Get the definition of “add2” from the environment.

Implementing evalCall

```
public static Object evalCall(ArrayList<Object> exp, Environment env) {
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  // Get the formal argument values passed to the function
  ArrayList<Object> passedArgs = (ArrayList<Object>) exp.get(2);
}
```

{“5”}

Implementing evalCall

```
public static Object evalCall(ArrayList<Object> exp, Environment env) {
  // Look up the defined procedure in the environment
  Procedure proc = ((Procedure)env.lookupVar((String)exp.get(1));

  // Get the formal argument values passed to the function
  ArrayList<Object> passedArgs = (ArrayList<Object>) exp.get(2);

  // Get the expected argument names from the procedure
  ArrayList<String> expectedArgNames = proc.args;
}
```

{“x”}

Implementing evalCall

```
public static Object evalCall(ArrayList<Object> exp, Environment env) {
  // Look up the defined procedure in the environment
  Procedure proc = ((Procedure)env.lookupVar((String)exp.get(1));

  // Get the formal argument values passed to the function
  ArrayList<Object> passedArgs = (ArrayList<Object>) exp.get(2);

  // Get the expected argument names from the procedure
  ArrayList<String> expectedArgNames = proc.args;

  // Create a new environment with the procedure's env as the parent
  Environment newEnv = new Environment(proc.env);
}
```

Copy of env…

Implementing evalCall

```
public static Object evalCall(ArrayList<Object> exp, Environment env) {
  // Look up the defined procedure in the environment
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  // Get the formal argument values passed to the function
  ArrayList<Object> passedArgs = (ArrayList<Object>) exp.get(2);

  // Get the expected argument names from the procedure
  ArrayList<String> expectedArgNames = proc.args;

  // Create a new environment with the procedure's env as the parent
  Environment newEnv = new Environment(proc.env);

  // Evaluate then bind each argument value to the argument name
  for (int i = 0; i < passedArgs.size(); i++)
   newEnv.addVar(expectedArgNames.get(i),meval(passedArgs.get(i),env));
}
```

meval(5) -> 5
env + (x -> 5)

Implementing evalCall

```
public static Object evalCall(ArrayList<Object> exp, Environment env) {
  // Look up the defined procedure in the environment
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  Environment newEnv = new Environment(proc.env);

  // Evaluate then bind each argument value to the argument name
  for (int i = 0; i < passedArgs.size(); i++)
   newEnv.addVar(expectedArgNames.get(i),meval(passedArgs.get(i),env));

  // Evaluate the function body with the new environment
  return meval(proc.body, new_env);
}
```

meval(return x + 2)

Implementing evalCall

```
public static Object evalCall(ArrayList<Object> exp, Environment env) {
  // Look up the defined procedure in the environment
  Procedure proc = ((Procedure)env.lookupVar((String)exp.get(1));

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   newEnv.addVar(expectedArgNames.get(i),meval(passedArgs.get(i),env));

  // Evaluate the function body with the new environment
  return meval(proc.body, new_env);
}
```


Homework

- Work on Problem Set #7
  - If we give you a long time before a problem set is due, what does that imply?