One-Slide Summary

- Building an interpreter is a fundamental idea in computing. Eval and Apply are mutually recursive.
- The most complicated parts of meval are the handling of function abstraction (lambda) and function application.
- The most complicated part of mapply is handling a non-primitive procedure: create a new environment, add variables to that environment corresponding to the arguments, and then apply the procedure body in that new environment.
- In lazy evaluation, a value is not computed until it is needed. A thunk is a piece of code that performs a delayed computation.

Outline

- Eval
- Apply
- Lazy
- Thunk

Problem Set 7

- You will be writing an interpreter for Charme
  - Charme is a simple version of Scheme
  - Your interpreter will be written in Python
  - This demonstrates that Python is at least as powerful as Scheme
    - Why?
  - It turns out that Scheme is also at least as powerful as Python
    - Why?

Conditionals

```python
def evalConditional(expr, env):
    assert isConditional(expr)
    if len(expr) <= 2:
        evalError("Bad ...")
    for clause in expr[1:]:
        if len(clause) != 2:
            evalError("Bad ...")
        predicate = clause[0]
        result = meval(predicate, env)
        if not result == False:
            return meval(clause[1], env)
    evalError("No ...")
    return None
```

Recall the conditional:

```
(cons ((< x 5) "small")
       (< x 10) "medium")
       (< x 99) "large"))
```
Implementing Procedures

What do we need to record?

Environment pointer

Input parameters (in mouth)

(+ x x) Procedure Body

Procedure Class

class Procedure:
    def __init__(self, params, body, env):
        self._params = params
        self._body = body
        self._env = env
    def getParams(self):
        return self._params
    def getBody(self):
        return self._body
    def getEnvironment(self):
        return self._env

Evaluating Lambda Expressions

def evalLambda(expr, env):
    assert isLambda(expr)
    if len(expr) != 3:
        evalError("Bad lambda ...")
    return Procedure(expr[1], expr[2], env)

Evaluating Applications

def meval(expr, env):
    ...
    elif isApplication(expr):
       return evalApplication(expr, env)
    else:
       evalError(...)

def evalApplication(expr, env):
    # To evaluate an application
    # evaluate all the subexpressions
    subexprvals = map(lambda subexpr:
        meval(subexpr, env), expr)
    # then, apply the value of the
    # first subexpression to the rest
    return mapply(subexprvals[0], subexprvals[1:])

Liberal Arts Trivia: Geography

• This island nation in southeast Asia is located about 20 miles off the southern coast of India.
  It is home to 20 million people (mostly Sinhalese and Tamils), is a center of the Buddhist religion, and possesses rich tropical forests. during WWII it was used as a base for Allied forces against the Japanese Empire. It was known as Ceylon before 1972.
Liberal Arts Trivia:
Italian Literature
• This Florentine poet of the Middle Ages is called *il Sommo Poeta*. His central work, the *Divinia Commedia*, is often considered the greatest literary work composed in the Italian language and is a masterpiece of world literature. He is often called the Father of the Italian Language: he wrote the *Commedia* in the early 14th century in a new language he called “Italian” based on the regional dialect of Tuscany with some Latin and other bits thrown in.
• Bonus: Who guides him in Hell and Purgatory?

```python
#13
mapply
def mapply(proc, operands):
    if (isPrimitiveProcedure(proc)):
        return proc(operands)
    elif isinstance(proc, Procedure):
        params = proc.getParams()
        newenv = Environment(proc.getEnvironment())
        if len(params) != len(operands):
            evalError("Parameter length mismatch ...")
        for i in range(0, len(params)):
            newenv.addVariable(params[i], operands[i])
        return meval(proc.getBody(), newenv)
    else:
        evalError("Application of non-procedure: %s" % (proc))
#14
mapply
def mapply(proc, operands):
    if (isPrimitiveProcedure(proc)):
        return proc(operands)
    elif isinstance(proc, Procedure):
        params = proc.getParams()
        newenv = Environment(proc.getEnvironment())
        if len(params) != len(operands):
            evalError("Parameter length mismatch ...")
        for i in range(0, len(operands)):
            ???
        return ???
    else:
        evalError("Application of non-procedure: %s" % (proc))
#15
mapply
def mapply(proc, operands):
    if (isPrimitiveProcedure(proc)):
        return proc(operands)
    elif isinstance(proc, Procedure):
        params = proc.getParams()
        newenv = Environment(proc.getEnvironment())
        if len(params) != len(operands):
            evalError("Parameter length mismatch ...")
        for i in range(0, len(operands)):
            newenv.addVariable(params[i], operands[i])
        return meval(proc.getBody(), newenv)
    else:
        evalError("Application of non-procedure: %s" % (proc))
#16
mapply
def mapply(proc, operands):
    if (isPrimitiveProcedure(proc)):
        return proc(operands)
    elif isinstance(proc, Procedure):
        params = proc.getParams()
        newenv = Environment(proc.getEnvironment())
        if len(params) != len(operands):
            evalError("Parameter length mismatch ...")
        for i in range(0, len(operands)):
            newenv.addVariable(params[i], operands[i])
        return meval(proc.getBody(), newenv)
    else:
        evalError("Application of non-procedure: %s" % (proc))
```

Implemented Interpreter!

What’s missing?

Special forms:
- if, begin, set!
Primitive procedures:
- lots and lots
Built-in types:
- floating point numbers,
- strings, lists, etc.
Lazy Evaluation

- **Lazy Evaluation:** don’t evaluate expressions until their value is really needed
  - We might save work this way, since sometimes we don’t need the value of an expression
  - We might change the meaning of some expressions, since the order of evaluation matters
- Not a wise policy for problem sets (all answer values will always be needed!)

Lazy Examples

Charme> ((lambda (x) 3) (* 2 2))
3
LazyCharme> ((lambda (x) 3) (* 2 2))
3
Charme>((lambda (x) 3) (car 3))
error: car expects a pair, applied to 3
LazyCharme> ((lambda (x) 3) (car 3))
3
Charme> ((lambda (x) 3) (loop-forever))
no value – loops forever
LazyCharme> ((lambda (x) 3) (loop-forever))
3

Laziness can be useful!

To evaluate an application,

- **evaluate** all the subexpressions
- **apply** the value of the first subexpression to the values of the other subexpressions.

How do we make our evaluation rules lazier?

- **evaluate** the first subexpression, and **delay** evaluating the operand subexpressions until their values are needed.

How do we make our evaluation rules lazier?

Liberal Arts Trivia: Canadian Literature

- In this 1908 book, the title character is a talkative red-haired orphan. She moves to the village of Avonlea to live with farmers Matthew and Marilla Cuthbert. She becomes bosom friends with Diana Barry and has a complex relationship with Gilbert Blythe. Her vivid imagination and cheerful outlook often land her in trouble.
- **Bonus:** Name the setting’s Canadian Province.
Liberal Arts Trivia: Biology
This generic term is used for many plants in the genus Allium. The plant is edible, grown underground as a vertical shoot that is used for food storage. It is one of the oldest vegetables, and is available fresh, frozen, canned, carmelized, pickled, powdered, chopped, and dehydrated. They are rarely eaten alone, and can be sharp, spicy, tangy, pungent, mild or sweet. Tissue from this plant is often used in science education to demonstrate microscope usage because it has large cells. In Bronze age settlements, traces have been found near the fig and date going back to 5000 BCE. The ancient Egyptians worshiped it, believing that its spherical shape and concentric rings symbolized eternal life; it was used in Egyptian burial rituals (e.g., placed in the eye sockets of Ramesses IV).

Liberal Arts Trivia: Neuroscience
This medical visualization technique is most commonly used to visualize the internal structure and function of the body. Notably, it uses no ionizing radiation, but instead uses powerful fields to align the hydrogen atoms in water in the body. Radiofrequency fields are used to alter the alignment of the hydrogen atoms, which can then be detected by a scanner. The process was first used on humans in 1977.

Evaluation of Arguments
- Applicative Order (“eager evaluation”)
  - Evaluate all subexpressions before apply
  - Scheme, original Charme, Java
- Normal Order (“lazy evaluation”)
  - Evaluate arguments when the value is needed
  - Algol60 (sort of), Haskell, Miranda, LazyCharme

“Normal” Scheme order is not “Normal Order”!

Delaying Evaluation
- Need to record everything we will need to evaluate the expression later
- After evaluating the expression, record the result for reuse
- A thunk is a piece of code that performs a delayed computation

Lazy Application

```
def evalApplication(expr, env):
    subexprvals = map(lambda sexpr: meval(sexpr, env), expr)
    return mapply(subexprvals[0], subexprvals[1:])
```

```
def evalApplication(expr, env):
    subexprvals = map(lambda sexpr: Thunk(sexpr, env), expr)
    return mapply(subexprvals[0], subexprvals[1:])
```

```
def evalApplication(expr, env):
    ops = map(lambda sexpr: Thunk(sexpr, env), expr[1:])
    return mapply(forceeval(expr[0], env), ops)
```
Forcing Evaluation

```python
class Thunk:
    def __init__(self, expr, env):
        self._expr = expr
        self._env = env
        self._evaluated = False
    def value(self):
        if not self._evaluated:
            self._value = forceeval(self._expr, self._env)
            self._evaluated = True
        return self._value

def forceeval(expr, env):
    value = meval(expr, env)
    if isinstance(value, Thunk):
        return value.value()
    else:
        return value
```

What else needs to change?

Hint: where do we need real values, instead of Thunks?

Primitive Procedures

- Option 1: redefine primitives to work on thunks
- Option 2: assume primitives need values of all their arguments

```python
def deThunk(expr):
    # how am I different from forceeval?
    if isThunk(expr):
        return expr.value()
    else:
        return expr

def mapply(proc, operands):
    if isPrimitiveProcedure(proc):
        operands = map(lambda op: deThunk(op), operands)
    return proc(operands)
```

We need the deThunk procedure because Python’s lambda construct can only have an expression as its body (not an if statement).

Lazy Conditionals

- We need to know the actual value of the predicate expression, to know how to evaluate the rest of the conditional.

```python
def evalConditional(expr, env):
    assert isConditional(expr)
    if len(expr) <= 2:
        evalError("Bad conditional expression: %s" % str(expr))
    for clause in expr[1:]:
        if len(clause) != 2:
            evalError("Bad conditional clause: %s" % str(clause))
        predicate = clause[0]
        result = meval(predicate, env)
        if not result == False:
            return meval(clause[1], env)
    evalError(...) 
    return None
```

What do we need to change?
def evalConditional(expr, env):
    assert isConditional(expr)
    if len(expr) <= 2:
        evalError ("Bad conditional expression: %s" % str(expr))
    for clause in expr[1:]:
        if len(clause) != 2:
            evalError ("Bad conditional clause: %s" % str(clause))
        predicate = clause[0]
    result = meval(predicate, env)
    if not result == False:
        return meval(clause[1], env)
    evalError (...)
    return None

result = forceeval(predicate, env)

Homework

- Read Chapter 13 for Wednesday
- PS 7 due Monday April 06
- Guest Lecture Monday April 06