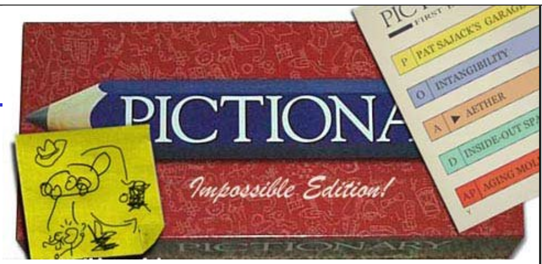
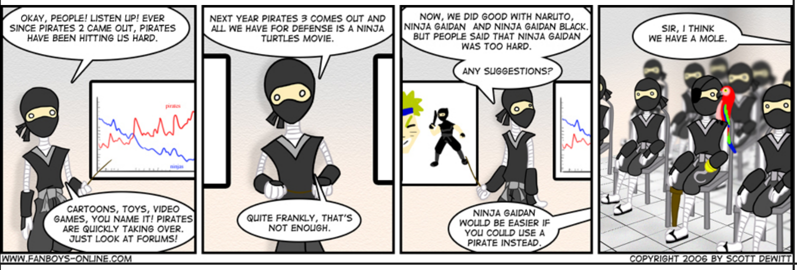


Types of Types

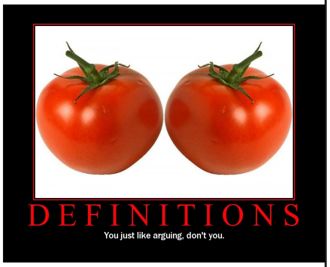

OKAY, PEOPLE! LISTEN UP! EVER SINCE PIRATES 2 CAME OUT, PIRATES HAVE BEEN HITTING US HARD.
pirates
ninjas
CARTOONS, TOYS, VIDEO GAMES, YOU NAME IT! PIRATES ARE QUICKLY TAKING OVER. JUST LOOK AT FORUMS!
NEXT YEAR PIRATES 3 COMES OUT AND ALL WE HAVE FOR DEFENSE IS A NINJA TURTLES MOVIE.
QUITE FRANKLY, THAT'S NOT ENOUGH.
NOW, WE DID GOOD WITH NARUTO, NINJA GAIDAN AND NINJA GAIDAN BLACK. BUT PEOPLE SAID THAT NINJA GAIDAN WAS TOO HARD.
ANY SUGGESTIONS?
NINJA GAIDAN WOULD BE EASIER IF YOU COULD USE A PIRATE INSTEAD.
SIR, I THINK WE HAVE A MOLE.
WWW.FANBOYS-ONLINE.COM
COPYRIGHT 2006 BY SCOTT DEWITT

One-Slide Summary

- In **lazy evaluation**, expressions are not evaluated until their values are needed. We can use lazy evaluation to program with **infinite data structures**, such as a list of all natural numbers.
- A **type** is a (possibly infinite) set of values.
- Each type supports a set of **valid operations**.
- Types can be latent or manifest, static or dynamic, strong or weak.
- We can change the Charme interpreter to support manifest (program visible) types.

Outline

- Administration
- Lazy Evaluation Recap
- Quiz Results
- Types
- Type Taxonomy
- Static Charme
  - Charme with Manifest Types



Administrivia

- Start PS7 Now
- **Kinga's Web Fault Research Survey**
  - http://www.cs.virginia.edu/~kld5r/webfault/
  - Worth 2 points of Extra Credit on Exam 2
  - Plus possibly $$$ ...
- **2009 Computing and Communication Scholarship for Undergraduate Women**
  - http://www.cs.virginia.edu/ccscholarship
  - $1000 merit scholarship, due June 30th

The Textbook

- I get the sense that some of the students are attempting to read the book on-line. I would encourage everyone to read it on paper. It is pretty well established that people read faster and understand better on paper than on the screen.
  - David Evans, Course Book Author

Problem Set 8

- Understand and modify a dynamic web application
- Already posted
- Due Monday April 13th

Problem Set 9

- Team requests and ideas due Friday April 10th (email me before midnight)

Lazy Evaluation Recap

- 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
- Change the Evaluation rule for Application
- Use thunks to delay evaluations

Lazy Application

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

⇩

```
def evalApplication(expr, env):
   # make Thunk object for each operand expression
   ops = map (lambda sexpr: Thunk(sexpr, env), expr[1:])
   return mapply(forceeval(expr[0], env), ops)
```

Lazy Data Structures

```
(define cons
  (lambda (a b)
     (lambda (p)
        (if p a b))))

(define car
  (lambda (p) (p #t)))

(define cdr
   (lambda (p) (p #f)))
```

Note: for PS7, you are defining these as *primitives*, which would not evaluate lazily.

Using Lazy Pairs

```
(define cons
  (lambda (a b)
     (lambda (p)
       (if p a b))))
```

```
(define car
   (lambda (p) (p #t)))
(define cdr
    (lambda (p) (p #f)))
```

```
LazyCharme> (define mypair (cons 3 error))
LazyCharme> mypair
<Procedure ['p'] / ['if', 'p', 'a', 'b']>
LazyCharme> (car mypair)
3
LazyCharme> (cdr mypair)
Error: Undefined name: error
```

Infinite Lists

```
(define ints-from
   (lambda (n)
      (cons n (ints-from (+ n 1)))))
```

```
LazyCharme> (define allnaturals (ints-from 0))
LazyCharme> (car allnaturals)
0
LazyCharme> (car (cdr allnaturals))
1
LazyCharme> (car (cdr (cdr (cdr (cdr allnaturals)))))
4
```

Infinite Fibonacci Sequence

```
(define fibo-gen (lambda (a b)
    (cons a (fibo-gen b (+ a b)))))

(define fibos (fibo-gen 0 1))

(define get-nth (lambda (lst n)
    (if (= n 0) (car lst)
        (get-nth (cdr lst) (- n 1)))))

(define fibo
  (lambda (n)  (get-nth fibos n)))
```

Alternate Implementation

Come back and understand this slide to study for the exams.

```
(define merge-lists
  (lambda (lst1 lst2 proc)
    (if (null? lst1) null
        (if (null? lst2) null
            (cons (proc (car lst1) (car lst2))
                  (merge-lists (cdr lst1) (cdr lst2) proc))))))
```

```
(define fiboms           ;;; merge-list variant
  (cons 0
        (cons 1
              (merge-lists fiboms (cdr fiboms) +))))
```

Quiz Results

Quiz Answers

- Programming languages designed by John Backus: Fortran, FP, FL

  (BNF - not a *programming* language)

2. What did Gödel prove?

   That any axiomatic system powerful enough to express “This statement cannot be proven in the system” must be incomplete.

3. What does SSS0 mean? 3

Quiz 4: Environment Class

```
class Environment:
  def __init__(self, parent):
    self._parent = parent
    self._frame = { }
  def addVariable(self, name, value):
    self._frame[name] = value
  def lookupVariable(self, name):
    if self._frame.has_key(name):
      return self._frame[name]
    elif self._parent:
      return self._parent.lookupVariable(name)
    else:
      evalError("Undefined name: %s" % (name))
```

Quiz 5: Viruses

- Is it possible to define a procedure that protects computer users from all viruses?

Here’s one procedure:
o Unplug the computer from the power
o Encase it in concrete
o Throw it in the Potomac River

This is a very different question from the “Is it possible to determine if a procedure specification is a virus?” question (which we proved in class is impossible by showing how a solution to it could be used to solve the Halting Problem).

Liberal Arts Trivia: Cognitive Science

- This philosophy of mind dominated for the first half of the 20th century. It developed as a reaction to the inadequacies of introspectionism. In it, all things which organisms do - including acting, thinking and feeling - should be regarded as actions or reactions, usually to the environment. It holds that there are no philosophical differences between publicly observable processes (actions) and privately observable processes (thinking and feeling).
- Bonus: B.F. Who?

Liberal Arts Trivia: Civil Rights

- The landmark 1967 Supreme Court case *Loving v. Virginia* declared Virginia's anti-miscegenation statue, the “Racial Integrity Act of 1924”, unconstitutional. This effectively ended laws preventing what?

Types

Types

Numbers

Strings

programs that halt

Colors

Beatle’s Songs that don’t end on the Tonic

lists of lists of lists of anything

- A **Type** is a (possibly infinite) set of values
- You can do some things with some types, but not others
  - Each Type has associated valid operations

Why have types?

- Detecting programming errors: (usually) better to notice error than report incorrect result
- Make programs easier to read, understand and maintain: thinking about types can help understand code
- Verification: types make it easier to prove properties about programs
- Security: can use types to constrain the behavior of programs

Types of Types

Does regular Scheme have types?

```
> (car 3)
car: expects argument of type <pair>; given 3
> (+ (cons 1 2))
+: expects argument of type <number>; given (1 . 2)
```

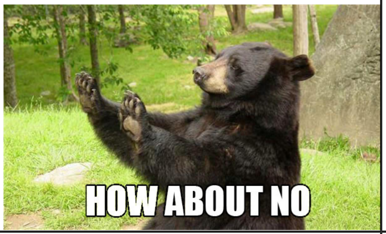
Yes, without types (car 3) would produce some silly result.
Because of types, it produces a type error.

Type Taxonomy

- **Latent** vs. **Manifest**
  - Are types visible in the program text?
- **Static** vs. **dynamic** checking
  - Do you have to run the program to know if it has type errors?
- **Weak** vs. **Strong** checking
  - How strict are the rules for using types?
    - (e.g., does the predicate for an **if** need to be a Boolean?)
  - Continuum (just matter of degree)

Scheme/Python/Charme

- Latent or Manifest?
  - All have **latent** types (none visible in code)
- Static or Dynamic?
  - All are **dynamic** (checked when expression is evaluated)
- Weak or Strong?
  - Which is the strictest?
  - You tell me!



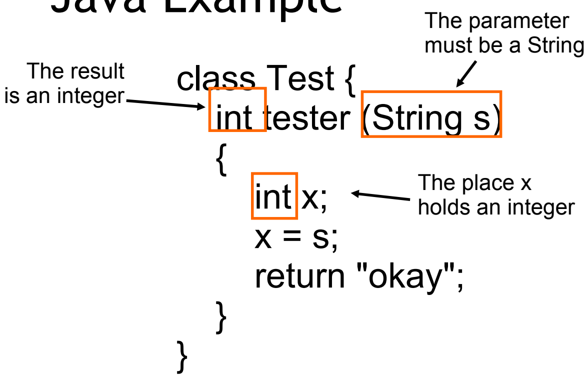
Strict Typing

```
Scheme> (+ 1 #t)
 +: expects type <number> as 2nd argument,
  given: #t; other arguments were: 1
Python>>> 1 + True
2
Charme> (+ 1 #t)
2
```

Scheme/Python/Charme → Java/StaticCharme

- Scheme, Python, and Charme have Latent, Dynamically checked types
  - Don’t see explicit types when you look at code
  - Checked when an expression is evaluated
- Java, StaticCharme have Manifest, Statically checked types
  - Type declarations must be included in code
  - Types are checked statically before running the program (Java: not all types checked statically)

Java Example



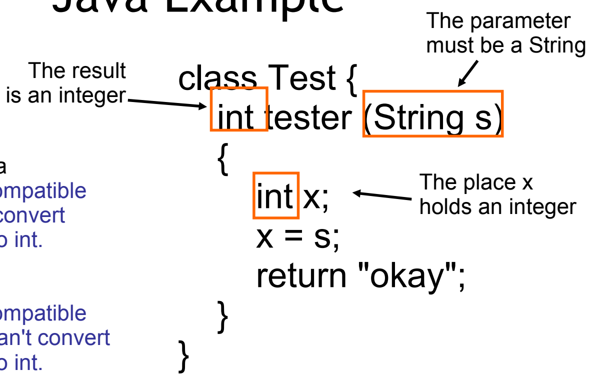
The result is an integer

The parameter must be a String

The place x holds an integer

```
class Test {
  int tester (String s)
  {
     int x;
     x = s;
     return "okay";
  }
}
```

Java Example



The result is an integer

The parameter must be a String

The place x holds an integer

```
class Test {
  int tester (String s)
  {
     int x;
     x = s;
     return "okay";
  }
}
```

```
> javac types.java
types.java:5: Incompatible
type for =. Can't convert
java.lang.String to int.
        x = s;
          ^
types.java:6: Incompatible
type for return. Can't convert
java.lang.String to int.
        return "okay";
        ^
2 errors
```

javac **compiles** (**and type checks**) the program. It does ***not*** execute it.

What do we need to do to change our Charme interpreter to provide manifest types?

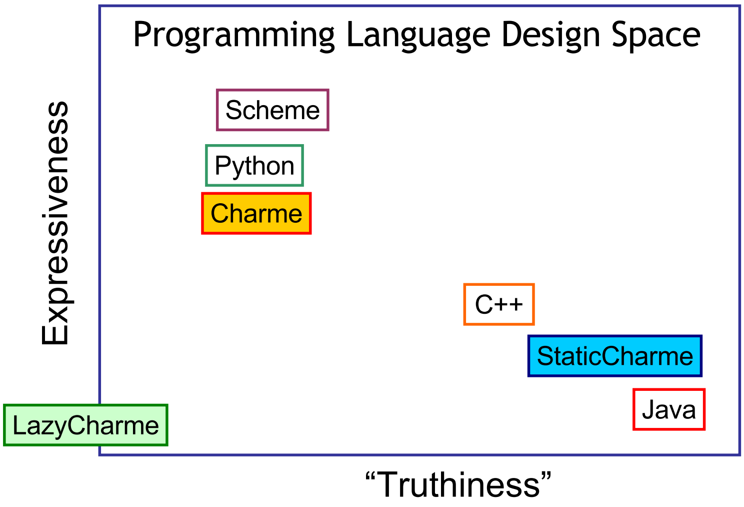
Truthiness!

Liberal Arts Trivia: Media Studies

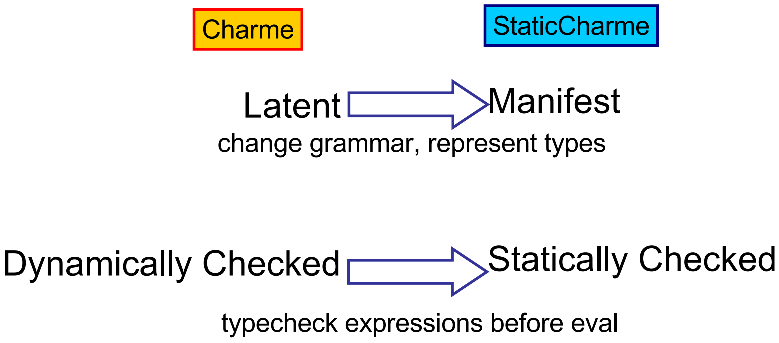
- This technique in film editing combines a series of short shots into a sequence of condensed narrative. It is usually used to advance the story as a whole and often to suggest the passage of time.

Liberal Arts Trivia: United Kingdom History

- This United Kingdom Tory prime minister was most famous for his military work during the Peninsular Campaign and the Napoleonic Wars. He was nicknamed the “Iron Duke” because of the iron shutters he had fixed to his windows to stop pro-reform mobs from breaking them – as an MP he was opposed to reform. It is unclear whether the well-known beef tenderloin, pate and puff pastry dish is named after him.



Types of Types



Manifest Types

Need to change the grammar rules to include types in definitions and parameter lists

Definition ::= **(define** *Name* **:** *Type Expression*)
Parameters ::= ε | *Parameter Parameters*
Parameter ::= *Name* **:** *Type*

Type ::= ??

Types in Charme

CType ::= *CPrimitiveType*
CType ::= *CProcedureType*
CType ::= *CProductType*

CPrimitiveType ::= **Number** | **Boolean**
CProcedureType ::= **(***CProductType* **->** *Type***)**
CProductType ::= **(***CTypeList***)**
CTypeList ::= *CType CTypeList*
CTypeList ::=

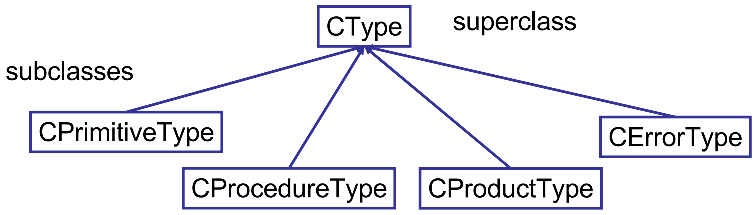
CType ::= *CPrimitiveType* | *CProcedureType* | *CProductType*
CPrimitiveType ::= **Number** | **Boolean**
CProcedureType ::= **(***CProductType* **->** *Type***)**
CProductType ::= **(***CTypeList***)**
CTypeList ::= *CType CTypeList*
CTypeList ::=

3
Number
+
((Number Number) -> Number)
(+ 3 3)
Number
(lambda (x:Number y:Number) (> x y))
((Number Number) -> Boolean)

Changed parameters grammar rule:
Parameter ::= *Name* **:** *Type*

Representing Types

CType ::= *CPrimitiveType* | *CProcedureType* | *CProductType*
CPrimitiveType ::= **Number** | **Boolean**
CProcedureType ::= **(***CProductType* **->** *Type***)**
CProductType ::= **(***CTypeList***)**
CTypeList ::= *CType CTypeList*
CTypeList ::=



```
class CType:
  @staticmethod
  def fromString(s):
    # create type from string
    tparse = parse(s)
    return CType.fromParsed(tparse[0])

  @staticmethod
  def fromParsed(typ):
     ... # create type from parsed type
  # These methods are overridden by subclasses
  def isPrimitiveType(self): return False
  def isProcedureType(self): return False
  def isProductType(self): return False
  def isError(self): return False
```

No self object

CPrimitiveType

```
class CPrimitiveType(CType):
  def __init__(self, s):
    self._name = s
  def __str__(self):
    return self._name
  def isPrimitiveType(self):
    return True
  def matches(self, other):
    return other.isPrimitiveType() \
```

???

class X(Y):
means **X** is a subclass of **Y**

Get out paper!

CPrimitiveType

```
class CPrimitiveType(CType):
  def __init__(self, s):
    self._name = s
  def __str__(self):
    return self._name
  def isPrimitiveType(self):
    return True
  def matches(self, other):
    return other.isPrimitiveType() \
           and self._name == other._name
```

class X(Y):
means **X** is a subclass of **Y**

CProcedureType

```
class CProcedureType(CType):
  def __init__(self, args, rettype):
    self._args = args
    self._rettype = rettype
  def __str__(self):
    return "(" + str(self._args) + " -> " \
          + str(self._rettype) + ")"
  def isProcedureType(self): return True
  def getReturnType(self): return self._rettype
  def getParameters(self): return self._args
  def matches(self, other):
    return other.isProcedureType() \
```

???

CProcedureType

```
class CProcedureType(CType):
  def __init__(self, args, rettype):
    self._args = args
    self._rettype = rettype
  def __str__(self):
    return "(" + str(self._args) + " -> " \
          + str(self._rettype) + ")"
  def isProcedureType(self): return True
  def getReturnType(self): return self._rettype
  def getParameters(self): return self._args
  def matches(self, other):
    return other.isProcedureType() \
      and self.getParameters().matches(other.getParameters()) \
      and self.getReturnType().matches(other.getReturnType())
```

CProductType

```
class CProductType(CType):
  def __init__(self, types): self._types = types
  def __str__(self): ...
  def isProductType(self): return True
  def matches(self, other):
    if other.isProductType():
```

???

CProductType

```
class CProductType(CType):
  def __init__(self, types): self._types = types
  def __str__(self): ...
  def isProductType(self): return True
  def matches(self, other):
    if other.isProductType():
      st = self._types
      ot = other._types
      if len(st) == len(ot):
        for i in range(0, len(st)):
          if not st[i].matches(ot[i]): return False
        # reached end of loop ==> all matched
        return True
    return False
```

Homework

- Show up to Gary McGraw guest lecture on Monday
- Problem Set 7 due Monday
- Problem Set 9 Team Requests Friday Apr 10th