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Instead, this is a class in Computation
We said at the start that this wasn’t a class in Scheme.
You’re probably never again going to code in Scheme.
Instead, this is a class in Computation.
How do the concepts from 6.001 apply elsewhere?
Syllabus and key ideas

- Procedural and data abstraction
- Conventional interfaces & programming paradigms
  - Type systems
  - Streams
  - Object-oriented programming
- Metalinguistic abstraction
  - Creating new languages
  - Evaluators
Static scoping is now standard

- Scheme stole static scoping (aka lexical scoping) from ALGOL
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- Most languages now are statically scoped, if only by block
Static scoping is now standard

- Scheme stole static scoping (aka lexical scoping) from **ALGOL**
- Most languages now are statically scoped, if only by block
- Environment model still describes how bindings work!
Many modern languages support first-class functions:

- Javascript, Perl, Python, Ruby, MATLAB, Mathematica, C++11, C#, Clojure
Higher-order functions

Many modern languages support first-class functions:
- Javascript, Perl, Python, Ruby, MATLAB, Mathematica, C++11, C#, Clojure
- Many even call anonymous functions lambdas
Closures

- Static scoping + first-class functions = closures
Closures

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- Great for data hiding
Closures

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- Great for data hiding
- ... access mediation
Closures

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- ... access mediation
- ... iterators
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Closures

- Static scoping + first-class functions = closures
- Great for data hiding
- ... access mediation
- ... iterators
- ... continuation passing style for flow control
- ... laziness or other delayed evaluation
Other languages have \texttt{filter, map, reduce}...
List operations with anonymous functions

- Other languages have `filter`, `map`, `reduce`...
- Map...Reduce?
Massively parallel architecture for handling Big Data™
Massively parallel architecture for handling Big Data™

Purely *functional* code is easy to parallelize – no read/write contention
- Massively parallel architecture for handling Big Data™
- Purely *functional* code is easy to parallelize – no read/write contention
- Idea based on every call to `func in (map func lst)` being able to be called in parallel
MapReduce

- Massively parallel architecture for handling Big Data™
- Purely *functional* code is easy to parallelize – no read/write contention
- Idea based on every call to `func in (map func lst)` being able to be called in parallel
- ... then also fed into `fold-right` in parallel
MapReduce

Congratulations, you already know how to write for Hadoop/MapReduce clusters
You know how to write evaluators

What good is writing an evaluator?
You know how to write evaluators

- What good is writing an evaluator?
- Allows you to move the level of abstraction
You know how to write evaluators

What good is writing an evaluator?
- Allows you to move the level of abstraction
- Writing code in Python but need to generate HTML forms?
You know how to write evaluators

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- Requires programmer have HTML knowledge
You know how to write evaluators

- What good is writing an evaluator?
- Allows you to move the level of abstraction
- Writing code in Python but need to generate HTML forms?
- Requires programmer have HTML knowledge
- ..or write a Domain-Specific Language (DSL) to generate it for you
External DSLs

- Read and parse a string (syntax)
- Apply arbitrary rules for meaning (semantics)
External DSLs

- Read and parse a string (syntax)
- Apply arbitrary rules for meaning (semantics)
- We know how to do the latter; there are tools for the former
Internal DSLs

- Can also just write clever function names
- Let your language do the parsing
Internal DSLs

- Can also just write clever function names
- Let your language do the parsing
- Constrains you to the syntax rules of your language
Internal DSLs

- Can also just write clever function names
- Let your language do the parsing
- Constrains you to the syntax rules of your language
- “For when you want to write code in one language, and get your errors in another!”
Data as code, and vice versa

- Scheme is useful because code and data are just a quote away
- Genetic Programming “evolves” programs by mutating syntax – doable because syntax is simple
- Lisp/Scheme key in early Artificial Intelligence in 1980s
- Useful in deduction languages – which led to PROLOG
Computers use a language where data is code all of the time.
Data as code now

- Computers use a language where data is code all of the time
- Assembly language is just bytes
Computers use a language where data is code all of the time
Assembly language is just bytes
Data it works on is just bytes
Some random bytes

BF FF FF FF FF 41 80
3C 08 00 75 F9 C3 90
BF FF FF FF FF 41 80
3C 08 00 75 F9 C3 90

BF FFFFFFFF Store -1 in variable C
41 Add 1 to C
80 3C 08 00 Compare memory at (A + C) to 0
75 F9 If that is not 0, go back 6 bytes
C3 Return
90 Do nothing
When data should not be code

- The most common security vulnerabilities are when computers are convinced that data is actually code.
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a.k.a “Buffer overflows”

Equivalent to making Scheme run an arbitrary function from inside `m-eval`
The most common security vulnerabilities are when computers are convinced that data is actually code

a.k.a “Buffer overflows”

Equivalent to making Scheme run an arbitrary function from inside `m-eval`

“Jumping out of the system”
Aside: Gödel, Escher, Bach

*Winner of the Pulitzer Prize*

**GÖDEL, ESCHER, BACH: AN ETERNAL GOLDEN BRAID**

**DOUGLAS R. HOFSTADTER**

*A Metaphorical Fugue on Minds and Machines in the Spirit of Lewis Carroll*
Change our evaluator to work in two phases; one parses the expression and returns a *Scheme* lambda.

The second phase just applies that lambda with a starting environment.
Evaluators as translators

- Change our evaluator to work in two phases; one parses the expression and returns a *Scheme* lambda
- The second phase just applies that lambda with a starting environment
- The first phase is a **translator** from one language to another
Evaluate as translators

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- No reason the language we translate to has to be scheme. . .
Evaluators as translators

- Change our evaluator to work in two phases; one parses the expression and returns a *Scheme* lambda.
- The second phase just applies that lambda with a starting environment.
- The first phase is a translator from one language to another.
- No reason the language we translate to has to be scheme. . .
- . . . how about assembly?
Lowering the abstraction barrier

| Scheme | Interpreter (m-eval) | Scheme | Interpreter (Racket) |
Lowering the abstraction barrier

Scheme

Assembler

Compiler

Interpreter (Racket)
Lowering the abstraction barrier

Scheme
Interpreter (m-eval)

Scheme
Compiler

Scheme
Interpreter (Racket)

Assembly

Scheme
Interpreter (m-eval)
Lowering the abstraction barrier

Mike Phillips <mpp> (MIT)
Now have interpreter in assembly, for Scheme
Now have interpreter in assembly, for Scheme
How *simple* a language can we build on?
Now have interpreter in assembly, for Scheme

How *simple* a language can we build on?

Are there functions which can be computed in Java but not Scheme?
Transforming from any language to an language

- Now have interpreter in assembly, for Scheme
- How *simple* a language can we build on?
- Are there functions which can be computed in Java but not Scheme?
- **Church-Turing** thesis: Turing Machines!
If a function can be computed by an algorithm, then it must also be computable by a Turing Machine.
Church-Turing thesis

- If a function can be computed by an algorithm, then it must also be computable by a Turing Machine.
- And vice-versa.
Church-Turing thesis

- If a function can be computed by an algorithm, then it must also be computable by a Turing Machine.
- And vice-versa.
- Thus Java, Scheme, Python, etc, are all equivalent in the functions they can compute.
So if all languages are fundamentally equivalent
So if all languages are fundamentally equivalent

... so what do we like about Scheme?
Language equivalence

- So if all languages are fundamentally equivalent
- ...so what do we like about Scheme?
- Lexical scoping, procedures as first-class objects, garbage collection, eval and apply, asynchronous event handling...
So if all languages are fundamentally equivalent
... so what do we like about Scheme?
Lexical scoping, procedures as first-class objects, garbage collection, eval and apply, asynchronous event handling...
We have just such a language:
So if all languages are fundamentally equivalent
... so what do we like about Scheme?
Lexical scoping, procedures as first-class objects, garbage collection, `eval` and `apply`, asynchronous event handling...
We have just such a language: Javascript
Brendan Eich was hired by Netscape in 1995 with the promise of “doing Scheme for the browser”
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But Java was also being implemented for the browser
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So if there was a second language, it should “look like Java”
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So if there was a second language, it should “look like Java”
So syntax closer to Java, but semantics stolen from Scheme
Brendan Eich was hired by Netscape in 1995 with the promise of "doing Scheme for the browser"

But Java was also being implemented for the browser

So if there was a second language, it should "look like Java"

So syntax closer to Java, but semantics stolen from Scheme

… JavaScript!
Code comparison

Scheme:

```
(define (make-counter incrementer)
  (let ((counter 0))
    (lambda ()
      (let ((current-val counter))
        (set! counter (incrementer counter))
        current-val))))
```

Javascript:

```
function make-counter(incrementer) {
  var counter = 0;
  return function () {
    var current_val = counter;
    counter = incrementer(counter);
    return current_val;
  }
}
```
Scheme:

(define (make-counter incrementer)
  (let ((counter 0))
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Javascript:

function make-counter(incrementer) {
  var counter = 0;
  return function () {
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    counter = incrementer(counter);
    return current_val;
  };
}
And now... And now for some magic!