6.001: Structure and Interpretation of Computer Programs

- Today
  - The structure of 6.001
  - The content of 6.001
  - Beginning to Scheme

6.001

- Main sources of information on logistics:
  - General information handout
  - Course web page
    - http://sicp.csail.mit.edu/
    - http://sicp.csail.mit.edu/Spring-2007/

Course structure

- Lectures
  - Delivered live here, twice a week (Tuesday and Thursday)
  - Versions of lectures also available on the web site, as audio annotated Power Point. Treat this like a live textbook. Versions are not identical to live lecture, but cover roughly same material.
  - Because lecture material is evolving, we **strongly** suggest that you attend live lectures, and use the online lectures as reinforcement.
- Recitations
  - Twice a week (Wednesday and Friday)
  - **For Wednesday, don't go to recitation assigned by registrar: check the web site for your assigned section. If you have conflict, contact course secretary by EMAIL only.**
  - You are expected to have attended the lecture (or listened to the online version) before recitation
  - Opportunity to reinforce ideas, learn details, clarify uncertainties, apply techniques to problems
- Tutorials
  - Once a week (typically Monday, some on Tuesday)
  - You should really be there – we provide a "carrot" to encourage you
  - Ask questions, participate in active learning setting

6.001

- Grades
  - 2 mid-term quizzes – 25%
  - Final exam – 25%
  - 1 introductory project and 5 extended programming projects – 40%
  - weekly problem sets – 10 %
    BUT YOU MUST ATTEMPT ALL OR COULD RESULT IN FAILING GRADE!!
  - **Participation** in tutorials and recitations – up to 5% bonus points!!

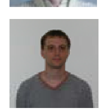
Contact information

- Web site: http://sicp.csail.mit.edu/
- Course secretary
  - Donna Kaufman, dkauf@mit.edu, 38-409a, 3-4624
- Instructor in charge, lecturer
  - Eric Grimson, welg@csail.mit.edu

- Co-lecturer
  - Rob Miller, rcm@csail.mit.edu

Section Instructors

Prof. Michael Collins



Gerald Dalley

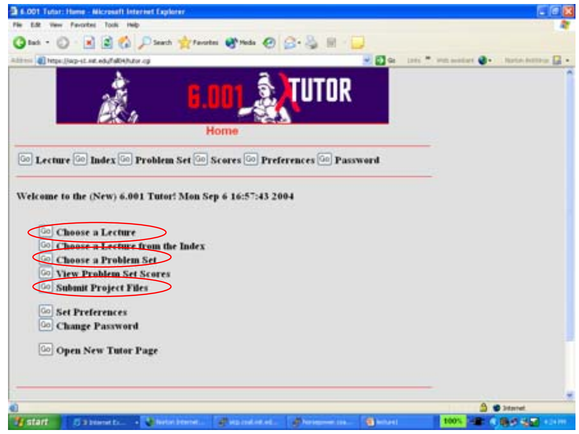
Prof. Peter Szolovits

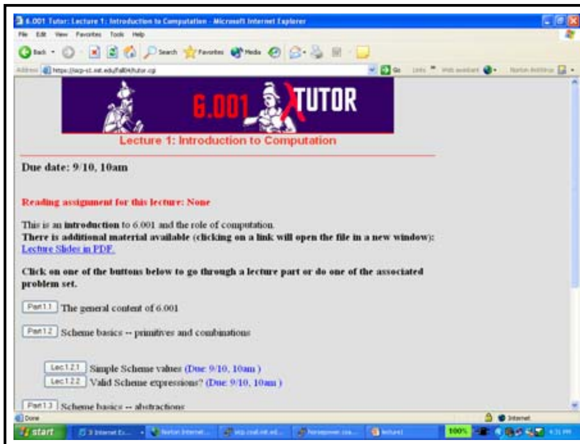
Prof. Berthold Horn

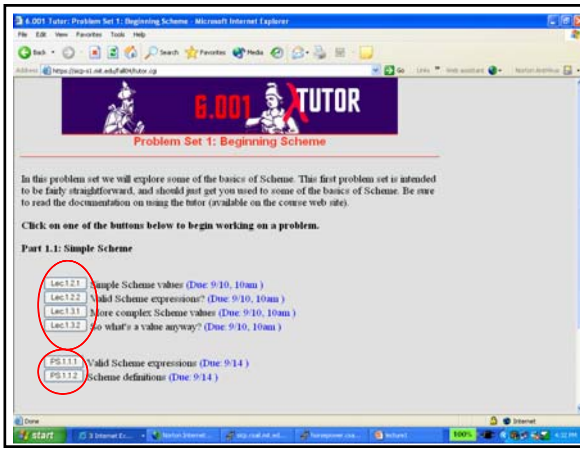
Dr. Kimberle Koile

Other logistics

- Problem sets
  - Are released through the online tutor (see website for link – there is a separate link to register for the tutor)
  - Are due electronically on the date posted
  - Includes lecture problems
    - You should **really** try to do these problems before the associated recitation
    - If section instructors find that too many students are coming unprepared, we will change these problems to be due on day of associated recitation!
  - First one was posted today!
- Projects
  - First one will be released today
  - Check website for updates







Other Issues

- Collaboration – Read description on web site
- Use of bibles – See description on web site
- Time spent on course
  - Survey shows 15-18 hours/week
  - Seeking help
    - Lab assistants
    - Other sources – departmental tutoring services, institute tutoring services (ask for help if you think you need it)
- 6.001 Lab – 34-501
- Combination
  - Inner door: **04862***
  - Outer door: **94210** (evenings, weekends)

Other Issues

- Slides: You have most of them.
- Because sometimes…
  - there are answers to problems
  - there are jokes
  - it's good to pay attention

Getting assigned to a recitation

- We are **NOT** going to use the registrar's recitation assignments
- Please take a few minutes to fill out the sign up sheet
  - Turn in at the end of lecture
- We will post assignments for tomorrow's section later this afternoon on the course web site

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What is the main focus of 6.001?

- This course is about ~~Computer~~ ~~Science~~
- Geometry was once equally misunderstood.
  - Term comes from *ghia* & *metra* or earth & measure – suggests geometry is about surveying
  - But in fact it's about…
- By analogy, computer science deals with *computation*; knowledge about *how to compute* things
- Imperative knowledge

Declarative Knowledge

- "What is true" knowledge

$$\sqrt{x} \text{ is the } y \text{ such that } y^2 = x \text{ and } y \geq 0$$

Imperative Knowledge

- "How to" knowledge
- To find an approximation of square root of x:
  - Make a guess G
  - Improve the guess by averaging G and x/G
  - Keep improving the guess until it is good enough

Example: $\sqrt{x}$ for $x = 2$.

X = 2	G = 1

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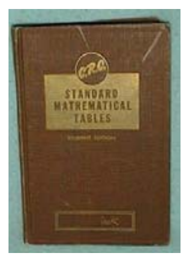
X/G = 24/17	G = ½ (17/12 + 24/17) = 1.4142156

"How to" knowledge

Why "how to" knowledge?

- Could just store tons of "what is" information



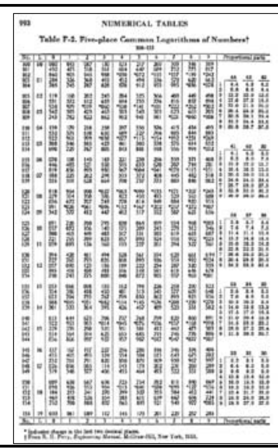

NUMERICAL TABLES

Table F-2. Five-place Common Logarithms of Numbers

"How to" knowledge

Why "how to" knowledge?

- Could just store tons of "what is" information
- Much more useful to capture "how to" knowledge – a series of steps to be followed to deduce a particular value
  - a recipe
  - called a procedure
- Actual evolution of steps inside machine for a particular version of the problem – called a process
- Want to distinguish between procedure (recipe for square root in general) and process (computation of specific result); former is often much more valuable

Describing "How to" knowledge

If we want to describe processes, we will need a language:

- Vocabulary – basic primitives
- Rules for writing compound expressions – syntax
- Rules for assigning meaning to constructs – semantics
- Rules for capturing process of evaluation – procedures

15 minutes

Using procedures to control complexity

This is what we are actually going to spend the term discussing

Goals: Given a specific problem domain, we need to

- Create a set of primitive elements– simple data and procedures
- Create a set of rules for combining elements of language
- Create a set of rules for abstracting elements – treat complex things as primitives

Why abstraction? -- Can create complex procedures while suppressing details

Target: Create complex systems while maintaining: efficiency, robustness, extensibility and flexibility.

Key Ideas of 6.001

- Linguistic perspective on engineering design But no HASS credit!
  - Primitives
  - Means of combination
  - Means of abstraction
  - Means for capturing common patterns

  Look at generic elements, but also at how to design for specific problem domain
- Controlling complexity
  - Procedural and data abstractions
    - Recursive programming, higher order procedures
  - Functional programming versus object oriented programming
- Metalinguistic abstraction
  - Creating new languages
  - Creating evaluators

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Computation as a metaphor

- Capture descriptions of computational processes
- Use abstractly to design solutions to complex problems
- Use a language to describe processes

Describing processes

- Computational process:
  - Precise sequence of steps used to infer new information from a set of data
- Computational procedure:
  - The "recipe" that describes that sequence of steps in general, independent of specific instance
- What are basic units on which to describe procedures?
  - Need to represent information somehow

Representing basic information

- Numbers
  - Primitive element – single binary variable
    - Takes on one of two values (0 or 1)
    - Represents one bit (binary digit) of information
  - Grouping together
    - Sequence of bits
      - Byte – 8 bits
      - Word – 16, 32 or 48 bits
- Characters
  - Sequence of bits that encode a character
    - EBCDIC, ASCII, other encodings
- Words
  - Collections of characters, separated by spaces, other delimiters

Binary numbers and operations

- Unsigned integers

Bit place i	N-1	N-2				1	0
				1	0	1	1
Weight b	2^(n-1)	2^(n-2)				2^1	2^0

$$\sum_{i=0}^{n-1} b_i \bullet 2^i \quad \text{where} \quad b_i \text{ is 0 or1}$$

1 + 2 + 8 = 11

Binary numbers and operations

- Addition

$$\begin{array}{r} 0 \\ +0 \\ \hline 0 \end{array} \quad \begin{array}{r} 0 \\ +1 \\ \hline 1 \end{array} \quad \begin{array}{r} 1 \\ +0 \\ \hline 1 \end{array} \quad \begin{array}{r} 1 \\ +1 \\ \hline 10 \end{array}$$

$$\begin{array}{r} 10101 \\ 111 \\ \hline 11100 \end{array}$$

Binary numbers and operations

- Can extend to signed integers (reserve one bit to denote positive versus negative)
- Can extend to character encodings (use some high order bits to mark characters versus numbers, plus encoding)

Where *Are* The 0's and 1's?

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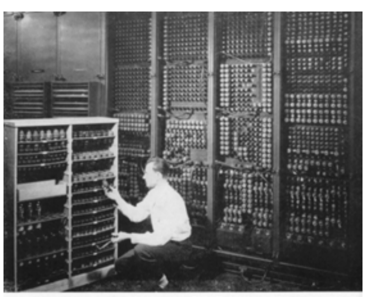


Replacing a bad tube meant checking among ENIAC's 19,000 possibilities.

Where *Are* The 0's and 1's?

… we don’t care at some level!

- Dealing with procedures at level of bits is **way too low-level!**
- From perspective of language designer, simply need to know the interface between
  - Internal machine representation of bits of information, and
  - Abstractions for representing higher-order pieces of information, plus
  - Primitive, or built-in, procedures for crossing this boundary
    - you give the procedure a higher-order element, it converts to internal representation, runs some machinery, and returns a higher-order element

Assuming a basic level of abstraction

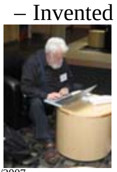
- We assume that our language provides us with a basic set of data elements …
  - Numbers
  - Characters
  - Booleans
- … and with a basic set of operations on these primitive elements, together with a “contract” that assures a particular kind of output, given legal input
- Can then focus on using these basic elements to construct more complex processes

Our language for 6.001

- Scheme
  - Invented in 1975
- Dialect of Lisp
  - Invented in 1959

Guy Steele

Gerry Sussman



John McCarthy

Rules for describing processes in Scheme

1. Legal expressions have rules for constructing from simpler pieces **Syntax**
2. (Almost) every **expression** has a **value**, which is “returned” when an expression is **“evaluated”.** **Semantics**
3. Every value has a **type,** hence every (almost) expression has a **type.**

Kinds of Language Constructs

- Primitives
- Means of combination
- Means of abstraction

Language elements – primitives

- Self-evaluating primitives – value of expression is just object itself
  - Numbers: 29, -35, 1.34, 1.2e5
  - Strings: “this is a string” “ this is another string with %&^ and 34”
  - Booleans: #t, #f

George Boole

A Founder

An Investigation of the Laws of Thought, 1854
-- “a calculus of symbolic reasoning”

Language elements – primitives

- Built-in procedures to manipulate primitive objects
  - Numbers: +, -, *, /, >, <, >=, <=, =
  - Strings: string-length, string=?
  - Booleans: boolean/and, boolean/or, not

Language elements – primitives

- Names for built-in procedures
  - +, *, -, /, =, …
  - What is the value of such an expression?
  - + → [#procedure …]
  - Evaluate by looking up value associated with name in a special table

Language elements – combinations

- How do we create expressions using these procedures?

(+ 2 3)

Close paren
Other expressions
Open paren
Expression whose value is a procedure

- Evaluate by getting values of sub-expressions, then applying operator to values of arguments

Language elements - combinations

- Can use nested combinations – just apply rules recursively

```
(+ (* 2 3) 4)
→10

(* (+ 3 4)
   (- 8 2))
→42
```


Language elements -- abstractions

- In order to abstract an expression, need way to give it a name

```
(define score 23)
```

- This is a special form
  - Does not evaluate second expression
  - Rather, it pairs name with value of the third expression
- Return value is unspecified

Language elements -- abstractions

- To get the value of a name, just look up pairing in environment

  score → 23

  – Note that we already did this for **+**, *****, …

  `(define total (+ 12 13))`

  `(* 100 (/ score total))` **→ 92**

- This creates a loop in our system, can create a complex thing, name it, treat it as primitive

Scheme Basics

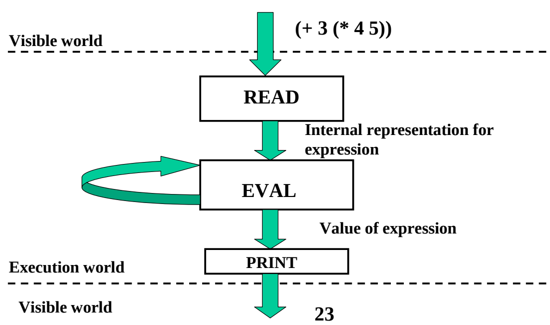
- Rules for evaluation

1. If **self-evaluating,** return value.
2. If a **name,** return value associated with name in environment.
3. If a **special form,** do something special.
4. If a **combination,** then

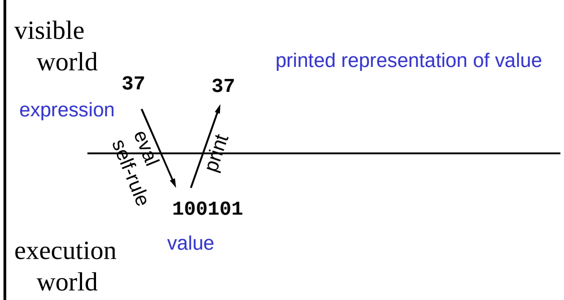
   a. *Evaluate* all of the subexpressions of combination (in any order)

   b. *apply* the operator to the values of the operands (arguments) and return result

Read-Eval-Print Loop



A new idea: two worlds



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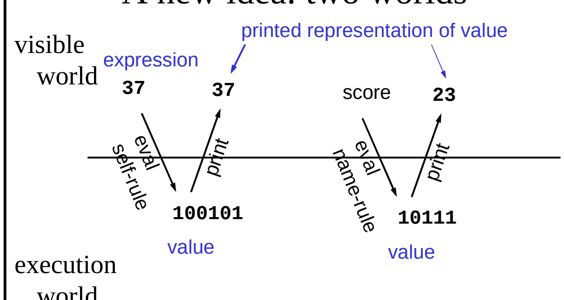
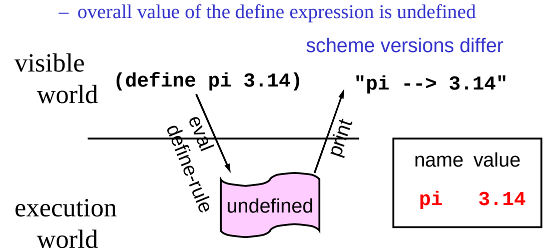


name-rule: look up value of name in current environment

Define special form

- define-rule:
  – evaluate 2nd operand only
  – name in 1st operand position is bound to that value
  – overall value of the define expression is undefined



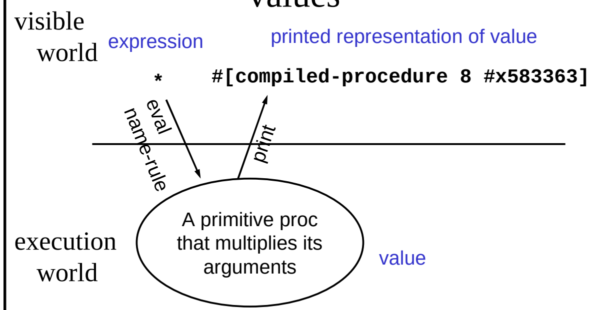
Mathematical operators are just names

```
(+ 3 5)              ➔ 8

(define fred +)      ➔ undef

(fred 4 6)           ➔ 10
```

- How to explain this?

- Explanation
  - + is just a name
  - + is bound to a value which is a procedure
  - line 2 binds the name **`fred`** to that same value

Primitive procedures are just values



Summary

- Primitive data types
- Primitive procedures
- Means of combination
- Means of abstraction – names