

## 6.001: Structure and Interpretation of Computer Programs

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

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## 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/>

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## 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

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## 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!!

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## Contact information

- Web site: <http://sicp.csail.mit.edu/>
- Course secretary
  - Donna Kaufman, [dkauf@mit.edu](mailto:dkauf@mit.edu), 38-409a, 3-4624
- Instructor in charge, lecturer
  - Eric Grimson, [welg@csail.mit.edu](mailto:welg@csail.mit.edu)
- Co-lecturer
  - Rob Miller, [rcm@csail.mit.edu](mailto:rcm@csail.mit.edu)



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## Section Instructors



Prof. Michael Collins



Gerald Dalley



Prof. Berthold Horn



Prof. Peter Szolovits



Dr. Kimberle Koile

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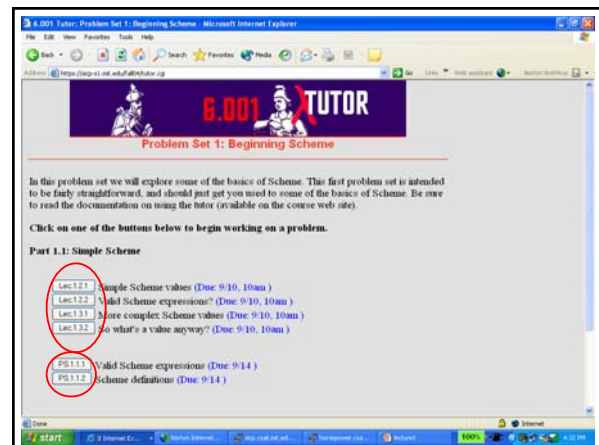
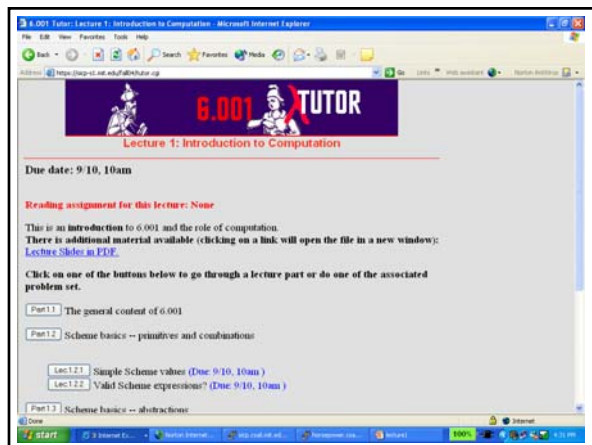
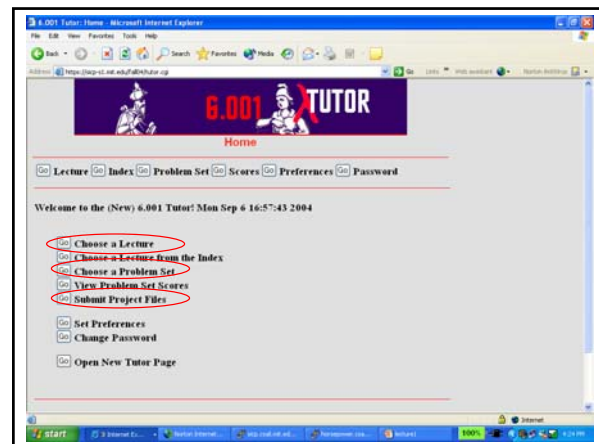
## Other logistics

- 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

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## 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)

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## Other Issues

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

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## 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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## 6.001

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

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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

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## Declarative Knowledge

- “What is true” knowledge

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

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## 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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## Imperative Knowledge

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

X = 2	G = 1
X/G = 2	G = $\frac{1}{2}(1 + 2) = 1.5$

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## Imperative Knowledge

- “How to” knowledge
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Example:  $\sqrt{x}$  for  $x = 2$ .

$X = 2$	$G = 1$
$X/G = 2$	$G = \frac{1}{2}(1 + 2) = 1.5$
$X/G = 4/3$	$G = \frac{1}{2}(3/2 + 4/3) = 17/12 = 1.416666$

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## Imperative Knowledge

- “How to” knowledge
- To find an approximation of square root of  $x$ :
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Example:  $\sqrt{x}$  for  $x = 2$ .

$X = 2$	$G = 1$
$X/G = 2$	$G = \frac{1}{2}(1 + 2) = 1.5$
$X/G = 4/3$	$G = \frac{1}{2}(3/2 + 4/3) = 17/12 = 1.416666$
$X/G = 24/17$	$G = \frac{1}{2}(17/12 + 24/17) = 1.4142156$

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## “How to” knowledge

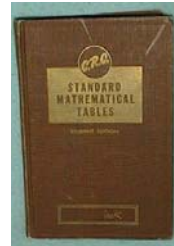
Why “how to” knowledge?

- Could just store tons of “what is” information

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NUMERICAL TABLES

Table F.4. Five-place Common Logarithms of Numbers\*

90-100

N	0	1	2	3	4	5	6	7	8	9
10	0.0000	0.0004	0.0008	0.0012	0.0015	0.0018	0.0021	0.0024	0.0027	0.0030
11	0.0033	0.0036	0.0039	0.0042	0.0045	0.0048	0.0051	0.0054	0.0057	0.0060
12	0.0063	0.0066	0.0069	0.0072	0.0075	0.0078	0.0081	0.0084	0.0087	0.0090
13	0.0093	0.0096	0.0099	0.0102	0.0105	0.0108	0.0111	0.0114	0.0117	0.0120
14	0.0123	0.0126	0.0129	0.0132	0.0135	0.0138	0.0141	0.0144	0.0147	0.0150
15	0.0153	0.0156	0.0159	0.0162	0.0165	0.0168	0.0171	0.0174	0.0177	0.0180
16	0.0183	0.0186	0.0189	0.0192	0.0195	0.0198	0.0201	0.0204	0.0207	0.0210
17	0.0213	0.0216	0.0219	0.0222	0.0225	0.0228	0.0231	0.0234	0.0237	0.0240
18	0.0243	0.0246	0.0249	0.0252	0.0255	0.0258	0.0261	0.0264	0.0267	0.0270
19	0.0273	0.0276	0.0279	0.0282	0.0285	0.0288	0.0291	0.0294	0.0297	0.0300
20	0.0303	0.0306	0.0309	0.0312	0.0315	0.0318	0.0321	0.0324	0.0327	0.0330
21	0.0333	0.0336	0.0339	0.0342	0.0345	0.0348	0.0351	0.0354	0.0357	0.0360
22	0.0363	0.0366	0.0369	0.0372	0.0375	0.0378	0.0381	0.0384	0.0387	0.0390
23	0.0393	0.0396	0.0399	0.0402	0.0405	0.0408	0.0411	0.0414	0.0417	0.0420
24	0.0423	0.0426	0.0429	0.0432	0.0435	0.0438	0.0441	0.0444	0.0447	0.0450
25	0.0453	0.0456	0.0459	0.0462	0.0465	0.0468	0.0471	0.0474	0.0477	0.0480
26	0.0483	0.0486	0.0489	0.0492	0.0495	0.0498	0.0501	0.0504	0.0507	0.0510
27	0.0513	0.0516	0.0519	0.0522	0.0525	0.0528	0.0531	0.0534	0.0537	0.0540
28	0.0543	0.0546	0.0549	0.0552	0.0555	0.0558	0.0561	0.0564	0.0567	0.0570
29	0.0573	0.0576	0.0579	0.0582	0.0585	0.0588	0.0591	0.0594	0.0597	0.0600
30	0.0603	0.0606	0.0609	0.0612	0.0615	0.0618	0.0621	0.0624	0.0627	0.0630
31	0.0633	0.0636	0.0639	0.0642	0.0645	0.0648	0.0651	0.0654	0.0657	0.0660
32	0.0663	0.0666	0.0669	0.0672	0.0675	0.0678	0.0681	0.0684	0.0687	0.0690
33	0.0693	0.0696	0.0699	0.0702	0.0705	0.0708	0.0711	0.0714	0.0717	0.0720
34	0.0723	0.0726	0.0729	0.0732	0.0735	0.0738	0.0741	0.0744	0.0747	0.0750
35	0.0753	0.0756	0.0759	0.0762	0.0765	0.0768	0.0771	0.0774	0.0777	0.0780
36	0.0783	0.0786	0.0789	0.0792	0.0795	0.0798	0.0801	0.0804	0.0807	0.0810
37	0.0813	0.0816	0.0819	0.0822	0.0825	0.0828	0.0831	0.0834	0.0837	0.0840
38	0.0843	0.0846	0.0849	0.0852	0.0855	0.0858	0.0861	0.0864	0.0867	0.0870
39	0.0873	0.0876	0.0879	0.0882	0.0885	0.0888	0.0891	0.0894	0.0897	0.0900
40	0.0903	0.0906	0.0909	0.0912	0.0915	0.0918	0.0921	0.0924	0.0927	0.0930
41	0.0933	0.0936	0.0939	0.0942	0.0945	0.0948	0.0951	0.0954	0.0957	0.0960
42	0.0963	0.0966	0.0969	0.0972	0.0975	0.0978	0.0981	0.0984	0.0987	0.0990
43	0.0993	0.0996	0.0999	0.1002	0.1005	0.1008	0.1011	0.1014	0.1017	0.1020
44	0.1023	0.1026	0.1029	0.1032	0.1035	0.1038	0.1041	0.1044	0.1047	0.1050
45	0.1053	0.1056	0.1059	0.1062	0.1065	0.1068	0.1071	0.1074	0.1077	0.1080
46	0.1083	0.1086	0.1089	0.1092	0.1095	0.1098	0.1101	0.1104	0.1107	0.1110
47	0.1113	0.1116	0.1119	0.1122	0.1125	0.1128	0.1131	0.1134	0.1137	0.1140
48	0.1143	0.1146	0.1149	0.1152	0.1155	0.1158	0.1161	0.1164	0.1167	0.1170
49	0.1173	0.1176	0.1179	0.1182	0.1185	0.1188	0.1191	0.1194	0.1197	0.1200
50	0.1203	0.1206	0.1209	0.1212	0.1215	0.1218	0.1221	0.1224	0.1227	0.1230
51	0.1233	0.1236	0.1239	0.1242	0.1245	0.1248	0.1251	0.1254	0.1257	0.1260
52	0.1263	0.1266	0.1269	0.1272	0.1275	0.1278	0.1281	0.1284	0.1287	0.1290
53	0.1293	0.1296	0.1299	0.1302	0.1305	0.1308	0.1311	0.1314	0.1317	0.1320
54	0.1323	0.1326	0.1329	0.1332	0.1335	0.1338	0.1341	0.1344	0.1347	0.1350
55	0.1353	0.1356	0.1359	0.1362	0.1365	0.1368	0.1371	0.1374	0.1377	0.1380
56	0.1383	0.1386	0.1389	0.1392	0.1395	0.1398	0.1401	0.1404	0.1407	0.1410
57	0.1413	0.1416	0.1419	0.1422	0.1425	0.1428	0.1431	0.1434	0.1437	0.1440
58	0.1443	0.1446	0.1449	0.1452	0.1455	0.1458	0.1461	0.1464	0.1467	0.1470
59	0.1473	0.1476	0.1479	0.1482	0.1485	0.1488	0.1491	0.1494	0.1497	0.1500
60	0.1503	0.1506	0.1509	0.1512	0.1515	0.1518	0.1521	0.1524	0.1527	0.1530
61	0.1533	0.1536	0.1539	0.1542	0.1545	0.1548	0.1551	0.1554	0.1557	0.1560
62	0.1563	0.1566	0.1569	0.1572	0.1575	0.1578	0.1581	0.1584	0.1587	0.1590
63	0.1593	0.1596	0.1599	0.1602	0.1605	0.1608	0.1611	0.1614	0.1617	0.1620
64	0.1623	0.1626	0.1629	0.1632	0.1635	0.1638	0.1641	0.1644	0.1647	0.1650
65	0.1653	0.1656	0.1659	0.1662	0.1665	0.1668	0.1671	0.1674	0.1677	0.1680
66	0.1683	0.1686	0.1689	0.1692	0.1695	0.1698	0.1701	0.1704	0.1707	0.1710
67	0.1713	0.1716	0.1719	0.1722	0.1725	0.1728	0.1731	0.1734	0.1737	0.1740
68	0.1743	0.1746	0.1749	0.1752	0.1755	0.1758	0.1761	0.1764	0.1767	0.1770
69	0.1773	0.1776	0.1779	0.1782	0.1785	0.1788	0.1791	0.1794	0.1797	0.1800
70	0.1803	0.1806	0.1809	0.1812	0.1815	0.1818	0.1821	0.1824	0.1827	0.1830
71	0.1833	0.1836	0.1839	0.1842	0.1845	0.1848	0.1851	0.1854	0.1857	0.1860
72	0.1863	0.1866	0.1869	0.1872	0.1875	0.1878	0.1881	0.1884	0.1887	0.1890
73	0.1893	0.1896	0.1899	0.1902	0.1905	0.1908	0.1911	0.1914	0.1917	0.1920
74	0.1923	0.1926	0.1929	0.1932	0.1935	0.1938	0.1941	0.1944	0.1947	0.1950
75	0.1953	0.1956	0.1959	0.1962	0.1965	0.1968	0.1971	0.1974	0.1977	0.1980
76	0.1983	0.1986	0.1989	0.1992	0.1995	0.1998	0.2001	0.2004	0.2007	0.2010
77	0.2									

\* Additional figures in the last two columns given.

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## 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.

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## 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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## 6.001

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

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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

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## 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**

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## 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

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## Binary numbers and operations

- Unsigned integers

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

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

$$1 + 2 + 8 = 11$$

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## Binary numbers and operations

- Addition

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

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

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## 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)

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



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



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

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## 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

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## 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

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## Our language for 6.001

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



Guy Steele

Gerry Sussman



John McCarthy

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## Rules for describing processes in Scheme

1. Legal expressions have rules for **Syntax** constructing from simpler pieces
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**.

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## Kinds of Language Constructs

- Primitives
- Means of combination
- Means of abstraction

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## 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

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## George Boole



A Founder

*An Investigation of the Laws of Thought*, 1854  
-- "a calculus of symbolic reasoning"

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## Language elements – primitives

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

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## 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

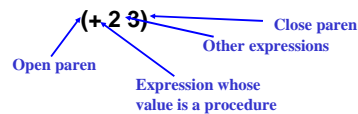
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## Language elements – combinations

- How do we create expressions using these procedures?



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

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## Language elements - combinations

- Can use nested combinations – just apply rules recursively

`(+ (* 2 3) 4)`  
→10

`(* (+ 3 4)  
(- 8 2))`  
→42

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## 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

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## 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

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## Scheme Basics

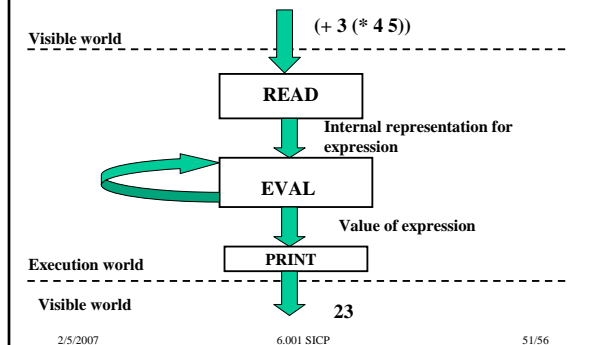
- Rules for evaluation
  - If **self-evaluating**, return value.
  - If a **name**, return value associated with name in environment.
  - If a **special form**, do something special.
  - If a **combination**, then
    - Evaluate all of the subexpressions of combination (**in any order**)
    - apply the operator to the values of the operands (arguments) and return result

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## Read-Eval-Print Loop

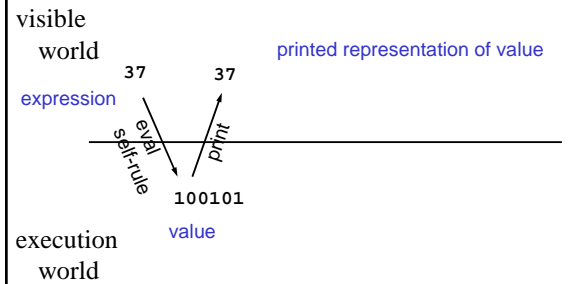


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## A new idea: two worlds

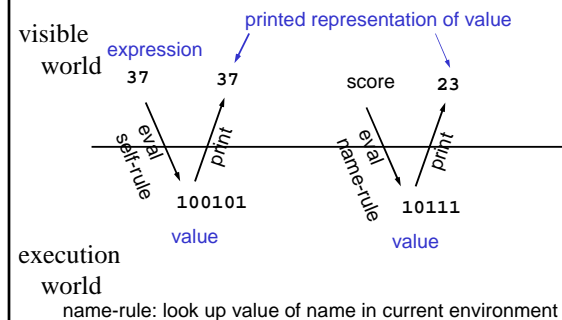


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## A new idea: two worlds



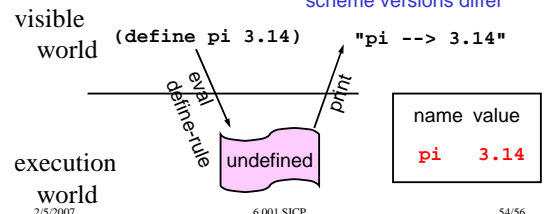
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## Define special form

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



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## Mathematical operators are just names

```
(+ 3 5)      → 8  
(define fred +)  → undef  
(fred 4 6)    → 10
```

• How to explain this?

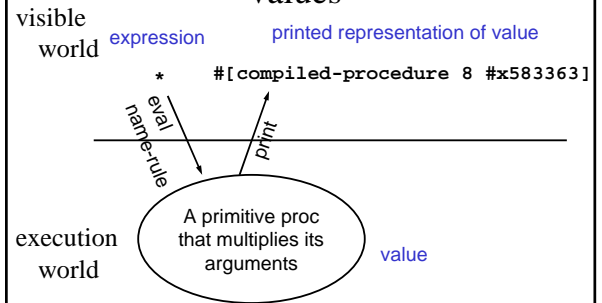
- Explanation
  - + is just a name
  - + is bound to a value which is a procedure
  - line 2 binds the name **fred** to **that same value**

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## Primitive procedures are just values



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## Summary

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

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