CIS 110

Introduction to Computer Programming
University of Pennsylvania
Summer 2012

Benedict Brown

www.seas.upenn.edu/~cis110

Overview

What is CIS 110? Introduction to programming and computer science

Goals
- Demystify computer systems: what can computer do?
- Demystify computer science: what are the intellectual underpinnings?
- Demystify computer scientists: how do we think?

Topics
- Programming in Java
- Designing and understanding behavior of algorithms
- Applications to science, engineering, and commercial computing

> *" Computers are incredibly fast, accurate, and stupid; humans are incredibly slow, inaccurate, and brilliant; together they are powerful beyond imagination. "* – *Albert Einstein*

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The Basics

Lectures. [Benedict Brown]
- Monday - Thursday, Towne 303, 10am - 11am
- Office hours: TBD in GRW 258 — and by appointment
- Email: `bjbrown@cis.upenn.edu`

Recitations
- Monday - Thursday, Towne 311 and TBD, 11am - 12pm
- Attendance required
- Two TAs per section: twice the fun!
- Clarify lecture material, tips on assignments, group activities

Computer laboratory
- TA office hours in Moore computer lab (TBD)
- Help with debugging

Full details and office hours. See `www.seas.upenn.edu/~cis110`

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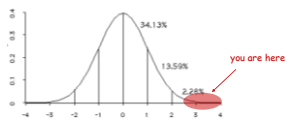
Grades

Course grades No preset curve or quota, but all work will be curved

~6 programming assignments	50%
Midterm	20%
Final Exam	30%
Extra credit and staff discretion	Adjust borderline cases.

Check grades Course web site



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Course Materials

Course website [`www.seas.upenn.edu/~cis110`]
- Programming assignments and checklists
- Submit assignments
- Lecture slides ← usually posted after lecture
- ~~Lecture videos~~ ← don't always record properly, and don't record everything!
- Discussion board

skim before lecture; read thoroughly afterwards

Required text. Sedgewick and Wayne. *Intro to Programming in Java: An Interdisciplinary Approach.*

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Programming Assignments

Desiderata
- Address an important scientific or commercial problem
- Illustrate the importance of a fundamental CS concept
- You solve problem from scratch!

Due 9pm on due date via Web submission
- 3 hour grace period (no extra credit, won't get questions answered)
- No late days! No extensions! — Summer term is too compressed

Computing equipment.
- Your laptop [OS X, Windows, Linux, ...]
- Moore computer labs

Advice.
- Start early; plan multiple sessions
- Seek help when needed — our job is to help you!

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What's Ahead?

Lecture 2 Intro to Java (11am)

First recitation Tomorrow

Change your section? Contact Dr. Brown [bjbrown@cis.upenn.edu]

Assignment 0. Due tomorrow, May 22, 9pm.

- Read Sections 1.1 and 1.2 in textbook.
- Install Java programming environment + a few exercises.
- Register for Piazza [http://piazza.com/upenn/summer2012/cis110]
- Lots of help available, don't be bashful.

END OF ADMINISTRATIVE STUFF

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Languages

Machine languages. Tedious and error-prone.

Natural languages. Ambiguous and hard for computer to parse.

Kids Make Nutritious Snacks
Red Tape Holds Up New Bridge
Police Squad Helps Dog Bite Victim
Local High School Dropouts Cut in Half
[real newspaper headlines, compiled by Rich Pattis]

'At Last' Singer Etta James Terminally Ill
[New York Time Online, 16 December 2011]

"Santorum is an Unpleasant By-Product of Sex"
[deredactie.be, 6 January 2012]

High-level programming languages. Acceptable tradeoff.

"Instead of imagining that our main task is to instruct a computer what to do, let us concentrate rather on explaining to human beings what we want a computer to do." – Donald Knuth

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Hello, World

0. Prologue: A Simple Machine

Secure Chat

Alice wants to send a secret message to Bob?

- Sometime in the past, they exchange a one-time pad
- Alice uses the pad to encrypt the message
- Bob uses the same pad to decrypt the message

Key point Without the pad, Eve cannot understand the message

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Encryption Machine

Goal Design a machine to encrypt and decrypt data

S	E	N	D	M	O	N	E	Y

encrypt

g	X	7	6	W	3	v	7	K

decrypt

S	E	N	D	M	O	N	E	Y

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Encryption Machine

Goal Design a machine to encrypt and decrypt data

S	E	N	D	M	O	N	E	Y

encrypt

g	X	7	6	W	3	v	7	K

decrypt

S	E	N	D	M	O	N	E	Y

Enigma encryption machine

- "Unbreakable" German code during WWII
- Broken by Turing bombe
- One of first uses of computers
- Helped win Battle of Atlantic by locating U-boats

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A Digital World

Data is a sequence of bits [bit = 0 or 1]

- Text
- Programs, executables
- Documents, pictures, sounds, movies, …

File formats txt, pdf, java, exe, docx, pptx, jpeg, mp3, divx, …

computer with a lens

computer with earbuds

computer with a radio

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A Digital World

Data is a sequence of bits [bit = 0 or 1]

- Text
- Programs, executables
- Documents, pictures, sounds, movies, …

File formats txt, pdf, java, exe, docx, pptx, jpeg, mp3, divx, …

computer with a cash dispenser

computer with a ballot box

computer with a heating element

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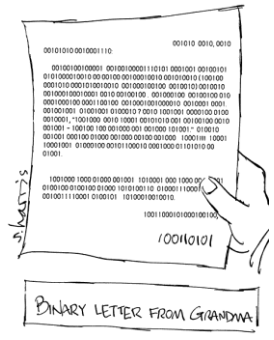

Copyright 2004, Sidney Harris, http://www.sciencecartoonsplus.com

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A Digital World

Data is a sequence of bits [bit = 0 or 1]

- Text
- Programs, executables
- Documents, pictures, sounds, movies, …

Base64 encoding Use 6 bits to represent each alphanumeric symbol.

very weak type of encryption

Binary	Char	Binary	Char	Binary	Char	Binary	Char	Binary	Char	Binary	Char
000000	A	001011	L	010110	W	100001	h	101100	s	110111	3
000001	B	001100	M	010111	X	100010	i	101101	t	111000	4
000010	C	001101	N	011000	Y	100011	j	101110	u	111001	5
000011	D	001110	O	011001	Z	100100	k	101111	v	111010	6
000100	E	001111	P	011010	a	100101	l	110000	w	111011	7
000101	F	010000	Q	011011	b	100110	m	110001	x	111100	8
000110	G	010001	R	011100	c	100111	n	110010	y	111101	9
000111	H	010010	S	011101	d	101000	o	110011	z	111110	+
001000	I	010011	T	011110	e	101001	p	110100	0	111111	/
001001	J	010100	U	011111	f	101010	q	110101	1		
001010	K	010101	V	100000	g	101011	r	110110	2		

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One-Time Pad Encryption

Encryption

- Convert text message to N bits

Base64 Encoding

char	dec	binary
A	0	000000
B	1	000001
…	…	…
M	12	001100
…	…	…

S	E	N	D	M	O	N	E	Y	
010010	000100	001101	000011	001100	001110	001101	000100	011000	base64

message

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One-Time Pad Encryption

Encryption

- Convert text message to N bits
- Generate N random bits (one-time pad)

S	E	N	D	M	O	N	E	Y	
010010	000100	001101	000011	001100	001110	001101	000100	011000	base64
110010	010011	110110	111001	011010	111001	100010	111111	010010	random bits

message

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One-Time Pad Encryption

Encryption

- Convert text message to N bits
- Generate N random bits (one-time pad)
- Take bitwise XOR of two bitstrings

sum corresponding pair of bits: 1 if sum is odd, 0 if even

XOR Truth Table

x	y	x ^ y
0	0	0
0	1	1
1	0	1
1	1	0

S	E	N	D	M	O	N	E	Y	
010010	000100	001101	000011	001100	001110	001101	000100	011000	base64
110010	010011	110110	111001	011010	111001	100010	111111	010010	random bits
100000	010111	111011	111010	010110	110111	101111	111011	001010	XOR

message

0 ^ 1 = 1

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One-Time Pad Encryption

Encryption

- Convert text message to N bits
- Generate N random bits (one-time pad)
- Take bitwise XOR of two bitstrings
- Convert binary back into text

Base64 Encoding

char	dec	binary
A	0	000000
B	1	000001
…	…	…
w	22	010110
…	…	…

S	E	N	D	M	O	N	E	Y	
010010	000100	001101	000011	001100	001110	001101	000100	011000	base64
110010	010011	110110	111001	011010	111001	100010	111111	010010	random bits
100000	010111	111011	111010	010110	110111	101111	111011	001010	XOR
g	X	7	6	W	3	v	7	K	encrypted

message

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Secure Chat (review)

Alice wants to send a secret message to Bob?

- Sometime in the past, they exchange a one-time pad
- Alice uses the pad to encrypt the message
- Bob uses the same pad to decrypt the message

Key point Without the pad, Eve cannot understand the message

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One-Time Pad Decryption

Decryption

- Convert encrypted message to binary

g	X	7	6	W	3	v	7	K	
									encrypted

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One-Time Pad Decryption

Decryption

- Convert encrypted message to binary

Base64 Encoding

char	dec	binary
A	0	000000
B	1	000001
...	...	...
W	22	010110
...	...	...

g	X	7	6	W	3	v	7	K	
100000	010111	111011	111010	010110	110111	101111	111011	001010	base64

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One-Time Pad Decryption

Decryption

- Convert encrypted message to binary
- Use same N random bits (one-time pad)

g	X	7	6	W	3	v	7	K	
100000	010111	111011	111010	010110	110111	101111	111011	001010	encrypted
100000	010111	111011	111010	010110	110111	101111	111011	001010	base64
110010	010011	110110	111001	011010	111001	100010	111111	010010	random bits

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One-Time Pad Decryption

Decryption

- Convert encrypted message to binary
- Use same N random bits (one-time pad)
- Take bitwise XOR of two bitstrings

XOR Truth Table

x	y	x ^ y
0	0	0
0	1	1
1	0	1
1	1	0

g	X	7	6	W	3	v	7	K	
100000	010111	111011	111010	010110	110111	101111	111011	001010	encrypted
100000	010111	111011	111010	010110	110111	101111	111011	001010	base64
110010	010011	110110	111001	011010	111001	100010	111111	010010	random bits
010010	000100	001101	000011	001100	001110	001101	000100	011000	XOR

1 ^ 1 = 0

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One-Time Pad Decryption

Decryption

- Convert encrypted message to binary
- Use same N random bits (one-time pad)
- Take bitwise XOR of two bitstrings
- Convert back into text

Base64 Encoding

char	dec	binary
A	0	000000
B	1	000001
...	...	...
M	12	001100
...	...	...

g	X	7	6	W	3	v	7	K	
100000	010111	111011	111010	010110	110111	101111	111011	001010	encrypted
100000	010111	111011	111010	010110	110111	101111	111011	001010	base64
110010	010011	110110	111001	011010	111001	100010	111111	010010	random bits
010010	000100	001101	000011	001100	001110	001101	000100	011000	XOR
S	E	N	D	M	O	N	E	Y	message

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Why Does It Work?

Crucial property Decrypted message = original message

Notation	Meaning
a	original message bit
b	one-time pad bit
^	XOR operator
a ^ b	encrypted message bit
(a ^ b) ^ b	decrypted message bit

XOR Truth Table

x	y	x ^ y
0	0	0
0	1	1
1	0	1
1	1	0

Why is crucial property true?

- Use properties of XOR.
- (a ^ b) ^ b = a ^ (b ^ b) = a ^ 0 = a

associativity of ^ · always 0 · identity

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One-Time Pad Decryption (with the wrong pad)

Decryption

- Convert encrypted message to binary

g	X	7	6	W	3	v	7	K	
									encrypted

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One-Time Pad Decryption (with the wrong pad)

Decryption

- Convert encrypted message to binary

g	X	7	6	W	3	v	7	K	
100000	010111	111011	111010	010110	110111	101111	111011	001010	encrypted
100000	010111	111011	111010	010110	110111	101111	111011	001010	base64

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One-Time Pad Decryption (with the wrong pad)

Decryption

- Convert encrypted message to binary
- Use wrong N bits (bogus one-time pad)

g	X	7	6	W	3	v	7	K	
100000	010111	111011	111010	010110	110111	101111	111011	001010	encrypted
100000	010111	111011	111010	010110	110111	101111	111011	001010	base64
101000	011100	110101	101111	010010	111001	100101	101010	001010	wrong bits

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One-Time Pad Decryption (with the wrong pad)

Decryption

- Convert encrypted message to binary
- Use wrong N bits (bogus one-time pad)
- Take bitwise XOR of two bitstrings

g	X	7	6	W	3	v	7	K	
100000	010111	111011	111010	010110	110111	101111	111011	001010	encrypted
100000	010111	111011	111010	010110	110111	101111	111011	001010	base64
101000	011100	110101	101111	010010	111001	100101	101010	001010	wrong bits
001000	001011	001110	010101	000100	001110	001010	010001	000000	XOR

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One-Time Pad Decryption (with the wrong pad)

Decryption

- Convert encrypted message to binary
- Use wrong N bits (bogus one-time pad)
- Take bitwise XOR of two bitstrings
- Convert back into text: Oops

g	X	7	6	W	3	v	7	K	
100000	010111	111011	111010	010110	110111	101111	111011	001010	encrypted
100000	010111	111011	111010	010110	110111	101111	111011	001010	base64
101000	011100	110101	101111	010010	111001	100101	101010	001010	wrong bits
001000	001011	001110	010101	000100	001110	001010	010001	000000	XOR
I	L	O	V	E	O	K	R	A	wrong message

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Goods and Bads of One-Time Pads

Good
- Easily computed by hand
- Very simple encryption/decryption processes
- Provably unbreakable if bits are truly random [Shannon, 1940s]

eavesdropper Eve sees only random bits

"one time" means one time only

Bad
- Easily breakable if pad is re-used
- Pad must be as long as the message
- Truly random bits are very hard to come by
- Pad must be distributed securely

impractical for Web commerce

a Russian one-time pad

Pseudo-Random Bit Generator

Practical middle-ground
- Let's make a "random"-bit generator gadget
- Alice and Bob each get identical small gadgets

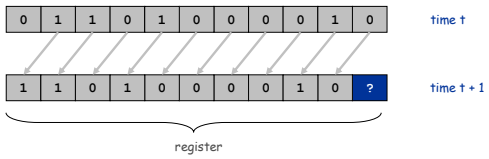
instead of identical large one-time pads

How to make small gadget that produces "random" bits
- Enigma machine
- Linear feedback shift register
- Linear congruential generator
- Blum-Blum-Shub generator
- ...

" Anyone who considers arithmetical methods of producing random digits is, of course, in a state of sin. "
– Jon von Neumann (left)
– ENIAC (right)

Shift Register

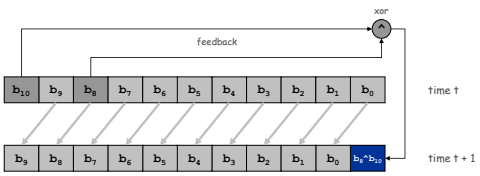
Shift register terminology.
- Bit: 0 or 1
- Cell: storage element that holds one bit
- Register: sequence of cells
- Seed: initial sequence of bits
- Shift register: when clock ticks, bits propagate one position to left



Linear Feedback Shift Register (LFSR)

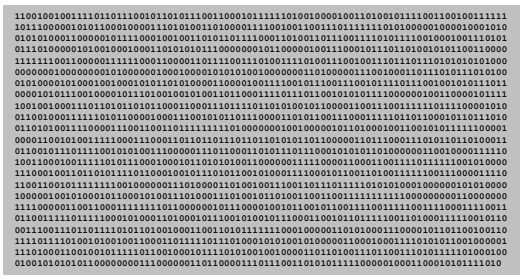
{8, 10} linear feedback shift register
- Shift register with 11 cells
- Bit b_0 is is XOR of previous bits b_8 and b_{10}
- Pseudo-random bit = b_0

LFSR demo



Random Numbers

Q. Are these 2000 numbers random? If not, what is the pattern?



A. No. This is output of {8, 10} LFSR with seed 01101000010!

LFSR Encryption

LFSR encryption
- Convert text message to N bits
- Initialize LFSR with small seed
- Generate N bits with LFSR
- Take bitwise XOR of two bitstrings
- Convert binary back into text

Base64 Encoding

char	dec	binary
A	0	000000
B	1	000001
…	…	…
W	22	010110
…	…	…

S	E	N	D	M	O	N	E	Y	message
010010	000100	001101	000011	001100	001110	001101	000100	011000	base64
110010	010011	110110	111001	011010	111001	100010	111111	010010	LFSR bits
100000	010111	111011	111010	010110	110111	101111	111011	001010	XOR
g	X	7	6	W	3	v	7	K	encrypted

LFSR Decryption

LFSR Decryption
- Convert encrypted message to N bits
- Initialize identical LFSR with same seed
- Generate N bits with LFSR
- Take bitwise XOR of two bitstrings
- Convert binary back into text

Base64 Encoding

char	dec	binary
A	0	000000
B	1	000001
…	…	…
M	12	001100
…	…	…

g	X	7	6	W	3	v	7	K	encrypted
100000	010111	111011	111010	010110	110111	101111	111011	001010	base64
110010	010011	110110	111001	011010	111001	100010	111111	010010	LFSR bits
010010	000100	001101	000011	001100	001110	001101	000100	011000	XOR
S	E	N	D	M	O	N	E	Y	message

Goods and Bads of LFSR Encryption

Goods
- Easily computed with simple machine
- Very simple encryption/decryption process
- Scalable: 20 cells for 1 million bits; 30 cells for 1 billion bits
  [but need theory of finite groups to know where to put taps]

a commercially available LFSR

Bads
- Still need secure, independent way to distribute LFSR seed
- The bits are not truly random
  [bits in our 11-bit LFSR cycle after 2^{11} - 1 = 2047 steps]
- Experts have cracked LFSR
  [more complicated machines needed]

Other LFSR Applications

What else can we do with a LFSR?
- DVD encryption with CSS
- DVD decryption with DeCSS!
- Subroutine in military cryptosystems

DVD Jon
(Norwegian hacker)

```
/*    sfdct.c    Author:  Charles M. Hannum <root@ihack.net>                */
/*    Usage is:  cat title-key scrambled.vob | sfdct >clear.vob             */

#define m(i)(x[i]^s[i+84])<<

                  unsigned char x[5]      ,y,s[2048];main(
                  n){for( read(0,x,5      );read(0,s  ,n=2048
                         ); write(1    ,s,n)         );if(s
                  [y=s      [13]%8+20]  /16%4  ==1       ){int
                  i=m(      1)17  ^256 *m(0)   8,k      =m(2)
                  0,j=      m(4)   17^ m(3)   9*k+      2-k%8
                  ^8,s      =0,c    =26;for   (s[y]     -=16;
                  --c;j     *=2)a=      a*2^i&    1,i=i /2^j&1
                  <<24;for(j=           127;      ++j<c;c+=2>
                                        y)
                                        c

                        +=y=i^i/8^i>>4^i>>12,
                    i=i>>8^y<<17,a^=a>>14,y=a^a*8^a<<6,a=a
                  >>8^y<<9,k=s[j],k       =7&0-~G_\216^[k
                  &7]+2^"cr3sfw6v;*k+>/n."[k>>4]*2^k*257/
                        8,s[j]=k^(k&k*2&34)*6^c+-y
                                  ;}}
```

http://www.cs.cmu.edu/~dst/DeCSS/Gallery

LFSR vs. General-Purpose Computer

Important properties
- Built from simple components
- Scales to handle huge problems
- Requires a deep understanding to use effectively

Basic Component	LFSR	Computer
control	start, stop, load	same
clock	regular pulse	2.8 GHz pulse
memory	11 bits	4 GB
input	seed	sequence of bits
computation	shift, XOR	logic, arithmetic, …
output	pseudo-random bits	Sequence of bits

Critical difference. General-purpose computer can be programmed to simulate any abstract machine

A Profound Idea

Programming Can write a Java program to simulate the operations of any abstract machine
- Basis for theoretical understanding of computation
- Basis for bootstrapping real machines into existence

```
public class LFSR {
   private int seed[];
   private final int tap;
   private final int N;

   public LFSR(String seed, int tap) { … }

   public int step() { … }

   public static void main(String[] args) {
      LFSR lfsr = new LFSR("01101000010", 8);
      for (int i = 0; i < 2000; i++)
         StdOut.println(lfsr.step());
   }
}
```

```
% java LFSR
11001001001111011011001011010
01110011000101111101001000001
00110100101111001100100111...
```

A Closing Profound Question

Q. What is a random number?

LFSR does not produce random numbers
- It is a very simple deterministic machine
- But not obvious how to distinguish the bits it produces from random

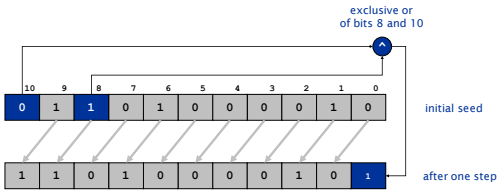
Q. Are truly random processes found in nature?
- Motion of cosmic rays or subatomic particles?
- Mutations in DNA?

Q. Or, is the natural world a (not-so-simple) deterministic machine?

" God does not play dice. "
– Albert Einstein

Extra Slides

Linear Feedback Shift Register



One step of an 11-bit LFSR with initial seed 01101000010 and tap at position 8