CS 33: Computer Organization

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Some notes adopted from Bryant and O'Hallaron

Updated COVID-19 protocols for spring quarter, beginning April 11

UCLA will see some significant COVID-19 protocol changes for those who are up to date with their COVID-19 vaccines (including boosters), depending on the public health conditions remaining constant.

If current trends continue, the following changes are anticipated to go into effect on Monday, April 11:

Surveillance testing and masking

Students, faculty and staff who are up to date with their COVID-19 vaccines may opt out of weekly surveillance testing and indoor mask wearing, although these precautionary mitigations remain highly recommended.

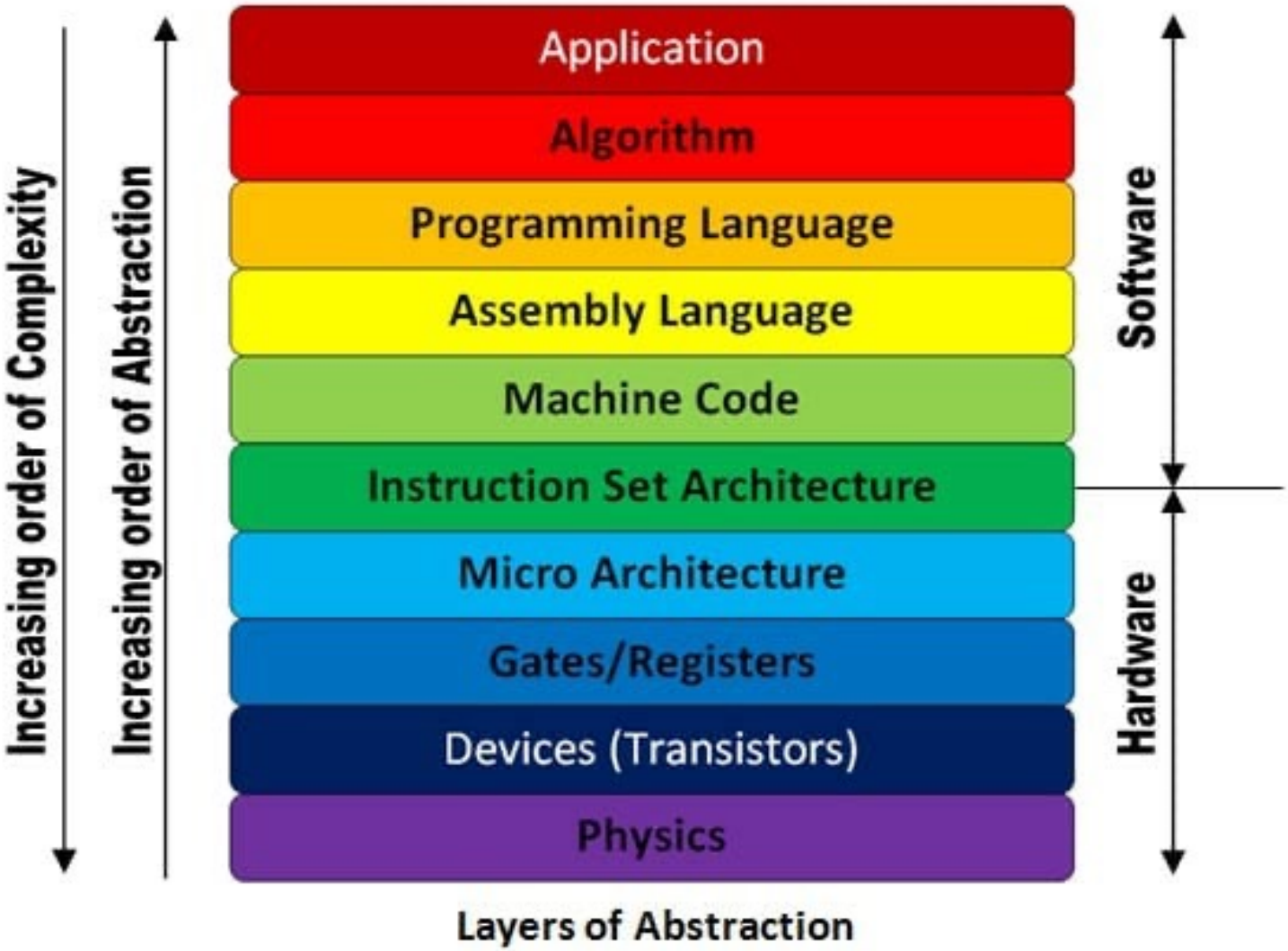
Masking exception: Instructors who are up to date with their COVID-19 vaccines and able to maintain at least six feet of distance from others may choose to remove their masks during lectures to enhance learning goals as early as March 28.

Students, faculty and staff who are not up to date with their COVID-19 vaccines and are learning, working, living or otherwise participating in activities on campus or other UCLA properties will continue to be required to participate in weekly surveillance testing and wear upgraded masks indoors until further notice.

UCLA Counseling and Psychological Services

John Wooden Center West
221 Westwood Plaza
Box 951556
Los Angeles, CA 90095-1556

Phone: (310) 825-0768
After-hours crisis counseling available by phone


Increasing order of Complexity
Increasing order of Abstraction
Application
Algorithm
Programming Language
Assembly Language
Machine Code
Instruction Set Architecture
Micro Architecture
Gates/Registers
Devices (Transistors)
Physics
Software
Hardware
Layers of Abstraction

Course Components

- **Lectures**
  - Higher level concepts
- **Discussions**
  - Applied concepts, important tools and skills for labs, clarification of lectures, exam coverage
- **Labs**
  - The heart of the course
  - Provide in-depth understanding of an aspect of systems
  - Programming and measurement

More Info

- **Web**
  - Class web page hosted by BruinLearn
  - Copies of lectures, assignments, exams, solutions
  - Forum
- **Office Hours**
- **Textbook**
  - Randal E. Bryant and David R. O'Hallaron. "Computer Systems: A Programmer's Perspective", **3rd Edition**, Prentice Hall 2015.

Grading

- **Exams (50%)**
  - Midterm (20%)
  - Final (30%)
  - All exams are open book/open notes.
- **Labs (35%)**
  - 4 labs (8% each)
  - 1 warmup lab (3%)
  - You must work alone on all labs
- **Discussion (10%)**
- **Homework (5%)**
  - Electronic submission only

Tentative Calendar

Wk #	Monday's	Wednesday's	Friday's
1	Intro + Bits and Bytes (1,2)	Integers (2)	Warmup Lab Due
2	Machine-Lvl Prog I: Basics (3)	Machine-Lvl Prog II: Control (3)	
3	Machine-Lvl Prog III: Procedures (3)	Machine-Lvl Prog IV: Data (3)	Data Lab Due
4	Machine-Lvl Prog V: Adv Topics (3)	Floating Point (2)	
5	MIDTERM EXAM	Program Optimization (5)	Bomb Lab Due
6	The Memory Hierarchy (6)	Cache Memories (6)	
7	Concurrency (12+handouts)	Concurrency (12+handouts)	Attack Lab Due
8	Linking + Exceptions (7,8)	Virtual Memory (9)	
9	I/O (10)	MIPS (handouts)	
10	Holiday	Review	Parallel Lab Due

- **Homework and Labs Due via CourseWeb by 11:59pm**
- **Final Exam: Monday, June 6th, 11:30am-2:30pm**

Cheating

- **What is cheating?**
  - Sharing code: either by copying, retyping, looking at, or supplying a copy of a file.
- **What is NOT cheating?**
  - Helping others use systems or tools.
  - Helping others with high-level design issues.
  - Helping others debug their code.
- **Penalty for cheating:**
  - At the discretion of the Associate Dean

102.01a: Cheating
Cheating includes, but is not limited to, the use of unauthorized materials (including online sources such as Course Hero, GitHub or Chegg), information, or study aids in any academic exercise; the alteration of any answers on a graded document before submitting it for re-grading; or the failure to observe the expressed procedures or instructions of an academic exercise (e.g., examination instructions regarding alternate seating or conversation during an examination).

Lab Facilities

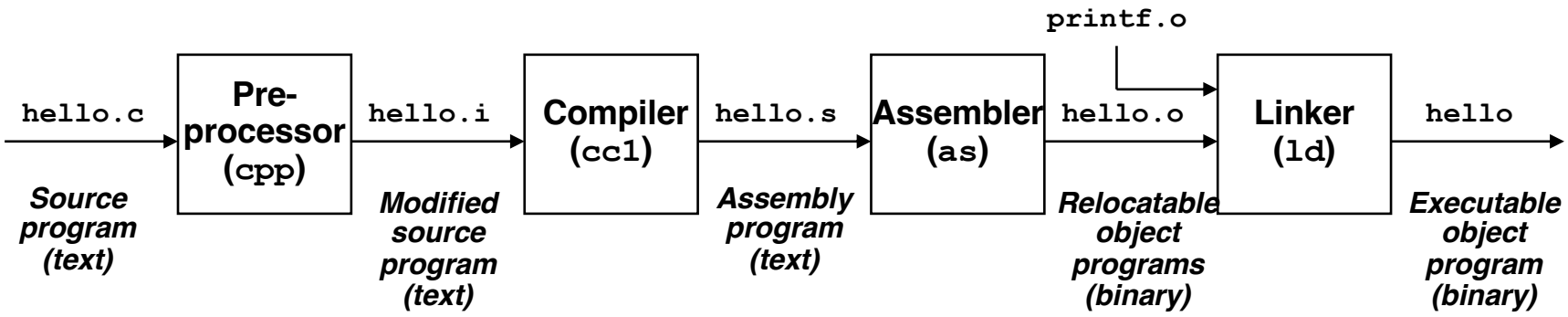
- **SEAS Administered Linux Machine**
  - `cs33.seas.ucla.edu`
  - Remote access only
    - Use ssh to log in with your SEAS account
  - Please direct any account issues to the SEAS help desk as they are the only ones with root access on this machine
- **Alternatives (Not Recommended)**
  - You may use other alternatives to develop your code
  - **BUT: We will test on the SEAS machines**
    - **Your code must work correctly on these machines for credit**

Course Theme

- **Abstraction is good, but don't forget reality!**
- **Abstractions have limits**
  - Things are more complex in hardware than they look in C/Java!!
  - Bugs are hard to track/understand if looking only from a high-level point of view
- **Useful outcomes**
  - Become more effective programmers
    - Able to find and eliminate bugs efficiently
    - Able to tune program performance
  - Prepare for later "systems" classes in CS
    - Compilers, Operating Systems, Networks, Computer Architecture, Parallel Programming

The Compilation System

```
#include <stdio.h>
int main()
{
    printf("hello, world\n");
}
```



Encoding Byte Values

- **Byte = 8 bits**
  - Binary 00000000_2 to 11111111_2
  - Decimal: 0_{10} to 255_{10}
  - Hexadecimal 00_{16} to FF_{16}
    - Base 16 number representation
    - Use characters ‘0’ to ‘9’ and ‘A’ to ‘F’
    - Write $FA1D37B_{16}$ in C as
      - 0xFA1D37B
      - 0xfa1d37b

Hex	Decimal	Binary
0	0	0000
1	1	0001
2	2	0010
3	3	0011
4	4	0100
5	5	0101
6	6	0110
7	7	0111
8	8	1000
9	9	1001
A	10	1010
B	11	1011
C	12	1100
D	13	1101
E	14	1110
F	15	1111

Bit-Level Operations in C

- **Operations `&`, `|`, `~`, `^` Available in C**
  - Apply to any "integral" data type
    - `long, int, short, char, unsigned`
  - View arguments as bit vectors
  - Arguments applied bit-wise
- **Examples (Char data type)**
  - ~0x41 → 0xBE
    - $\sim 01000001_2 \rightarrow 10111110_2$
  - ~0x00 → 0xFF
    - $\sim 00000000_2 \rightarrow 11111111_2$
  - 0x69 & 0x55 → 0x41
    - $01101001_2 \,\&\, 01010101_2 \rightarrow 01000001_2$
  - 0x69 | 0x55 → 0x7D
    - $01101001_2 \mid 01010101_2 \rightarrow 01111101_2$

Contrast: Logic Operations in C

- **Contrast to Logical Operators**
  - `&&, ||, !`
    - View 0 as "False"
    - Anything nonzero as "True"
    - Always return 0 or 1
    - Early termination
- **Examples (char data type)**
  - !0x41 → 0x00
  - !0x00 → 0x01
  - !!0x41 → 0x01

  - 0x69 && 0x55 → 0x01
  - 0x69 || 0x55 → 0x01
  - p && *p (avoids null pointer access)

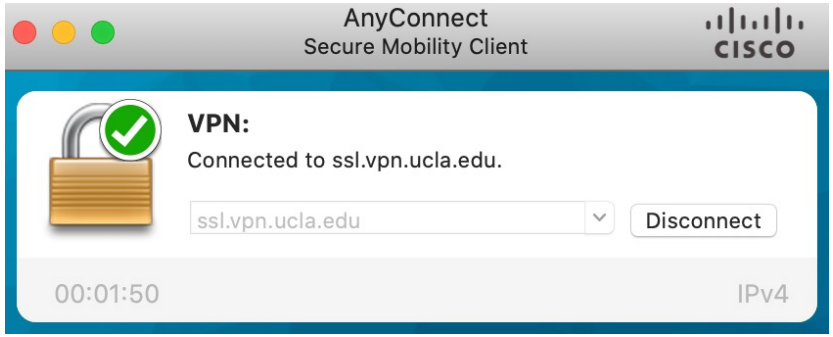
Shift Operations

- **Left Shift: `x << y`**
  - Shift bit-vector `x` left `y` positions
    - Throw away extra bits on left
  - Fill with 0's on right
- **Right Shift: `x >> y`**
  - Shift bit-vector `x` right `y` positions
  - Throw away extra bits on right
  - Logical shift
    - Fill with 0's on left
  - Arithmetic shift
    - Replicate most significant bit on left
- **Undefined Behavior**
  - Shift amount < 0 or ≥ word size

Argument `x`	01100010
<< 3	00010*000*
Log. >> 2	*00*011000
Arith. >> 2	*00*011000

Argument `x`	10100010
<< 3	00010*000*
Log. >> 2	*00*101000
Arith. >> 2	*11*101000

Connecting to Lab Computers




```
[kiwi.cs.ucla.edu] 51 % ssh cs33.seas.ucla.edu
reinman@cs33.seas.ucla.edu's password:
Last login: Sun Mar 27 22:10:54 2022 from kiwi.cs.ucla.edu
*********************************************************************
                        lnxsrv06.seas.ucla.edu RHEL 7
*********************************************************************

        * User processes older than 36 hours will be cleaned up

*********************************************************************
*********************************************************************
* SEASnet Computing Access                                          *
*                                                                   *
* Priority is given both on the servers and in the student labs to those   *
* students doing coursework. Computing support for research is provided by  *
* each department.                                                  *
*********************************************************************
* For assistance please contact help@seas.ucla.edu or call 206-6864.        *
*********************************************************************
[reinman@lnxsrv06 ~]$
```

Editing

- Use your linux editor of choice (emacs, vi, …)

```
[[reinman@lnxsrv03 ~/code]$ emacs -nw bits-demo.c
```

```c
#include <string.h>
#include <stdlib.h>
#include <stdio.h>

void binary_dump (char printme) {
  int i;

  for (i = 0; i < 8; i++) {
    printf("%d", !!((printme << i) & 0x80));
  }
  printf("\n");
}

int main( int argc, const char* argv[] ) {
  char stringy[8];
  char charbq;
  int integrr;
  char byteme;
  char bitarray;

  charbq = 0x74;
  strcpy (stringy,"abcdefg");
  integrr = 42;
  byteme = 0b01101111;
  //byteme = 0x6F   0110 1111
  bitarray = 0b01010101;
  //byteme = 0x55 0101 0101

  printf("stringy = %s\n", stringy);
  printf("charbq = %c\n", charbq);
  printf("integrr = %d\n", integrr);

  printf("byteme = %c 0x%x\n", byteme, byteme);

  printf("byteme: ");
  binary_dump(byteme);

  printf("bitarray: ");
-UU-:----F1  bits-demo.c    Top L20    (C/l Abbrev)----------------------------------------------------------
```

Sample C Code

```
int main( int argc, const char* argv[] ) {
  char stringy[8];
  char charbq;
  int integrr;
  char byteme;
  char bitarray;

  charbq = 0x74;
  strcpy (stringy,"abcdefg");
  integrr = 42;
  byteme = 0b01101111;
  //byteme = 0x6F   0110 1111
  bitarray = 0b01010101;
  //byteme = 0x55 0101 0101

  printf("stringy = %s\n", stringy);
  printf("charbq = %c\n", charbq);
  printf("integrr = %d\n", integrr);

  printf("byteme = %c 0x%x\n", byteme, byteme);

  printf("byteme: ");
  binary_dump(byteme);

  printf("bitarray: ");
  binary_dump(bitarray);

  printf("AND: ");
  binary_dump(byteme & bitarray);

  printf("OR: ");
  binary_dump(byteme | bitarray);

  printf("XOR: ");
  binary_dump(byteme ^ bitarray);

  printf("NOT Byteme: ");
  binary_dump(~byteme);
-UU-:----F1  bits-demo.c    21% L33    (C/l Abbrev)----------------------------------------------------------------
```

Code Interaction

```
Welcome to the Emacs shell

~/code $ gcc bits-demo.c
~/code $ objdump -s -j .rodata a.out > dataseg
~/code $ objdump -d a.out > textseg
~/code $ ./a.out
stringy = abcdefg
charbq = t
integrr = 42
byteme = o 0x6f
byteme: 01101111
bitarray: 01010101
AND: 01000101
OR: 01111111
XOR: 00111010
NOT Byteme: 10010000
~/code $
```

```
File Edit Options Buffers Tools C Help
Welcome to the Emacs shell

~/code $ gcc bits-demo.c
~/code $ objdump -s -j .rodata a.out > dataseg
~/code $ objdump -d a.out > textseg
~/code $ ./a.out
stringy = abcdefg
charbq = t
integrr = 42
byteme = o 0x6f
byteme: 01101111
bitarray: 01010101
AND: 01000101
OR: 01111111
XOR: 00111010
NOT Byteme: 10010000
~/code $
```

```
-UUU:----F1  *eshell*       All L17    (EShell)----------
```

```
00000000004005b6 <main>:
  4005b6:       55                      push   %rbp
  4005b7:       48 89 e5                mov    %rsp,%rbp
  4005ba:       48 83 ec 30             sub    $0x30,%rsp
  4005be:       89 7d dc                mov    %edi,-0x24(%rbp)
  4005c1:       48 89 75 d0             mov    %rsi,-0x30(%rbp)
  4005c5:       c6 45 f7 74             movb   $0x74,-0x9(%rbp)
  4005c9:       b9 2b 08 40 00          mov    $0x40082b,%ecx
  4005ce:       48 8d 45 e0             lea    -0x20(%rbp),%rax
  4005d2:       ba 08 00 00 00          mov    $0x8,%edx
  4005d7:       48 89 ce                mov    %rcx,%rsi
  4005da:       48 89 c7                mov    %rax,%rdi
  4005dd:       e8 7e fe ff ff          callq  400460 <memcpy@plt>
  4005e2:       c7 45 f8 2a 00 00 00    movl   $0x2a,-0x8(%rbp)
  4005e9:       c6 45 fe 6f             movb   $0x6f,-0x2(%rbp)
  4005ed:       c6 45 ff 55             movb   $0x55,-0x1(%rbp)
  4005f1:       b8 33 08 40 00          mov    $0x400833,%eax
  4005f6:       48 8d 55 e0             lea    -0x20(%rbp),%rdx
  4005fa:       48 89 d6                mov    %rdx,%rsi
  4005fd:       48 89 c7                mov    %rax,%rdi
  400600:       b8 00 00 00 00          mov    $0x0,%eax
  400605:       e8 26 fe ff ff          callq  400430 <printf@plt>
  40060a:       0f be 55 f7             movsbl -0x9(%rbp),%edx
  40060e:       b8 41 08 40 00          mov    $0x400841,%eax
  400613:       89 d6                   mov    %edx,%esi
  400615:       48 89 c7                mov    %rax,%rdi
  400618:       b8 00 00 00 00          mov    $0x0,%eax
  40061d:       e8 0e fe ff ff          callq  400430 <printf@plt>
  400622:       b8 4e 08 40 00          mov    $0x40084e,%eax
  400627:       8b 55 f8                mov    -0x8(%rbp),%edx
  40062a:       89 d6                   mov    %edx,%esi
  40062c:       48 89 c7                mov    %rax,%rdi
  40062f:       b8 00 00 00 00          mov    $0x0,%eax
  400634:       e8 f7 fd ff ff          callq  400430 <printf@plt>
  400639:       0f be 55 fe             movsbl -0x2(%rbp),%edx
  40063d:       0f be 4d fe             movsbl -0x2(%rbp),%ecx
```

```
-UU-:----F1  textseg        45% L175   (Fundamental)----------
```

```
#include <string.h>
#include <stdlib.h>
#include <stdio.h>

void binary_dump (char printme) {
  int i;

  for (i = 0; i < 8; i++) {
    printf("%d", !!((printme << i) & 0x80));
  }
  printf("\n");
}

int main( int argc, const char* argv[] ) {
  char stringy[8];
  char charbq;
  int integrr;
  char byteme;
  char bitarray;

  charbq = 0x74;
  strcpy (stringy,"abcdefg");
  integrr = 42;
  byteme = 0b01101111;
  //byteme = 0x6F   0110 1111
  bitarray = 0b01010101;
  //byteme = 0x55 0101 0101

  printf("stringy = %s\n", stringy);
  printf("charbq = %c\n", charbq);
  printf("integrr = %d\n", integrr);

  printf("byteme = %c 0x%x\n", byteme, byteme);

  printf("byteme: ");
  binary_dump(byteme);

  printf("bitarray: ");
```

```
-UU-:----F1  bits-demo.c    Top L1     (C/l Abbrev)----------
```

```
a.out:     file format elf64-x86-64

Contents of section .rodata:
 400818 01000200 00000000 00000000 00000000  ................
 400828 25640061 62636465 66670073 7472696e  %d.abcdefg.strin
 400838 6779203d 2025730a 00636861 72627120  gy = %s..charbq
 400848 3d202563 0a00696e 74656772 72203d20  = %c..integrr =
 400858 25640a00 62797465 6d65203d 20256320  %d..byteme = %c
 400868 30782578 0a006279 74656d65 3a200062  0x%x..byteme: .b
 400878 69746172 7261793a 2000414e 443a2000  itarray: .AND: .
 400888 4f523a20 00584f52 3a20004e 4f542042  OR: .XOR: .NOT B
 400898 7974656d 653a2000                    yteme: .
```

```
-UU-:----F1  dataseg        All L1     (Fundamental)----------
```

```
File Edit Options Buffers Tools C Help
Welcome to the Emacs shell

~/code $ gcc bits-demo.c
~/code $ objdump -s -j .rodata a.out > dataseg
-UUU:----F1  *eshell*       All L17    (EShell)----------------------------------------------------------------------------
#include <string.h>
#include <stdlib.h>
#include <stdio.h>

void binary_dump (char printme) {
  int i;

  for (i = 0; i < 8; i++) {
    printf("%d", !!((printme << i) & 0x80));
  }
  printf("\n");
}

int main( int argc, const char* argv[] ) {
  char stringy[8];
  char charbq;
  int integrr;
  char byteme;
  char bitarray;

  charbq = 0x74;
  strcpy (stringy,"abcdefg");
  integrr = 42;
  byteme = 0b01101111;
  //byteme = 0x6F   0110 1111
  bitarray = 0b01010101;
  //byteme = 0x55 0101 0101

  printf("stringy = %s\n", stringy);
  printf("charbq = %c\n", charbq);
  printf("integrr = %d\n", integrr);

  printf("byteme = %c 0x%x\n", byteme, byteme);

  printf("byteme: ");
  binary_dump(byteme);

  printf("bitarray: ");
-UU-:----F1  bits-demo.c     Top L1     (C/l Abbrev)----------------------------------------------------------------------
printf("bitarray: ");
-UU-:----F1  bits-demo.c     Top L1     (C/l Abbrev)----------------------------------------------------------------------

00000000004005b6 <main>:
  4005b6:       55                      push   %rbp
  4005b7:       48 89 e5                mov    %rsp,%rbp
-UU-:----F1  dataseg        All L1     (Fundamental)----------------------------------------------------------------------
```

```
File Edit Options
Welcome to the Em

~/code $ gcc bits
~/code $ objdump
~/code $ objdump
~/code $ ./a.out
stringy = abcdefg
charbq = t
integrr = 42
byteme = o 0x6f
byteme: 01101111
bitarray: 0101010
AND: 01000101
OR: 01111111
XOR: 00111010
NOT Byteme: 10010
~/code $
```

```
-UUU:----F1  *esh
#include <string.
#include <stdlib.
#include <stdio.h

void binary_dump
  int i;

  for (i = 0; i <
    printf("%d",
  }
  printf("\n");
}

int main( int arg
  char stringy[8]
  char charbq;
  int integrr;
  char byteme;
  char bitarray;

  charbq = 0x74;
  strcpy (stringy
  integrr = 42;
  byteme = 0b0110
  //byteme = 0x6F
  bitarray = 0b01
  //byteme = 0x55

  printf("stringy
  printf("charbq
  printf("integrr

  printf("byteme

  printf("byteme:
  binary_dump(byt

  printf("bitarra
-UU-:----F1  bits
```

```
00000000004005b6 <main>:
  4005b6:       55                      push   %rbp
  4005b7:       48 89 e5                mov    %rsp,%rbp
  4005ba:       48 83 ec 30             sub    $0x30,%rsp
  4005be:       89 7d dc                mov    %edi,-0x24(%rbp)
  4005c1:       48 89 75 d0             mov    %rsi,-0x30(%rbp)
  4005c5:       c6 45 f7 74             movb   $0x74,-0x9(%rbp)
  4005c9:       b9 2b 08 40 00          mov    $0x40082b,%ecx
  4005ce:       48 8d 45 e0             lea    -0x20(%rbp),%rax
  4005d2:       ba 08 00 00 00          mov    $0x8,%edx
  4005d7:       48 89 ce                mov    %rcx,%rsi
  4005da:       48 89 c7                mov    %rax,%rdi
  4005dd:       e8 7e fe ff ff          callq  400460 <memcpy@plt>
  4005e2:       c7 45 f8 2a 00 00 00    movl   $0x2a,-0x8(%rbp)
  4005e9:       c6 45 fe 6f             movb   $0x6f,-0x2(%rbp)
  4005ed:       c6 45 ff 55             movb   $0x55,-0x1(%rbp)
  4005f1:       b8 33 08 40 00          mov    $0x400833,%eax
  4005f6:       48 8d 55 e0             lea    -0x20(%rbp),%rdx
  4005fa:       48 89 d6                mov    %rdx,%rsi
  4005fd:       48 89 c7                mov    %rax,%rdi
  400600:       b8 00 00 00 00          mov    $0x0,%eax
  400605:       e8 26 fe ff ff          callq  400430 <printf@plt>
  40060a:       0f be 55 f7             movsbl -0x9(%rbp),%edx
  40060e:       b8 41 08 40 00          mov    $0x400841,%eax
  400613:       89 d6                   mov    %edx,%esi
  400615:       48 89 c7                mov    %rax,%rdi
  400618:       b8 00 00 00 00          mov    $0x0,%eax
  40061d:       e8 0e fe ff ff          callq  400430 <printf@plt>
  400622:       b8 4e 08 40 00          mov    $0x40084e,%eax
  400627:       8b 55 f8                mov    -0x8(%rbp),%edx
  40062a:       89 d6                   mov    %edx,%esi
  40062c:       48 89 c7                mov    %rax,%rdi
  40062f:       b8 00 00 00 00          mov    $0x0,%eax
  400634:       e8 f7 fd ff ff          callq  400430 <printf@plt>
  400639:       0f be 55 fe             movsbl -0x2(%rbp),%edx
  40063d:       0f be 4d fe             movsbl -0x2(%rbp),%ecx
-UU-:----F1  textseg        45% L175    (Fundamental)
```

```
File Edit Options Buffers Tools C Help
Welcome to the Emacs shell

~/code $ gcc bits-demo.c
~/code $ objdump -s -j .rodata a.out > dataseg
~/code $ objdump -d a.out > textseg
~/code $ ./a.out
stringy = abcdefg
charbq = t
integrr = 42
byteme = o 0x6f
byteme: 01101111
bitarray: 0101010
AND: 01000101
OR: 01111111
XOR: 00111010
NOT Byteme: 10010
~/code $
```

```
00000000004005b6 <main>:
  4005b6:       55                      push   %rbp
  4005b7:       48 89 e5                mov    %rsp,%rbp
  4005ba:       48 83 ec 30             sub    $0x30,%rsp
  4005be:       89 7d dc                mov    %edi,-0x24(%rbp)
  4005c1:       48 89 75 d0             mov    %rsi,-0x30(%rbp)
  4005c5:       c6 45 f7 74             movb   $0x74,-0x9(%rbp)
  4005c9:       b9 2b 08 40 00          mov    $0x40082b,%ecx
  4005ce:       48 8d 45 e0             lea    -0x20(%rbp),%rax
  4005d2:       ba 08 00 00 00          mov    $0x8,%edx
```

```
00000000004005b6 <main>:
  4005b6:       55                      push   %rbp
  4005b7:       48 89 e5                mov    %rsp,%rbp
  4005ba:       48 83 ec 30             sub    $0x30,%rsp
  4005be:       89 7d dc                mov    %edi,-0x24(%rbp)
  400627:       8b 55 f8                mov    -0x8(%rbp),%edx
  40062a:       89 d6                   mov    %edx,%esi
  40062c:       48 89 c7                mov    %rax,%rdi
  40062f:       b8 00 00 00 00          mov    $0x0,%eax
  400634:       e8 f7 fd ff ff          callq  400430 <printf@plt>
  400639:       0f be 55 fe             movsbl -0x2(%rbp),%edx
  40063d:       0f be 4d fe             movsbl -0x2(%rbp),%ecx
```

```
-UUU:----F1  *eshell*       All L17    (EShell)----------
-UU-:----F1  textseg        45% L175   (Fundamental)----------
```

```
#include <string.h>
#include <stdlib.h>
#include <stdio.h>

void binary_dump
  int i;

  for (i = 0; i <
    printf("%d",
  }
  printf("\n");
}

int main( int arg
  char stringy[8]
  char charbq;
  int integrr;
  char byteme;
  char bitarray;

  charbq = 0x74;
  strcpy (stringy
  integrr = 42;
  byteme = 0b0110
  //byteme = 0x6F
  bitarray = 0b01
  //byteme = 0x55

  printf("stringy
  printf("charbq
  printf("integrr

  printf("byteme = %c 0x%x\n", byteme, byteme);

  printf("byteme: ");
  binary_dump(byteme);

  printf("bitarray: ");
```

```
a.out:     file format elf64-x86-64

Contents of section .rodata:
 400818 01000200 00000000 00000000 00000000  ................
 400828 25640061 62636465 66670073 7472696e  %d.abcdefg.strin
 400838 6779203d 2025730a 00636861 72627120  gy = %s..charbq
 400848 3d202563 0a00696e 74656772 72203d20  = %c..integrr =
 400858 25640a00 62797465 6d65203d 20256320  %d..byteme = %c
 400868 30782578 0a006279 74656d65 3a200062  0x%x..byteme: .b
 400878 69746172 7261793a 2000414e 443a2000  itarray: .AND: .
 400888 4f523a20 00584f52 3a20004e 4f542042  OR: .XOR: .NOT B
 400898 7974656d 653a2000                    yteme: .
```

```
-UU-:----F1  bits-demo.c    Top L1     (C/l Abbrev)----------
-UU-:----F1  dataseg        All L1     (Fundamental)----------
```

GDB – GNU Debugger

```
~/code $ gdb ./a.out
GNU gdb (GDB) Red Hat Enterprise Linux (7.2-92.el6)
Copyright (C) 2010 Free Software Foundation, Inc.
License GPLv3+: GNU GPL version 3 or later <http://gnu.org/licenses/gpl.html>
This is free software: you are free to change and redistribute it.
There is NO WARRANTY, to the extent permitted by law.  Type "show copying"
and "show warranty" for details.
This GDB was configured as "x86_64-redhat-linux-gnu".
For bug reporting instructions, please see:
<http://www.gnu.org/software/gdb/bugs/>...
Reading symbols from /w/fac.3/cs/reinman/code/a.out...(no debugging symbols found)...done.
(gdb) break *0x400605
Breakpoint 1 at 0x400605
(gdb) run
Starting program: /w/fac.3/cs/reinman/code/a.out

Breakpoint 1, 0x0000000000400605 in main ()
Missing separate debuginfos, use: debuginfo-install glibc-2.12-1.212.el6_10.3.x86_64
(gdb)
```

```
(gdb) i r
rax            0x0       0
rbx            0x0       0
rcx            0x67666564636261
rdx            0x7fffffffe810
rsi            0x7fffffffe810
rdi            0x400833 4196403
rbp            0x7fffffffe830
rsp            0x7fffffffe800
r8             0x3e8c18fba0
r9             0x3e8ba0ee20
r10            0x7fffffffe580
r11            0x3e8be89720
r12            0x400470 4195440
r13            0x7fffffffe910
r14            0x0       0
r15            0x0       0
rip            0x400605 0x400605
eflags         0x246     [ PF ZF
cs             0x33      51
ss             0x2b      43
ds             0x0       0
es             0x0       0
fs             0x0       0
gs             0x0       0
(gdb) x/64xb $rsi
0x7fffffffe810: 0x61    0x62    0x63    0x64    0x65    0x66    0x67    0x00
0x7fffffffe818: 0x70    0x04    0x40    0x00    0x00    0x00    0x00    0x00
0x7fffffffe820: 0x10    0xe9    0xff    0xff    0xff    0x7f    0x00    0x74
0x7fffffffe828: 0x2a    0x00    0x00    0x00    0x00    0x00    0x6f    0x55
0x7fffffffe830: 0x00    0x00    0x00    0x00    0x00    0x00    0x00    0x00
0x7fffffffe838: 0x20    0xed    0xe1    0x8b    0x3e    0x00    0x00    0x00
0x7fffffffe840: 0x00    0x00    0x00    0x00    0x00    0x00    0x00    0x00
0x7fffffffe848: 0x18    0xe9    0xff    0xff    0xff    0x7f    0x00    0x00
(gdb)
-UUU:**--F1  *eshell*       Bot L69    (EShell)----------
```

Dec	Hx	Oct	Char		Dec	Hx	Oct	Html	Chr	Dec	Hx	Oct	Html	Chr	Dec	Hx	Oct	Html	Chr
0	0	000	NUL	(null)	32	20	040		Space	64	40	100	@	@	96	60	140	`	`
1	1	001	SOH	(start of heading)	33	21	041	!	!	65	41	101	A	A	97	61	141	a	a
2	2	002	STX	(start of text)	34	22	042	"	"	66	42	102	B	B	98	62	142	b	b
3	3	003	ETX	(end of text)	35	23	043	#	#	67	43	103	C	C	99	63	143	c	c
4	4	004	EOT	(end of transmission)	36	24	044	$	$	68	44	104	D	D	100	64	144	d	d
5	5	005	ENQ	(enquiry)	37	25	045	%	%	69	45	105	E	E	101	65	145	e	e
6	6	006	ACK	(acknowledge)	38	26	046	&	&	70	46	106	F	F	102	66	146	f	f
7	7	007	BEL	(bell)	39	27	047	'	'	71	47	107	G	G	103	67	147	g	g
8	8	010	BS	(backspace)	40	28	050	(	(	72	48	110	H	H	104	68	150	h	h
9	9	011	TAB	(horizontal tab)	41	29	051	)	)	73	49	111	I	I	105	69	151	i	i
10	A	012	LF	(NL line feed, new line)	42	2A	052	*	*	74	4A	112	J	J	106	6A	152	j	j
11	B	013	VT	(vertical tab)	43	2B	053	+	+	75	4B	113	K	K	107	6B	153	k	k
12	C	014	FF	(NP form feed, new page)	44	2C	054	,	,	76	4C	114	L	L	108	6C	154	l	l
13	D	015	CR	(carriage return)	45	2D	055	-	-	77	4D	115	M	M	109	6D	155	m	m
14	E	016	SO	(shift out)	46	2E	056	.	.	78	4E	116	N	N	110	6E	156	n	n
15	F	017	SI	(shift in)	47	2F	057	/	/	79	4F	117	O	O	111	6F	157	o	o
16	10	020	DLE	(data link escape)	48	30	060	0	0	80	50	120	P	P	112	70	160	p	p
17	11	021	DC1	(device control 1)	49	31	061	1	1	81	51	121	Q	Q	113	71	161	q	q
18	12	022	DC2	(device control 2)	50	32	062	2	2	82	52	122	R	R	114	72	162	r	r
19	13	023	DC3	(device control 3)	51	33	063	3	3	83	53	123	S	S	115	73	163	s	s
20	14	024	DC4	(device control 4)	52	34	064	4	4	84	54	124	T	T	116	74	164	t	t
21	15	025	NAK	(negative acknowledge)	53	35	065	5	5	85	55	125	U	U	117	75	165	u	u
22	16	026	SYN	(synchronous idle)	54	36	066	6	6	86	56	126	V	V	118	76	166	v	v
23	17	027	ETB	(end of trans. block)	55	37	067	7	7	87	57	127	W	W	119	77	167	w	w
24	18	030	CAN	(cancel)	56	38	070	8	8	88	58	130	X	X	120	78	170	x	x
25	19	031	EM	(end of medium)	57	39	071	9	9	89	59	131	Y	Y	121	79	171	y	y
26	1A	032	SUB	(substitute)	58	3A	072	:	:	90	5A	132	Z	Z	122	7A	172	z	z
27	1B	033	ESC	(escape)	59	3B	073	;	;	91	5B	133	[	[	123	7B	173	{	{
28	1C	034	FS	(file separator)	60	3C	074	<	<	92	5C	134	\	\	124	7C	174			|
29	1D	035	GS	(group separator)	61	3D	075	=	=	93	5D	135	]	]	125	7D	175	}	}
30	1E	036	RS	(record separator)	62	3E	076	>	>	94	5E	136	^	^	126	7E	176	~	~
31	1F	037	US	(unit separator)	63	3F	077	?	?	95	5F	137	_	_	127	7F	177	&#127;	DEL

Source: www.LookupTables.com

Dec	Hx	Oct	Char		Dec	Hx	Oct	Html	Chr	Dec	Hx	Oct	Html	Chr	Dec	Hx	Oct	Html	Chr
0	0	000	NUL	(null)	32	20	040		Space	64	40	100	@	@	96	60	140	`	`
1	1	001	SOH	(start of heading)	33	21	041	!	!	65	41	101	A	A	97	61	141	a	a
2	2	002	STX	(start of text)	34	22	042	"	"	66	42	102	B	B	98	62	142	b	b
3	3	003	ETX	(end of text)	35	23	043	#	#	67	43	103	C	C	99	63	143	c	c
4	4	004	EOT	(end of transmission)	36	24	044	$	$	68	44	104	D	D	100	64	144	d	d
5	5	005	ENQ	(enquiry)	37	25	045	%	%	69	45	105	E	E	101	65	145	e	e
6	6	006	ACK	(acknowledge)	38	26	046	&	&	70	46	106	F	F	102	66	146	f	f
7	7	007	BEL	(bell)	39	27	047	'	'	71	47	107	G	G	103	67	147	g	g
8	8	010	BS	(backspace)	40	28	050	(	(	72	48	110	H	H	104	68	150	h	h
9	9	011	TAB	(horizontal tab)	41	29	051	)	)	73	49	111	I	I	105	69	151	i	i
10	A	012	LF	(NL line feed, new line)	42	2A	052	*	*	74	4A	112	J	J	106	6A	152	j	j
11	B	013	VT	(vertical tab)	43	2B	053	+	+	75	4B	113	K	K	107	6B	153	k	k
12	C	014	FF	(NP form feed, new page)	44	2C	054	,	,	76	4C	114	L	L	108	6C	154	l	l
13	D	015	CR	(carriage return)	45	2D	055	-	-	77	4D	115	M	M	109	6D	155	m	m
14	E	016	SO	(shift out)	46	2E	056	.	.	78	4E	116	N	N	110	6E	156	n	n
15	F	017	SI	(shift in)	47	2F	057	/	/	79	4F	117	O	O	111	6F	157	o	o
16	10	020	DLE	(data link escape)	48	30	060	0	0	80	50	120	P	P	112	70	160	p	p
17	11	021	DC1	(device control 1)	49	31	061	1	1	81	51	121	Q	Q	113	71	161	q	q
18	12	022	DC2	(device control 2)	50	32	062	2	2	82	52	122	R	R	114	72	162	r	r
19	13	023	DC3	(device control 3)	51	33	063	3	3	83	53	123	S	S	115	73	163	s	s
20	14	024	DC4	(device control 4)	52	34	064	4	4	84	54	124	T	T	116	74	164	t	t
21	15	025	NAK	(negative acknowledge)	53	35	065	5	5	85	55	125	U	U	117	75	165	u	u
22	16	026	SYN	(synchronous idle)	54	36	066	6	6	86	56	126	V	V	118	76	166	v	v
23	17	027	ETB	(end of trans. block)	55	37	067	7	7	87	57	127	W	W	119	77	167	w	w
24	18	030	CAN	(cancel)	56	38	070	8	8	88	58	130	X	X	120	78	170	x	x
25	19	031	EM	(end of medium)	57	39	071	9	9	89	59	131	Y	Y	121	79	171	y	y
26	1A	032	SUB	(substitute)	58	3A	072	:	:	90	5A	132	Z	Z	122	7A	172	z	z
27	1B	033	ESC	(escape)	59	3B	073	;	;	91	5B	133	[	[	123	7B	173	{	{
28	1C	034	FS	(file separator)	60	3C	074	<	<	92	5C	134	\	\	124	7C	174			|
29	1D	035	GS	(group separator)	61	3D	075	=	=	93	5D	135	]	]	125	7D	175	}	}
30	1E	036	RS	(record separator)	62	3E	076	>	>	94	5E	136	^	^	126	7E	176	~	~
31	1F	037	US	(unit separator)	63	3F	077	?	?	95	5F	137	_	_	127	7F	177	&#127;	DEL

Source: www.LookupTables.com

Lab 0

```
/*
 * ezThreeFourths - multiplies by 3/4 rounding toward 0,
 *   Should exactly duplicate effect of C expression (x*3/4),
 *   including overflow behavior.
 *   Examples: ezThreeFourths(11) = 8
 *             ezThreeFourths(-9) = -6
 *             ezThreeFourths(1073741824) = -268435456 (overflow)
 *   Legal ops: ! ~ & ^ | + << >>
 *   Max ops: 12
 *   Rating: 3
 */
int ezThreeFourths(int x) {
```