CS 33

Introduction to C
Part 4

Base Conversion Algorithm

```
void baseX(unsigned int num, unsigned int base) {
   char digits[] = {'0', '1', '2', '3', '4', '5', '6', … };
   char buf[8*sizeof(unsigned int)+1];
   int i;

   for (i = sizeof(buf) - 2; i >= 0; i--) {
      buf[i] = digits[num%base];
      num /= base;
      if (num == 0)
         break;
   }

   buf[sizeof(buf) - 1] = '\0';
   printf("%s\n", &buf[i]);
}
```

Or …

```
$ bc
obase=16
1999
7CF
$
```

Quiz 1

- **What's the decimal (base 10) equivalent of 25_{16}?**
  - a) 19
  - b) 35
  - c) 37
  - d) 38

Encoding Byte Values

- Byte = 8 bits
  - binary 00000000_2 to 11111111_2
  - octal 0_8 to 377_8
    - » write 377_8 in C as
      - 0377
  - 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	Octal	Binary
0	0	0	0000
1	1	1	0001
2	2	2	0010
3	3	3	0011
4	4	4	0100
5	5	5	0101
6	6	6	0110
7	7	7	0111
8	8	10	1000
9	9	11	1001
A	10	12	1010
B	11	13	1011
C	12	14	1100
D	13	15	1101
E	14	16	1110
F	15	17	1111

Unsigned 32-Bit Integers

b_{31}	b_{30}	b_{29}	…	b_2	b_1	b_0

$$\text{value} = \sum_{i=0}^{31} b_i \cdot 2^i$$

(we ignore negative integers for now)

Storing and Viewing Ints

```
int main() {
    unsigned int n = 57;
    printf("binary: %b, decimal: %u, "
           "hex: %x\n", n, n, n);
    return 0;
}
```

```
$ ./a.out
binary: 111001, decimal: 57, hex: 39
$
```

Boolean Algebra

- **Developed by George Boole in 19th Century**
  - **algebraic representation of logic**
    - » **encode "true" as 1 and "false" as 0**

And

- A&B = 1 when both A=1 and B=1

&	0	1
0	0	0
1	0	1

Or

- A|B = 1 when either A=1 or B=1

|	0	1
0	0	1
1	1	1

Not

- ~A = 1 when A=0

~	
0	1
1	0

Exclusive-Or (Xor)

- A^B = 1 when either A=1 or B=1, but not both

^	0	1
0	0	1
1	1	0

General Boolean Algebras

- **Operate on bit vectors**
  - **operations applied bitwise**

```
  01101001     01101001     01101001
& 01010101   | 01010101   ^ 01010101   ~ 01010101
  01000001     01111101     00111100     10101010
```

- **All of the properties of boolean algebra apply**

Example: Representing & Manipulating Sets

- **Representation**
  - width-w bit vector represents subsets of {0, …, w–1}
  - $a_j = 1$ iff $j \in A$

01101001	{ 0, 3, 5, 6 }
76543210	
01010101	{ 0, 2, 4, 6 }
76543210	

- **Operations**

&	intersection	01000001	{ 0, 6 }
|	union	01111101	{ 0, 2, 3, 4, 5, 6 }
^	symmetric difference	00111100	{ 2, 3, 4, 5 }
~	complement	10101010	{ 1, 3, 5, 7 }

Bit-Level Operations in C

- Operations &, |, ~, ^ available in C
  - apply to any "integral" data type
    - » long, int, short, char
  - view arguments as bit vectors
  - arguments applied bit-wise
- Examples (char datatype)

  ~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

  $01101001_2 \ | \ 01010101_2 \rightarrow 01111101_2$

Contrast: Logic Operations in C

- **Contrast to Logical Operators**
  - `&&, ||, !`
    - » view 0 as "false"
    - » anything nonzero as "true"
    - » always return 0 or 1
    - » early termination/short-circuited execution
- **Examples (char datatype)**

```
!0x41 → 0x00
!0x00 → 0x01
!!0x41 → 0x01

0x69 && 0x55 → 0x01
0x69 || 0x55 → 0x01
p && complicated_function(x)
```

Contrast: Logic Operations in C

- **Contrast to Logical Operators**
  - `&&, ||, !`
    - » vie "false"

Watch out for && vs. & (and || vs. |)… One of the more common oopsies in C programming

- **L**

```
!0x41 → 0x00
!0x00 → 0x01
!!0x41 → 0x01

0x69 && 0x55 → 0x01
0x69 || 0x55 → 0x01
p && complicated_function(x)
```

Quiz 2

- Which of the following would determine whether the next-to-the-rightmost bit of Y (declared as a char) is 1? (I.e., the expression evaluates to true if and only if that bit of Y is 1.)
  a) Y & 0x02
  b) !((~Y) & 0x02)
  c) none of the above
  d) both a and b

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

Digression

- **Pre-increment**
  - **++*b* means add one to *b;* the result of the expression is this new value of *b***
- **Post-increment**
  - ***b*++ means the value of the expression is the current value of *b*, then add one to *b***
- **Example**

```
int b=1;
printf("%d\n", (++b)*b);
```

output:

```
4
```

```
int b=1;
printf("%d\n", (b++)*b);
```

output:

```
2
```

Global Variables

The scope is global;
m can be used
by all functions

```
#define NUM_ROWS 3
#define NUM_COLS 4
int m[NUM_ROWS][NUM_COLS];

int main() {
   int row, col;
   for(row=0; row<NUM_ROWS; row++)
     for(col=0; col<NUM_COLS; col++)
        m[row][col] = row*NUM_COLS+col;
   return 0;
}
```

Global Variables

```
#define NUM_ROWS 3
#define NUM_COLS 4
int m[NUM_ROWS][NUM_COLS];

int main() {
   int row, col;
   printf("%u\n", m);
   printf("%u\n", &row);
   return 0;
}
```

```
$ ./a.out
8384
3221224352
```

Global Variables are Initialized!

```
#define NUM_ROWS 3
#define NUM_COLS 4
int m[NUM_ROWS][NUM_COLS];

int main() {
   printf("%d\n", m[0][0]);
   return 0;
}
```

```
$ ./a.out
0
```

Scope

```
int a;   // global variable

int main() {
   int a;   // local variable
   a = 0;
   proc();
   printf("a = %d\n", a); // what's printed?
   return 0;
}

int proc() {
   a = 1;
   return a;
}
```

```
$ ./a.out
0
```

Scope (continued)

```
int a;   // global variable

int main() {
   a = 2;
   proc(1);
   return 0;
}

int proc(int a) {
   printf("a = %d\n", a); // what's printed?
   return a;
}
```

```
$ ./a.out
1
```

Scope (still continued)

```
int a;   // global variable

int main() {
   a = 2;
   proc(1);
   return 0;
}

int proc(int a) {
   int a;
   printf("a = %d\n", a); // what's printed?
   return a;
}
```

```
$ gcc prog.c
prog.c:12:8: error: redefinition of 'a'
   int a;
       ^
```

Scope (more ...)

```
int a;   // global variable

int proc() {
   {
      // the brackets define a new scope
      int a;
      a = 6;
   }
   printf("a = %d\n", a); // what's printed?
   return 0;
}
```

```
$ ./a.out
0
```

Quiz 3

```
int a;

int proc(int b) {
    {int b=6;}
    a = b;
    return a+2;
}

int main() {
    {int a = proc(4);}
    printf("a = %d\n", a);
    return 0;
}
```

- **What's printed?**
  a) 0
  b) 4
  c) 6
  d) 8
  e) nothing; there's a syntax error

Scope and For Loops (1)

```
int A[100];
for (int i=0; i<100; i++) {
  // i is defined in this scope
  A[i] = i;
}
```

Scope and For Loops (2)

```
int A[100];
initializeA(A);
for (int i=0; i<100; i++) {
  // i is defined in this scope
  if (A[i] < 0)
    break;
}
if (i != 100)
  printf("A[%d] is negative\n", i);
```

syntax error: reference to *i* is out of scope.

Lifetime

```
int count;

int main() {
    func();
    ...
    func(); // what's printed by func?
    return 0;
}

int func() {
    int a;
    if (count == 0) a = 1;
    count = count + 1;
    printf("%d\n", a);
    return 0;
}
```

```
% ./a.out
1
-38762173
```

Lifetime (continued)

```
int main() {
   func(1); // what's printed by func?
   return 0;
}
int a;
int func(int x) {
   if (x == 1) {
      a = 1;
      func(2);
      printf("%d\n", a);
   } else
      a = 2;
   return 0;
}
```

```
% ./a.out
2
```

Lifetime (still continued)

```
int main() {
    func(1); // what's printed by func?
    return 0;
}

int func(int x) {
    int a;
    if (x == 1) {
        a = 1;
        func(2);
        printf("a = %d\n", a);
    } else
        a = 2;
    return 0;
}
```

```
% ./a.out
1
```

Lifetime (more ...)

```
int main() {
    int *a;
    a = func();
    printf("%d\n", *a); // what's printed?
    return 0;
}

int *func() {
    int x;
    x = 1;
    return &x;
}
```

```
% ./a.out
23095689
```

Lifetime (and still more ...)

```
int main() {
    int *a;
    a = func(1);
    printf("%d\n", *a); // what's printed?
    return 0;
}

int *func(int x) {
    return &x;
}
```

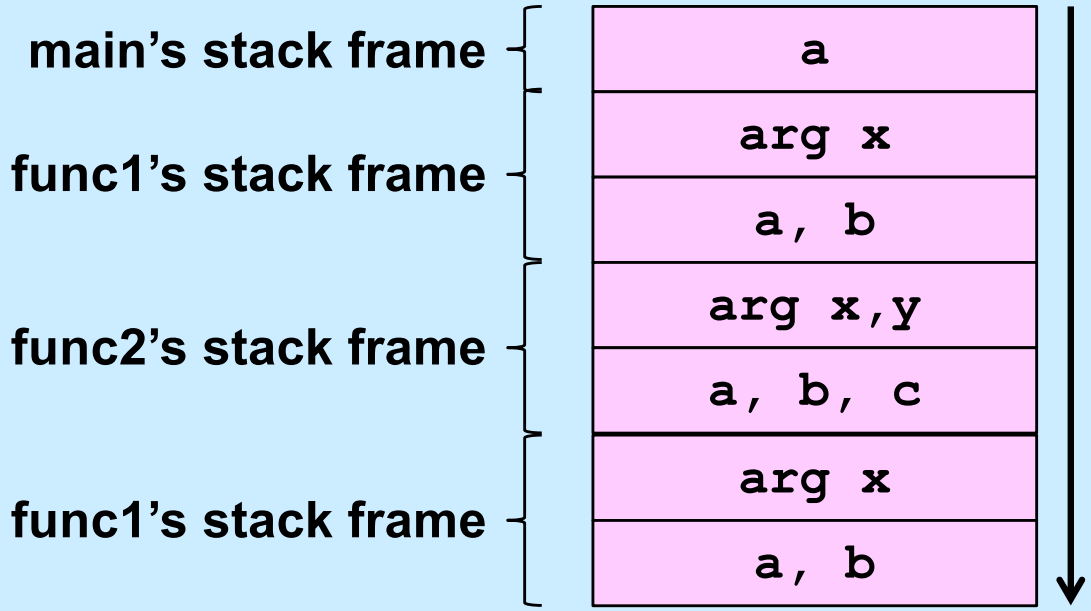
```
% ./a.out
98378932
```

Rules

- Global variables exist for the duration of program's lifetime
- Local variables and arguments exist for the duration of the execution of the function
  - from call to return
  - each execution of a function results in a new instance of its arguments and local variables

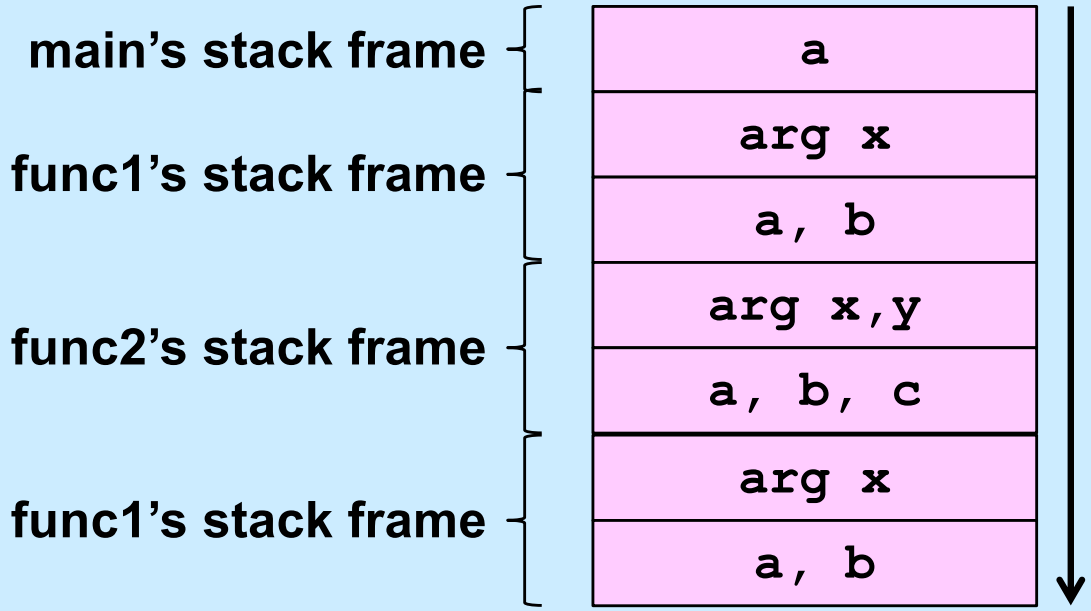
Implementation: Stacks

```
int main() {
    int a;
    func1(0);
    ...
}
int func1(int x) {
    int a,b;
    if (x==0) func2(a,2);
    ...
}
int func2(int x, int y) {
    int a,b,c;
    func1(1);
    ...
}
```



Implementation: Stacks

```
int main() {
    int a;
    func1(0);
    ...
}
int func1(int x) {
    int a,b;
    if (x==0) func2(a,2);
    ...
}
int func2(int x, int y) {
    int a,b,c;
    func1(1);
    ...
}
```



Quiz 4

```
void func(int a) {
    int b=2;
    if (a == 1) {
        func(2);
        printf("%d\n", b);
    } else {
        b = a*(b++)*b;
    }
}
int main() {
    func(1);
    return 0;
}
```

- **What's printed?**
  - **a) 0**
  - **b) 1**
  - **c) 2**
  - **d) 4**

Static Local Variables

```
int *sub1() {
  int var = 1;
  …
  return &var;
  /* amazingly illegal */
}
```

```
int *sub2() {
  static int var = 1;
  …
  return &var;
  /* (amazingly) legal */
}
```

- **Scope**
  - **like local variables**
- **Lifetime**
  - **like global variables**
- **Initialized just once**
  - **when program begins**
  - **implicit initialization to 0**

Quiz 5

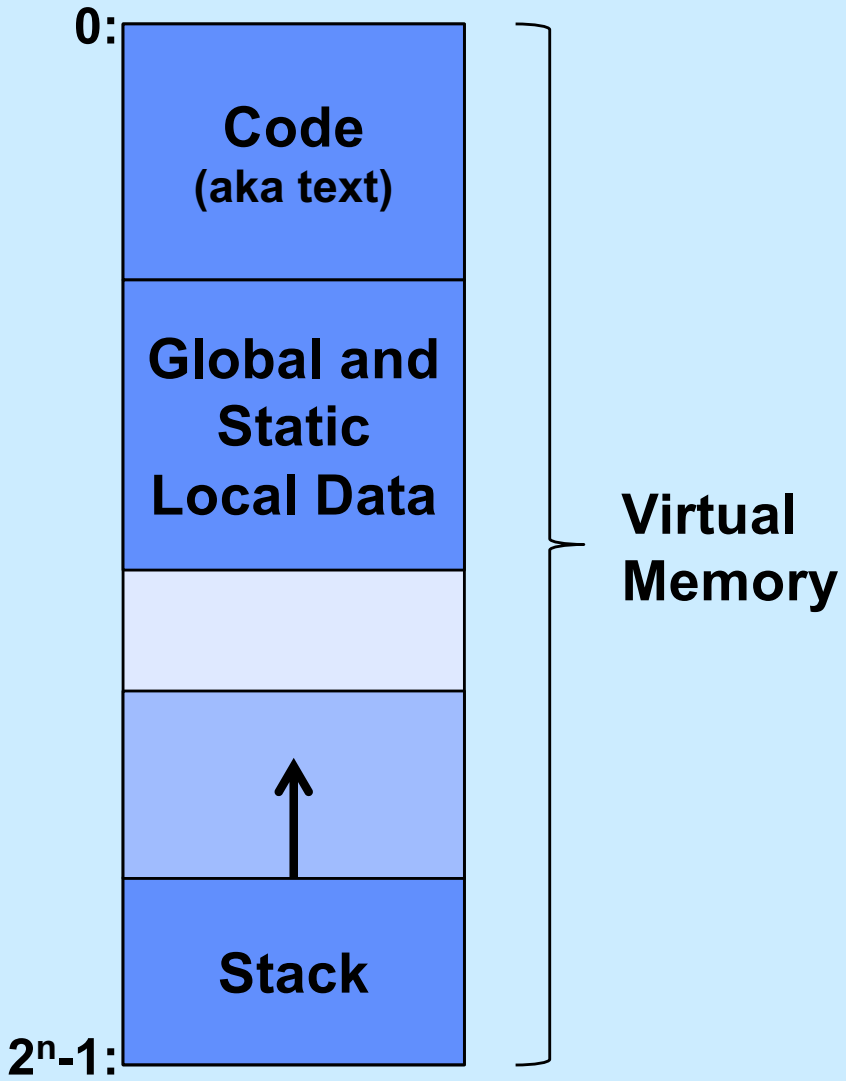
```
int sub() {
  static int svar = 2;
  int lvar = 1;
  svar += lvar;
  lvar++;
  return svar;
}

int main() {
  sub();
  printf("%d\n", sub());
  return 0;
}
```

What is printed?

a) 2
b) 3
c) 4
d) 5

Digression: Where Stuff Is
(Roughly)



scanf: Reading Data

```
int main() {
    int i, j;
    scanf("%d %d", &i, &j);
    printf("%d, %d", i, j);
}
```

```
$ ./a.out
    3          12
3, 12
```

Two parts

- **formatting instructions**
  - **whitespace in format string matches any amount of white space in input**
    - » **whitespace is space, tab, newline ('\n')**
- **arguments: must be addresses**
  - **why?**

#define (again)

```
#define CtoF(cel) (9.0*cel)/5.0 + 32.0
```

Simple textual substitution:

```
float tempc = 20.0;
float tempf = CtoF(tempc);
// same as tempf = (9.0*tempc)/5.0 + 32.0;
```

Careful ...

```
#define CtoF(cel)  (9.0*cel)/5.0 + 32.0
```

```
float tempc = 20.0;
float tempf = CtoF(tempc+10);
// same as tempf = (9.0*tempc+10)/5.0 + 32.0;
```

```
#define CtoF(cel)  (9.0*(cel))/5.0 + 32.0
```

```
float tempc = 20.0;
float tempf = CtoF(tempc+10);
// same as tempf = (9.0*(tempc+10))/5.0 + 32.0;
```

Conditional Compilation

```
#ifdef DEBUG
  #define DEBUG_PRINT(a1, a2) printf(a1,a2)
#else
  #define DEBUG_PRINT(a1, a2)
#endif
```

```
int buggy_func(int x) {
   DEBUG_PRINT("x = %d\n", x);
     // printed only if DEBUG is defined
   ...
}
```