CS 33

Introduction to C
Part 4

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

  ~01000001$_2$ → 10111110$_2$

  ~0x00 → 0xFF

  ~00000000$_2$ → 11111111$_2$

  0x69 & 0x55 → 0x41

  01101001$_2$ & 01010101$_2$ → 01000001$_2$

  0x69 | 0x55 → 0x7D

  01101001$_2$ | 01010101$_2$ → 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 && *p` **(avoids null pointer access)**

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 && *p (avoids null pointer access)

Quiz 1

- **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) **both of the above**
  d) **none of the above**

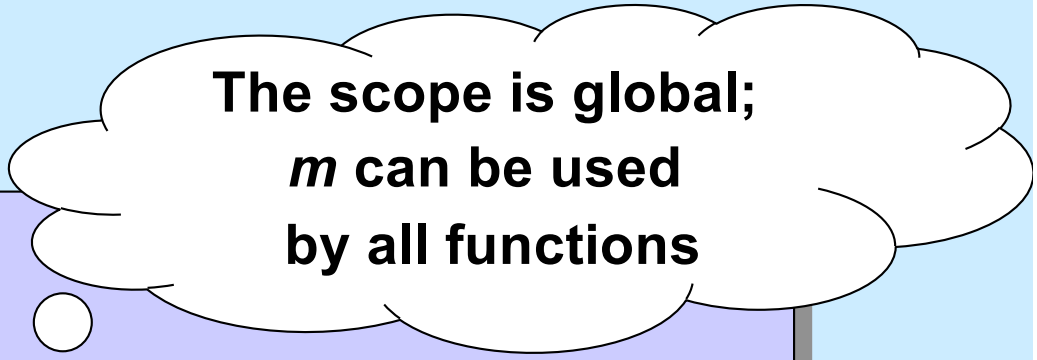
Shift Operations

- **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

Global Variables




```
#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 2

```
int a;

int proc(int b) {
    {int b=4;}
    a = b;
    return a+2;
}

int main() {
    {int a = proc(6);}
    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;
}
```

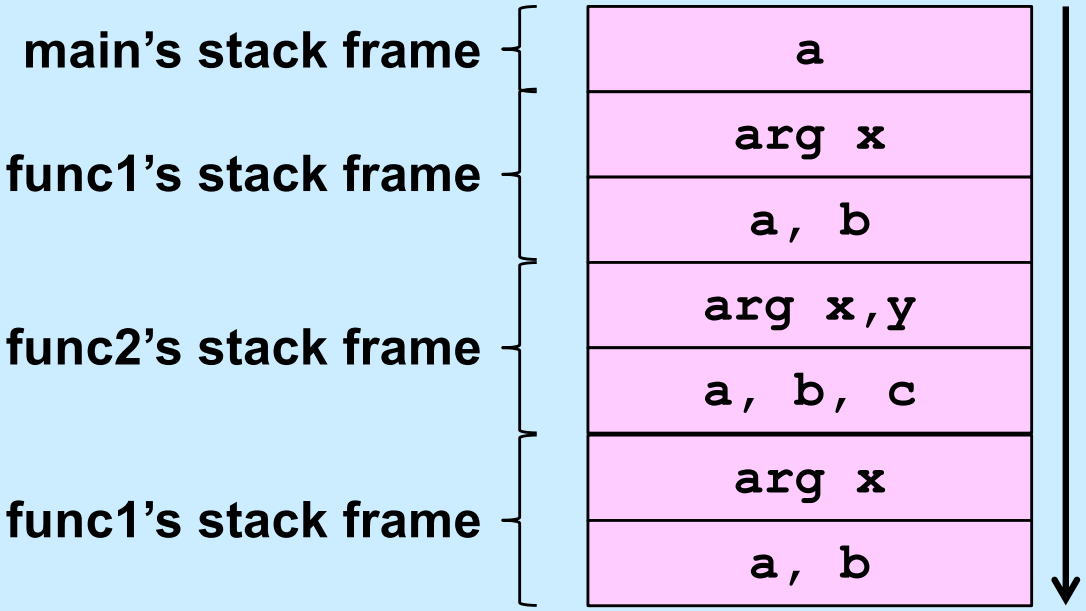
```
% ./a.out
98378932
```

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

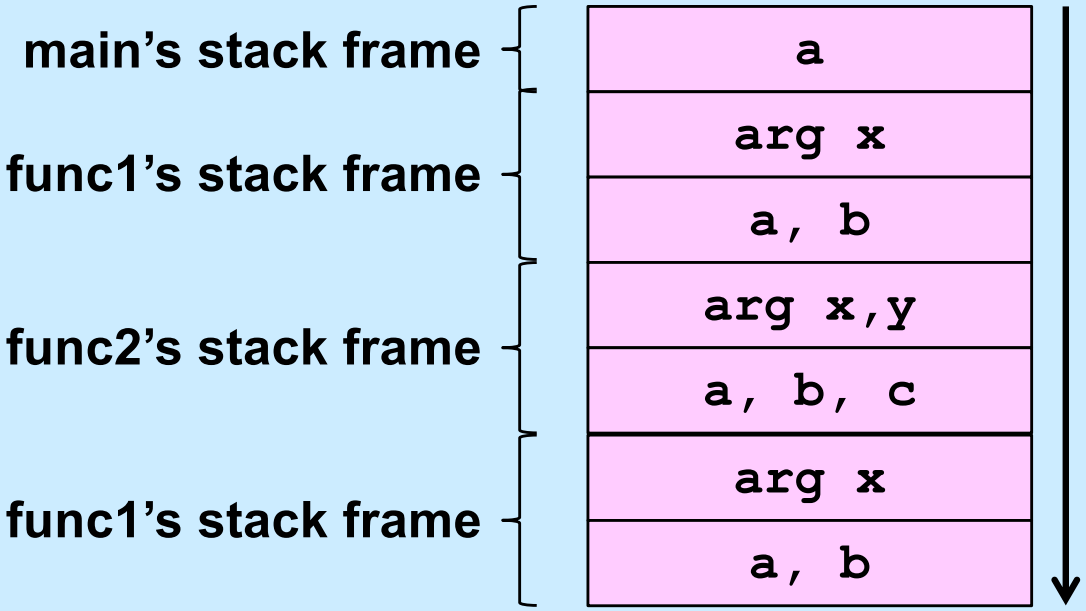
Implementation: Stacks

```
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 3

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

Quiz 4

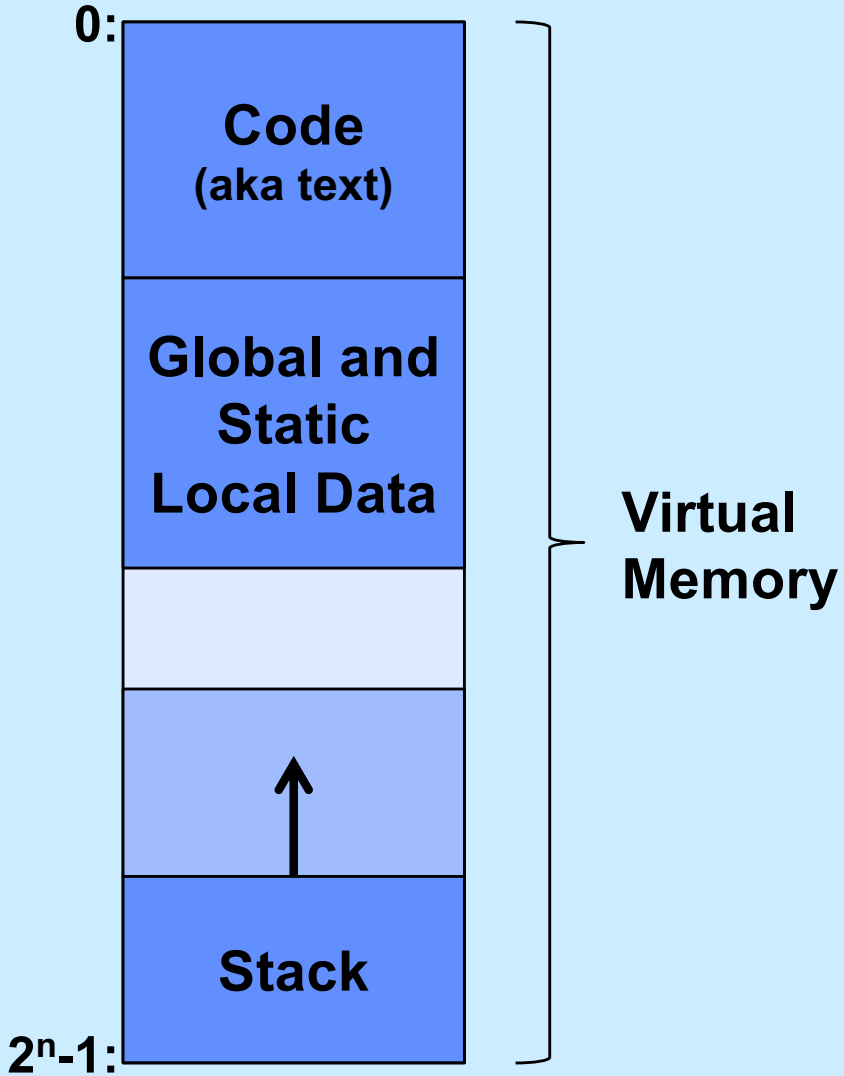
```
int sub() {
  static int svar = 1;
  int lvar = 1;
  svar += lvar;
  lvar++;
  return svar;
}

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;
```

Structures

```
struct ComplexNumber {
        float real;
        float imag;
};

struct ComplexNumber x;
x.real = 1.4;
x.imag = 3.65e-10;
```

Pointers to Structures

```
struct ComplexNumber {
        float real;
        float imag;
};

struct ComplexNumber x, *y;
x.real = 1.4;
x.imag = 3.65e-10;
y = &x;
y->real = 2.6523;
y->imag = 1.428e20;
```

*struct*s and Functions

```
struct ComplexNumber ComplexAdd(
            struct ComplexNumber a1,
            struct ComplexNumber a2) {
        struct ComplexNumber result;
        result.real = a1.real + a2.real;
        result.imag = a1.imag + a2.imag;
        return result;
}
```

Would This Work?

```
struct ComplexNumber *ComplexAdd(
            struct ComplexNumber *a1,
            struct ComplexNumber *a2) {
        struct ComplexNumber result;
        result.real = a1->real + a2->real;
        result.imag = a1->imag + a2->imag;
        return &result;
}
```

How About This?

```
void ComplexAdd(
        struct ComplexNumber *a1,
        struct ComplexNumber *a2,
        struct ComplexNumber *result) {
  result->real = a1->real + a2->real;
  result->imag = a1->imag + a2->imag;
  return;
}
```

Using It ...

```
struct ComplexNumber j1 = {3.6, 2.125};
struct ComplexNumber j2 = {4.32, 3.1416};
struct ComplexNumber sum;

ComplexAdd(&j1, &j2, &sum);
```

Arrays of *structs*

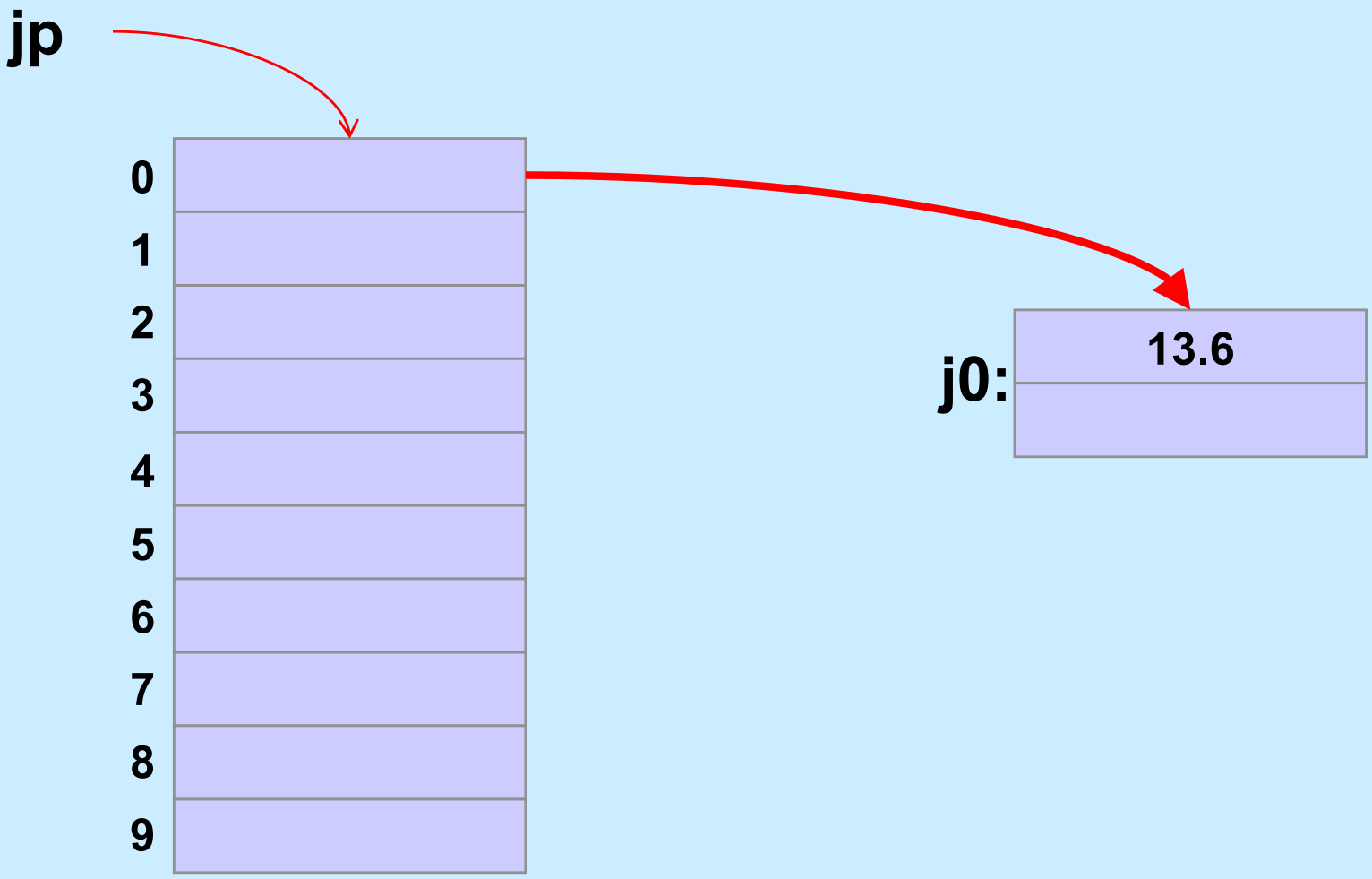
```
struct ComplexNumber j[10];
j[0].real = 8.127649;
j[0].imag = 1.76e18;
```

Arrays, Pointers, and *structs*

```
/* What's this? */
struct ComplexNumber *jp[10];
```

```
struct ComplexNumber j0;
jp[0] = &j0;
jp[0]->real = 13.6;
```

Memory View



Quiz 5

```
struct list_elem {
    int val;
    struct list_elem *next;
} a, b;

int main() {
    a->val = 1;
    a->next = &b;
    b->val = 2;
    printf("%d\n", a->next->val);
    return 0;
}
```

- **What happens?**
  a) **syntax error**
  b) **seg fault**
  c) **prints something and terminates**

Quiz 6

```
struct list_elem {
    int val;
    struct list_elem *next;
} a, b;

int main() {
    a.val = 1;
    a.next = &b;
    b.val = 2;
    printf("%d\n", a.next.val);
    return 0;
}
```

- **What happens?**
  a) **syntax error**
  b) **seg fault**
  c) **prints something and terminates**

Quiz 7

```
struct list_elem {
    int val;
    struct list_elem *next;
} a, b;

int main() {
    a.val = 1;
    b.val = 2;
    printf("%d\n", a.next->val);
    return 0;
}
```

- **What happens?**
  a) **syntax error**
  b) **seg fault**
  c) **prints something and terminates**

Quiz 8

```
struct list_elem {
    int val;
    struct list_elem *next;
} a, b;

int main() {
    a.val = 1;
    a.next = &b;
    b.val = 2;
    printf("%d\n", a.next->val);
    return 0;
}
```

- **What happens?**
  a) **syntax error**
  b) **seg fault**
  c) **prints something and terminates**