CS 33

Introduction to C
Part 3

The Preprocessor

`#include`

- calls the preprocessor to include a file

What do you include?

- your own *header* file:

```
#include "fact.h"
```

  - look in the current directory

- standard *header* file:

```
#include <assert.h>
#include <stdio.h>
```

  - look in a standard place

Contains declaration of *printf* (and other things)

Function Declarations

fact.h

```
float fact(int i);
```

main.c

```
#include "fact.h"
int main() {
  printf("%f\n", fact(5));
  return 0;
}
```

#define

```
#define SIZE 100
int main() {
    int i;
    int a[SIZE];
}
```

#define

- **defines a substitution**
- **applied to the program by the preprocessor**

#define

```
#define forever for(;;)
int main() {
    int i;
    forever {
      printf("hello world\n");
    }
}
```

assert

```
#include <assert.h>
float fact(int i) {
  int k; float res;
  assert(i >= 0);
  for(res=1,k=1; k<=i; k++)
    res = res * k;
  return res;
}
int main() {
  printf("%f\n", fact(-1));
```

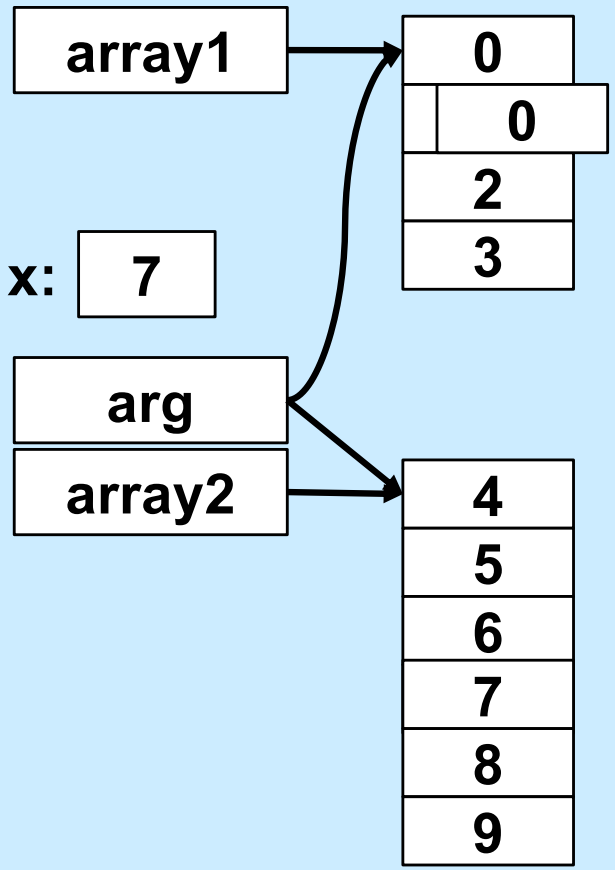
assert

- **verify that the assertion holds**
- **abort if not**

```
$ ./fact
main.c:4: failed assertion 'i >= 0'
Abort
```

Arrays and Parameters

```
int main() {
    int array1[4] = {0, 1, 2, 3};
    int x = func(array1);
    printf("%d, %d\n", x, array1[1]);
    return 0;
}

int func(int arg[]) {
    int array2[6] = {4, 5, 6, 7, 8, 9};
    arg[1] = 0;
    arg = array2;
    return arg[3];
}
```



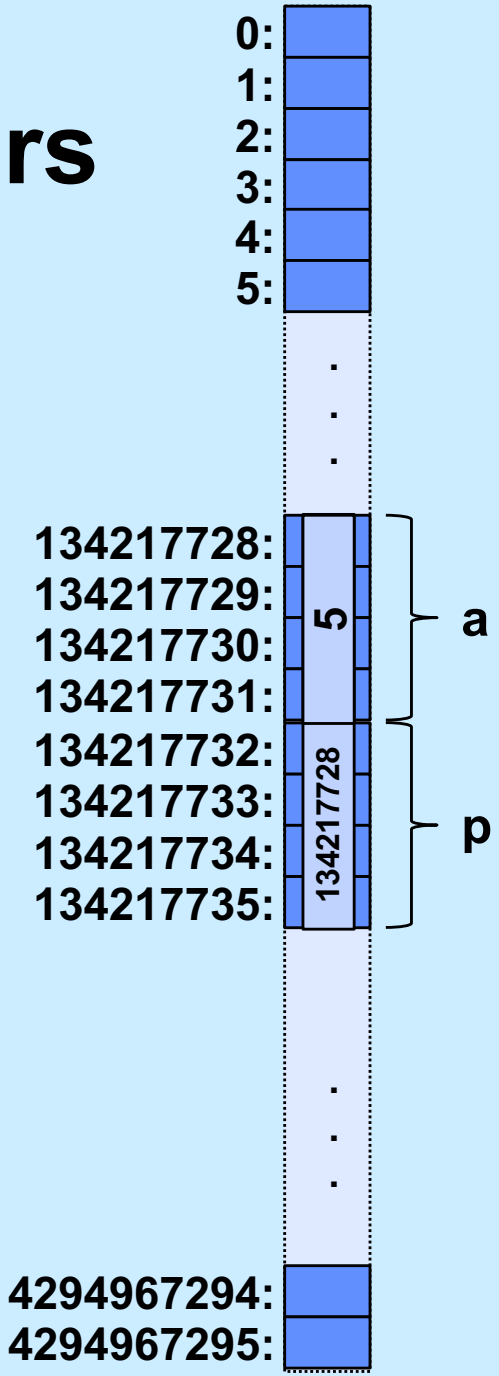

```
$ ./a.out
7 0
```

Arrays and Parameters

```
void func(int arg[]) {
   /* arg points to the caller's array */
   int local[7];     /* seven ints */
   arg++;            /* legal */
   arg = local;      /* legal */
   local++;          /* illegal */
   local = arg;      /* illegal */
}
```

Dereferencing C Pointers

```
int main() {
    int *p; int a = 4;
    p = &a;
    (*p)++;
    printf("%d %u\n", *p, p);
}
```

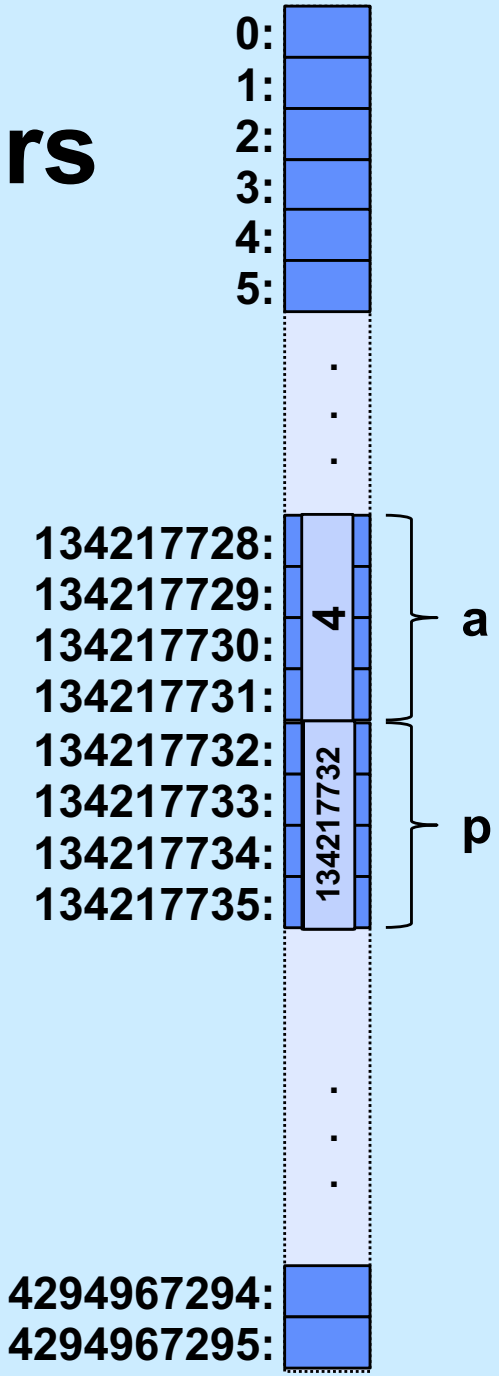



```
$ ./a.out
5 134217728
```

Dereferencing C Pointers

```
int main() {
    int *p; int a = 4;
    p = &a;
    *p++;
    printf("%d %u\n", *p, p);
}
```

```
$ ./a.out
134217732 134217732
```



Dereferencing C Pointers

```
int main() {
    int *p; int a = 4;
    p = &a;
    ++*p;
    printf("%d %u\n", *p, p);
}
```

```
$ ./a.out
5 134217728
```

Quiz 1

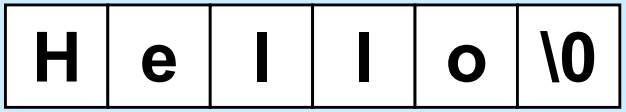
```
int proc(int arg[]) {
    arg++;
    return arg[1];
}

int main() {
    int A[3]={0, 1, 2};
    printf("%d\n",
      proc(A));
}
```

What's printed?

a) 0
b) 1
c) 2
d) indeterminate

Strings

- **Strings are arrays of characters terminated by '\0' (null character)**
  - **the '\0' is included at the end of string constants**
    - » `"Hello"`



Strings

```
int main() {
    printf("%s","Hello");
    return 0;
}
```

```
$ ./a.out
Hello$
```

Strings

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

```
$ ./a.out
Hello
$
```

Strings

```
void printString(char s[]) {
   int i;
   for(i=0; s[i]!='\0'; i++)
      printf("%c", s[i]);
}
int main() {
   printString("Hello");
   printf("\n");
   return 0;
}
```

Tells C that this function does not return a value

1-D Arrays

- If T is a datatype (such as int), then

```
T n[6]
```

  declares `n` to be an array of six `T`'s

  - the type of each element goes before the identifier
  - the number of elements goes after the identifier

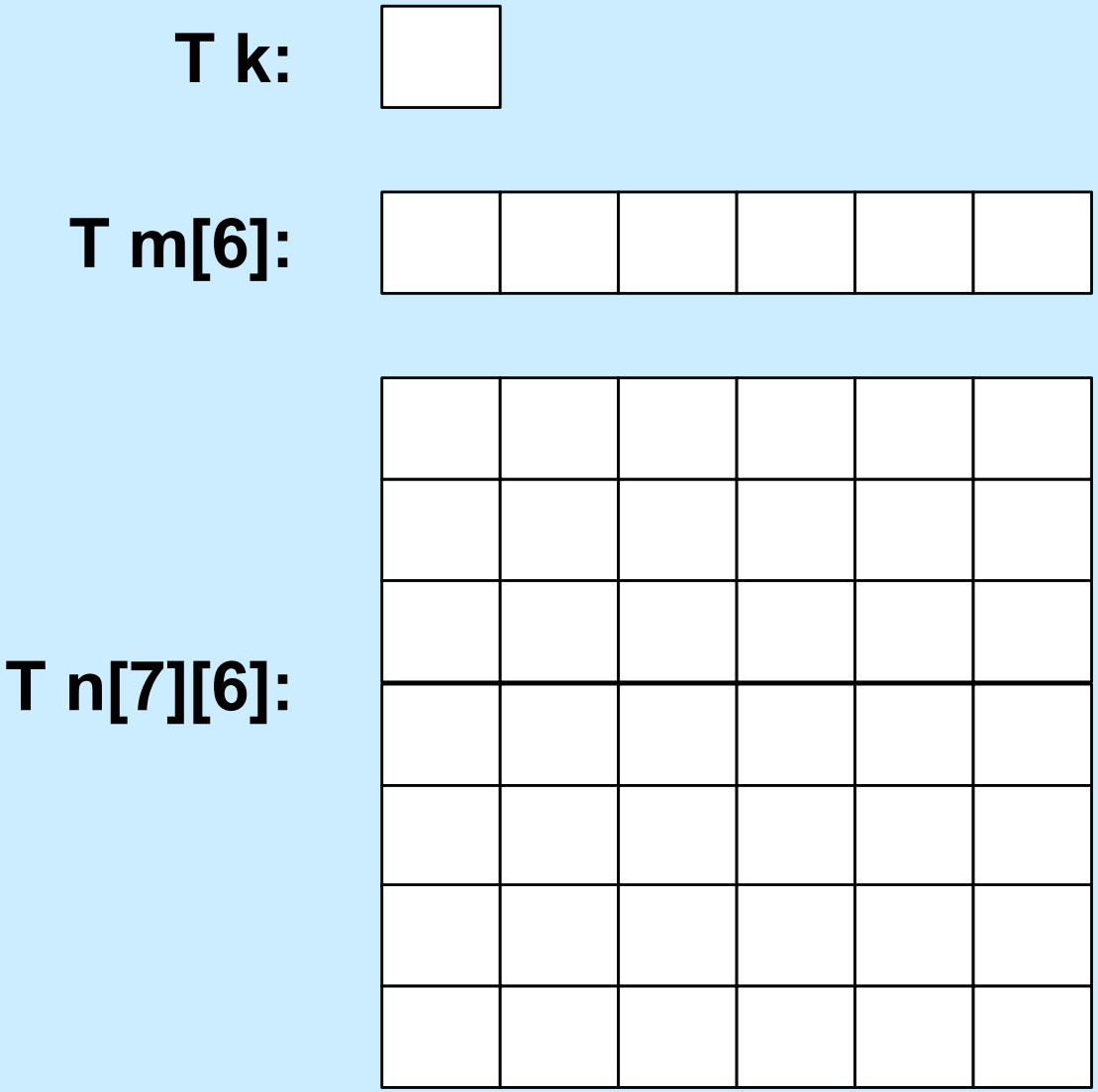
- What is n's type?

```
T[6]
```

2-D Arrays

- Suppose `T` is a datatype (such as `int`)
- `T n[6]`
  - declares `n` to be an array of (six) `T`
  - the type of `n` is `T[6]`
- Thus `T[6]` is effectively a datatype
- Thus we can have an array of `T[6]`
- `T m[7][6]`
  - `m` is an array of (seven) `T[6]`
  - `m[i]` is of type `T[6]`
  - `m[i][j]` is of type `T`

Example



3-D Arrays

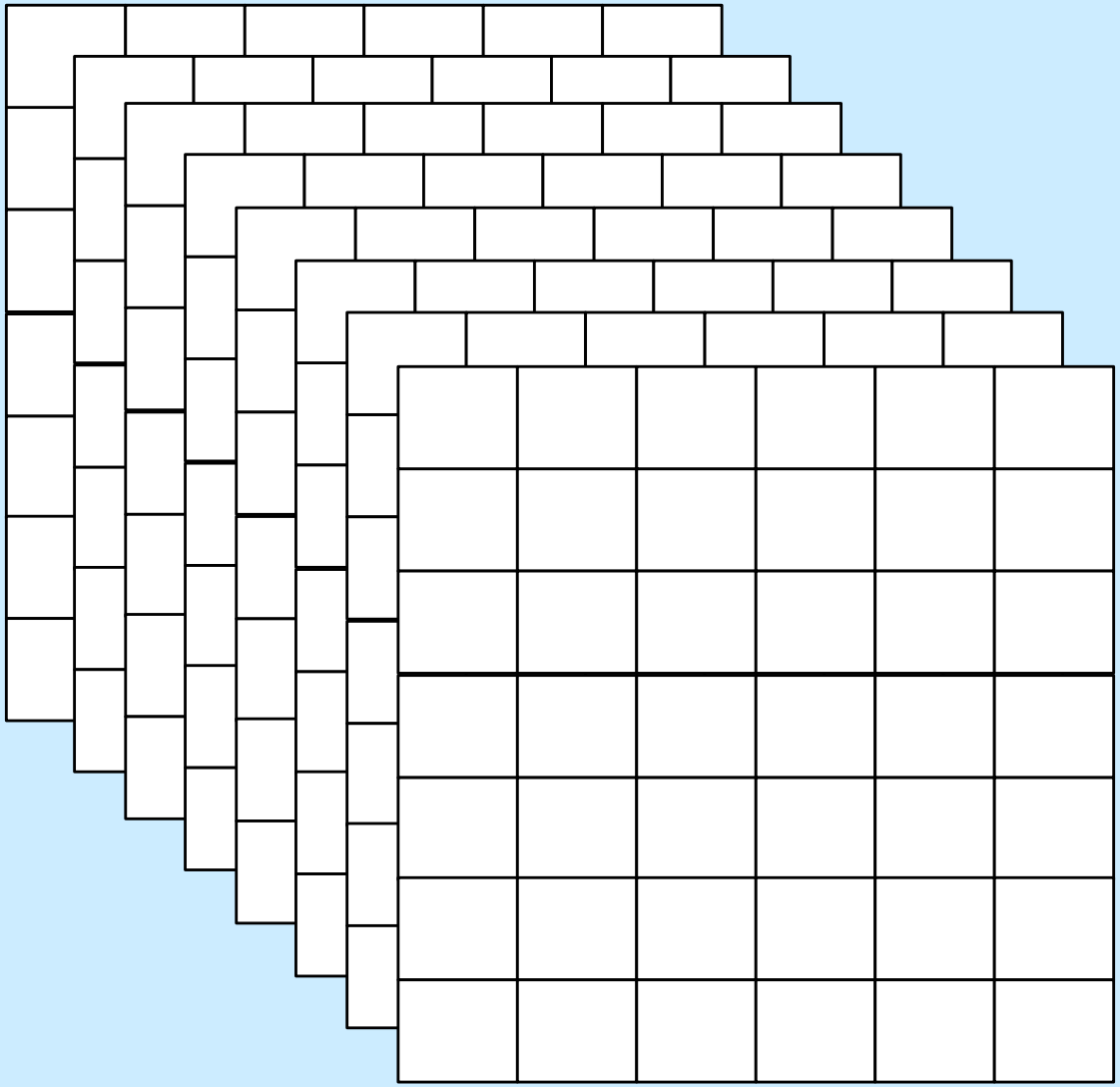
- How do we declare an array of eight `T[7][6]`?

  `T p[8][7][6]`

  - `p` is an array of (eight) `T[7][6]`
  - `p[i]` is of type `T[7][6]`
  - `p[i][j]` is of type `T[6]`
  - `p[i][j][k]` is of type `T`

Example

T m[8][7][6]:

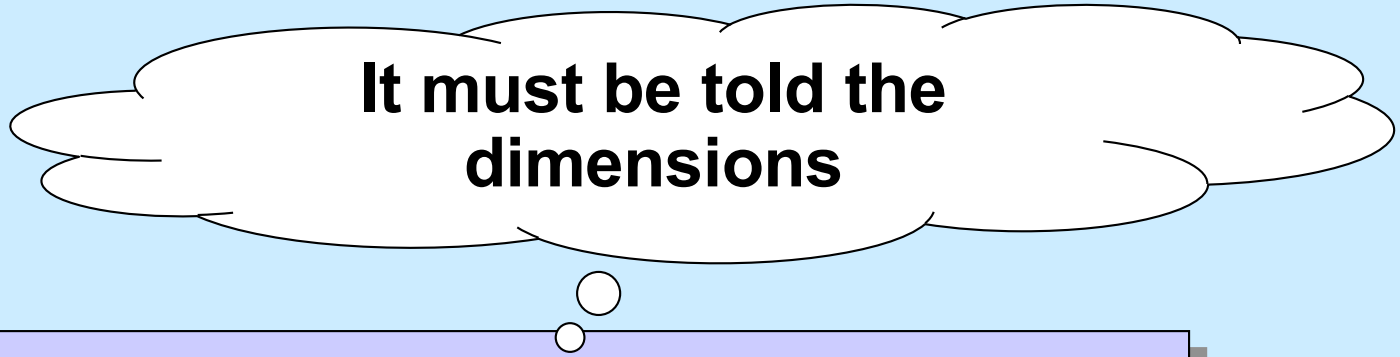


2-D Arrays

```
$ ./a.out
     0      1      2      3
     4      5      6      7
     8      9     10     11
```

```
#define NUM_ROWS 3
#define NUM_COLS 4
…
int main() {
    int row, col;
    int m[NUM_ROWS][NUM_COLS];
    for(row=0; row<NUM_ROWS; row++)
      for(col=0; col<NUM_COLS; col++)
          m[row][col] = row*NUM_COLS+col;
    printMatrix(NUM_ROWS, NUM_COLS, m);
    return 0;
}
```

2-D Arrays

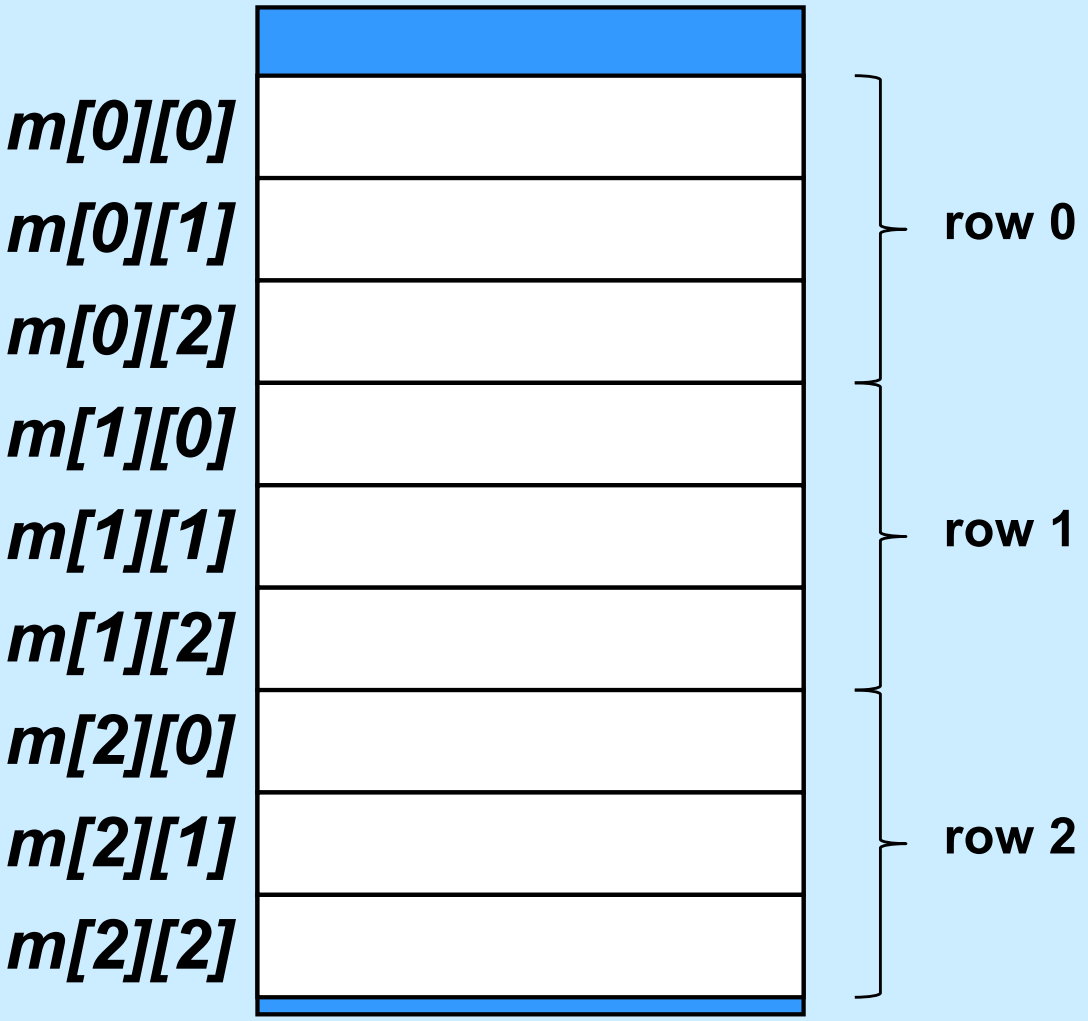



```
void printMatrix(int nr, int nc,
       int m[nr][nc]) {
   int row, col;
   for(row=0; row<nr; row++) {
     for(col=0; col<nc; col++)
        printf("%6d", m[row][col]);
     printf("\n");
   }
}
```

Memory Layout

```
#define NUM_ROWS 3
#define NUM_COLS 3
```

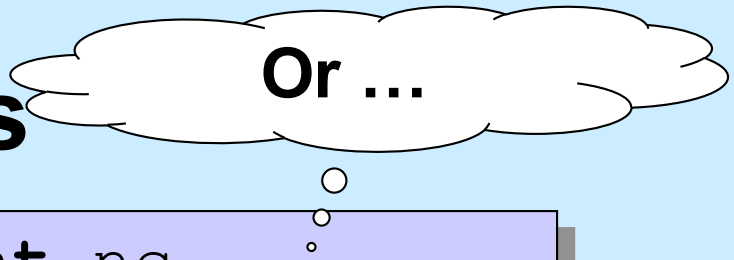
Row-Major Order



2-D Arrays


```
void printMatrix(int nr, int nc,
      int m[][nc]) {
   int row, col;
   for(row=0; row<nr; row++) {
     for(col=0; col<nc; col++)
        printf("%6d", m[row][col]);
     printf("\n");
}
```

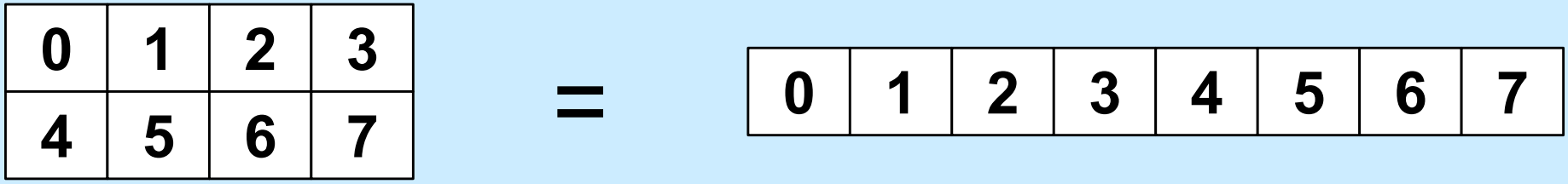
2-D Arrays




```
void printMatrix(int nr, int nc,
        int m[][nc]) {
    int i;
    for(i=0; i<nr; i++)
        printRow(nc, m[i]);
}
```

```
void printRow(int nc, int a[]) {
    int i;
    for(i=0; i<nc; i++)
        printf("%6d", a[i]);
    printf("\n");
}
```

2D as 1D




```
int A2D[2][4];          int A1D[8];

int AccessAs1D(int A[], int Row, int Col, int RowSize) {
    return A[Row*RowSize + Col];
}

int main(void) {
    int A2D[2][4] = {{0, 1, 2, 3}, {4, 5, 6, 7}};
    int *A1D = &A2D[0][0];
    int x = AccessAs1D(A1D, 1, 2, 4);
    printf("%d\n", x);
    return 0;
}
```

```
$ ./a.out
6
$
```

Quiz 2

Consider the array

```
int A[3][3];
```

- **which element is adjacent to `A[0][0]` in memory?**
  - a) `A[0][1]`
  - b) `A[1][0]`
  - c) none of the above

Quiz 3

Consider the array

```
int A[3][3];
int *B = &A[0][0];

B[8] = 8;
```

- **which element of A was modified?**
  - **a) A[0][3]**
  - **b) A[2][2]**
  - **c) A[3][0]**
  - **d) none of the above**

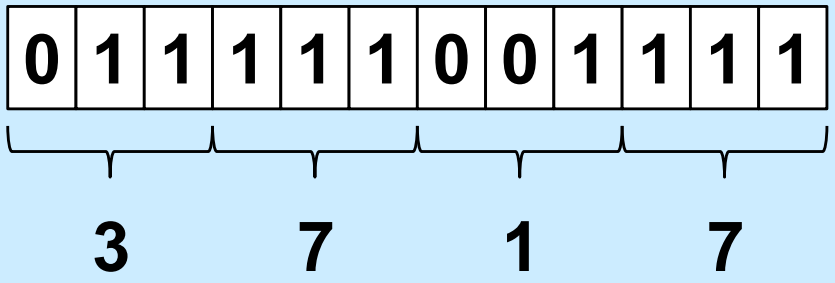
Number Representation

- Hindu-Arabic numerals
  - developed by Hindus starting in 5th century
    - » positional notation
    - » symbol for 0
  - adopted and modified somewhat later by Arabs
    - » known by them as “Rakam Al-Hind” (Hindu numeral system)
  - 1999 rather than MCMXCIX
    - » (try doing long division with Roman numerals!)

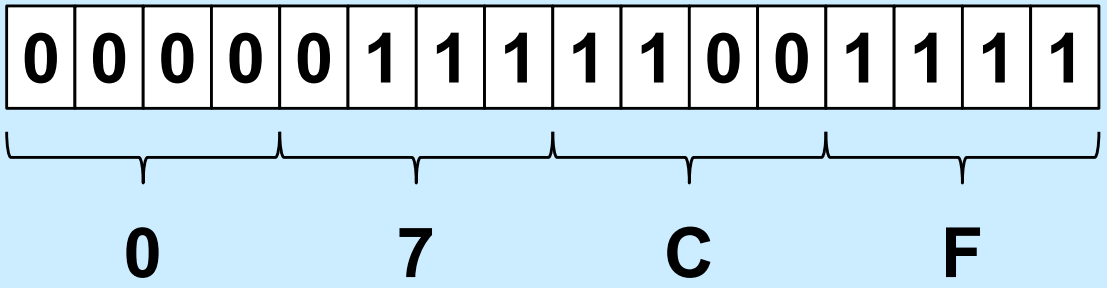
Which Base?

- 1999
  - base 10
    - » $9 \cdot 10^0 + 9 \cdot 10^1 + 9 \cdot 10^2 + 1 \cdot 10^3$
  - base 2
    - » 11111001111
      - $1 \cdot 2^0 + 1 \cdot 2^1 + 1 \cdot 2^2 + 1 \cdot 2^3 + 0 \cdot 2^4 + 0 \cdot 2^5 + 1 \cdot 2^6 + 1 \cdot 2^7 + 1 \cdot 2^8 + 1 \cdot 2^9 + 1 \cdot 2^{10}$
  - base 8
    - » 3717
      - $7 \cdot 8^0 + 1 \cdot 8^1 + 7 \cdot 8^2 + 3 \cdot 8^3$
    - » why are we interested?
  - base 16
    - » 7CF
      - $15 \cdot 16^0 + 12 \cdot 16^1 + 7 \cdot 16^2$
    - » why are we interested?

Words …



12-bit computer word



16-bit computer word

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 4

- **What's the decimal (base 10) equivalent of 23_{16}?**
  - **a) 19**
  - **b) 33**
  - **c) 35**
  - **d) 37**

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

Unsigned 32-Bit Integers

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

(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

  ~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 && (x || y) && ((x & z) | (y & z))
```

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 5

- **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