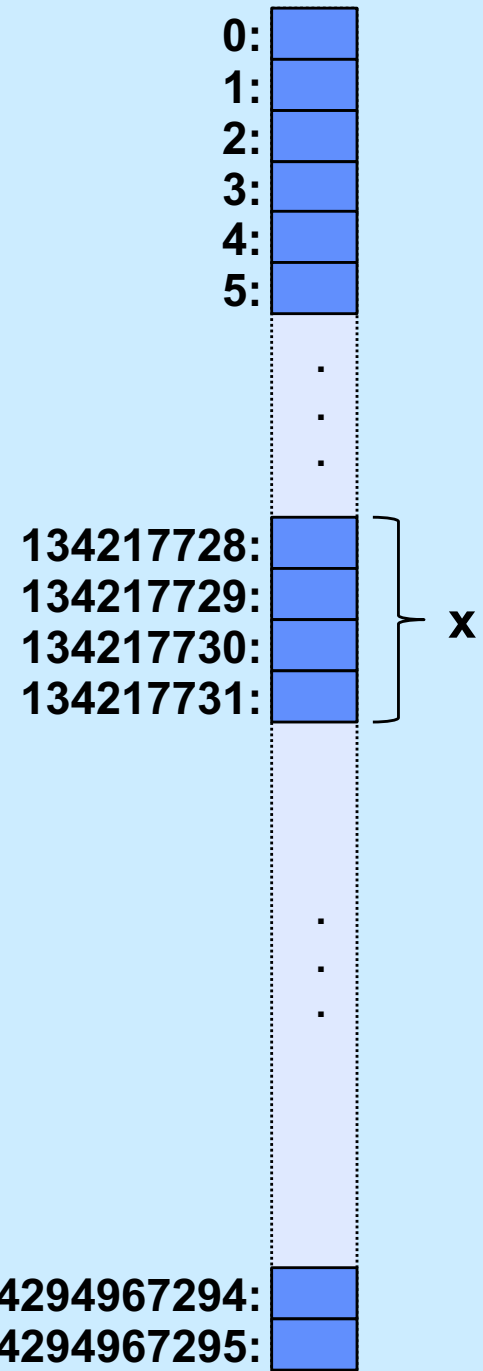# CS 33

Introduction to C
Part 2

Memory

- **"Real" memory**
    - it's complicated
    - it involves electronics, semiconductors, physics, etc.
    - it's not terribly relevant at this point

- **"Virtual" memory**
    - the notion of memory as used by programs
    - it involves logical concepts
    - it's how you should think about memory (most of the time)

Virtual Memory

- **It's a large array of bytes**
  - **one byte is eight bits**
  - **an int is four consecutive bytes**
  - **so is a float**
  - **a char is one byte**
- **The array index of a byte is its *address***
  - **the address of a larger item is the index of its first byte**

virtual memory

```
0:
1:
2:
3:
4:
5:
.
.
.
134217728:
134217729:     } x
134217730:
134217731:
.
.
.
4294967294:
4294967295:
```
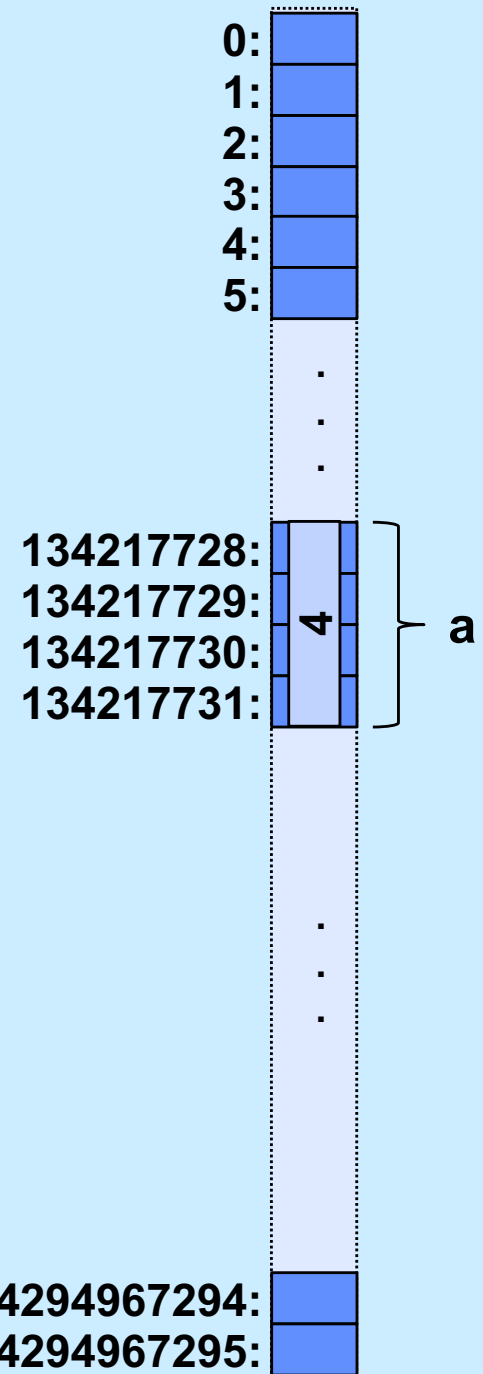
Memory addresses in C

- **In C**
  - **you can get the memory address of any variable**
  - **just use the operator &**

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

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

0:	
1:	
2:	
3:	
4:	
5:	

.
.
.

134217728:
134217729: 4   } a
134217730:
134217731:

.
.
.
.
.
.

4294967294:
4294967295:

C Pointers

- **What is a C pointer?**
  - **a variable that holds an address**

- **Pointers in C are "typed" (remember the promises)**
  - **pointer to an int**
  - **pointer to a char**
  - **pointer to a float**
  - **pointer to <whatever you can define>**

- **C has a syntax to declare pointer types**
  - **things start to get complicated …**

C Pointers

p is a pointer to an int

if you follow p, you find an int

```c
int main() {
    int *p;
    int a = 4;
    p = &a;
    printf("%u\n", p);
}
```
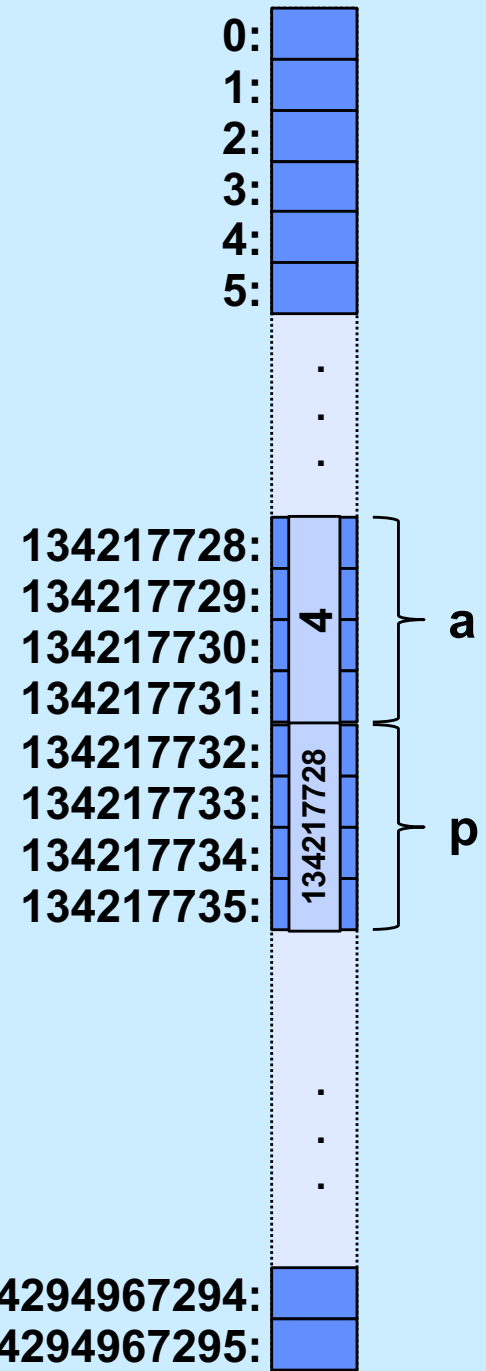
p is assigned the address of a

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

C Pointers

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

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

```
0:
1:
2:
3:
4:
5:

.
.
.

134217728:
134217729:        a
134217730:   4
134217731:
134217732:
134217733:  134217728
134217734:        p
134217735:

.
.
.

4294967294:
4294967295:
```

C Pointers

- **Pointers are typed**
  - the types of the items they point to are known
  - there is one exception (discussed later)

- **Pointers are first-class citizens**
  - they can be passed to functions
  - they can be stored in arrays and other data structures
  - they can be returned by functions

Swapping

What does this do?

```
void swap(int *i, int *j) {
    int *tmp;
    tmp = j; j = i; i = tmp;
}
int main() {
    int a = 4;
    int b = 8;
    swap(&a, &b);
    printf("a:%d  b:%d\n", a, b);
}
```
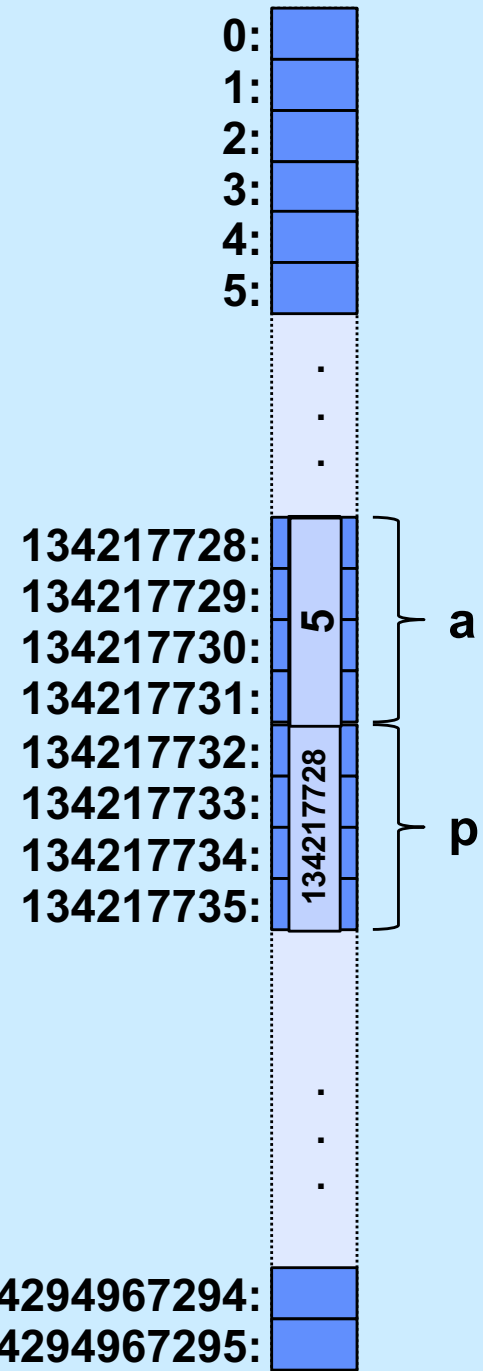
```
$ ./a.out
a:4  b:8
```

Damn!

C Pointers

- ## Dereferencing pointers
  - **accessing/modifying the value pointed to by a pointer**

```
int main() {
    int *p;
    int a = 4;
    p = &a;
    printf("%d\n", *p);
    *p = *p + 1;
    printf("%d\n", *p);
}
```

```
$ ./a.out
4
5
```

0:	
1:	
2:	
3:	
4:	
5:	
.	
.	
.	
134217728:	
134217729:	5 → a
134217730:	
134217731:	
134217732:	
134217733:	134217728 → p
134217734:	
134217735:	
.	
.	
.	
4294967294:	
4294967295:	

Dereferencing C Pointers

```c
int main() {
    int *p;
    int a = 4;
    p = &a;
    printf("%d\n", *p);
    *p = *p + 1;
    *p += 3;
    printf("%d\n", a);
}
```

```
$ ./a.out
4
8
```

Swapping

```
void swap(int *i, int *j) {
    int tmp;
    tmp = *j; *j = *i; *i = tmp;
}
int main() {
    int a = 4;
    int b = 8;
    swap(&a, &b);
    printf("a:%d  b:%d\n", a, b);
}
```

```
$ ./a.out
a:8   b:4
```

Hooray!
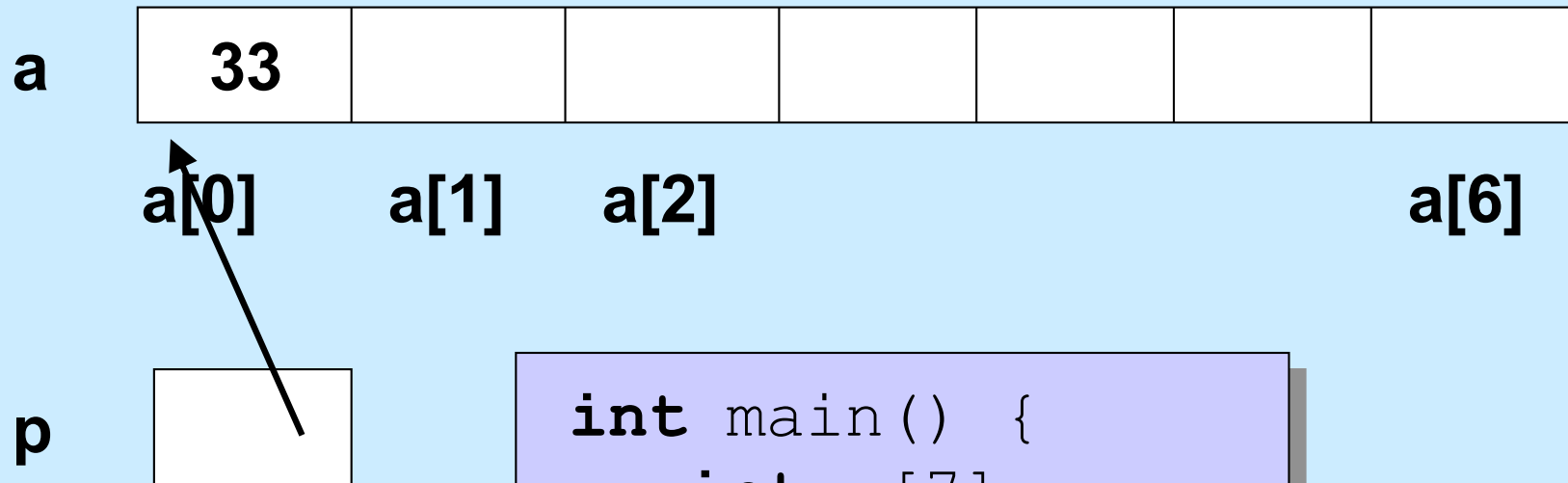
Quiz 1

```c
int doubleit(int *p) {
    *p = 2*(*p);
    return *p;
}
int main() {
    int a = 4;
    int b;
    b = doubleit(&a);
    printf("%d\n", a*b);
}
```

What's printed?

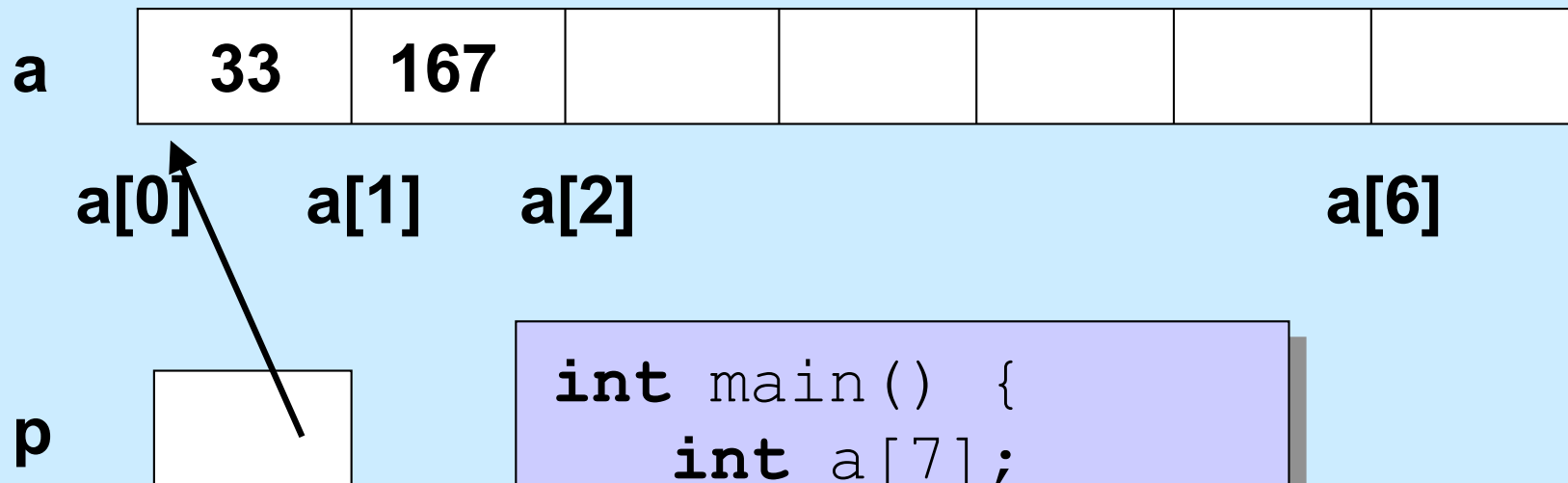   a) 64
    b) 32
    c) 16
    d) 8

Pointers and Arrays

a

| 33 | | | | | | |

a[0]   a[1]   a[2]   a[6]

p

```
int main() {
    int a[7];
    int *p;
    p = &a[0];
    *p = 33;
}
```

Pointer Arithmetic

Pointers can be incremented/decremented

   − **what this does depends on its type**

a	33	167					

  a[0]   **a[1]**   **a[2]**   **a[6]**
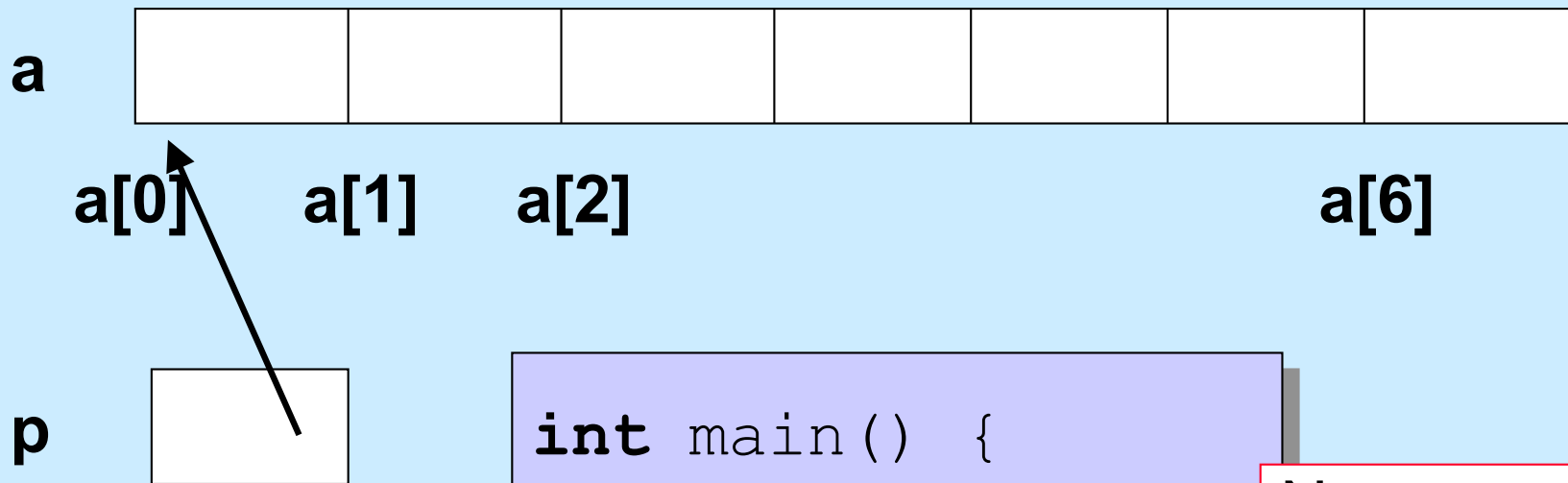
p

```
int main() {
    int a[7];
    int *p;
    p = &a[0];
    *p = 33;
    *(p+1) = 167;
}
```

Pointer Arithmetic

Pointers can be incremented/decremented

– **what this does depends on its type**

a

a[0]   **a[1]**   **a[2]**   **a[6]**
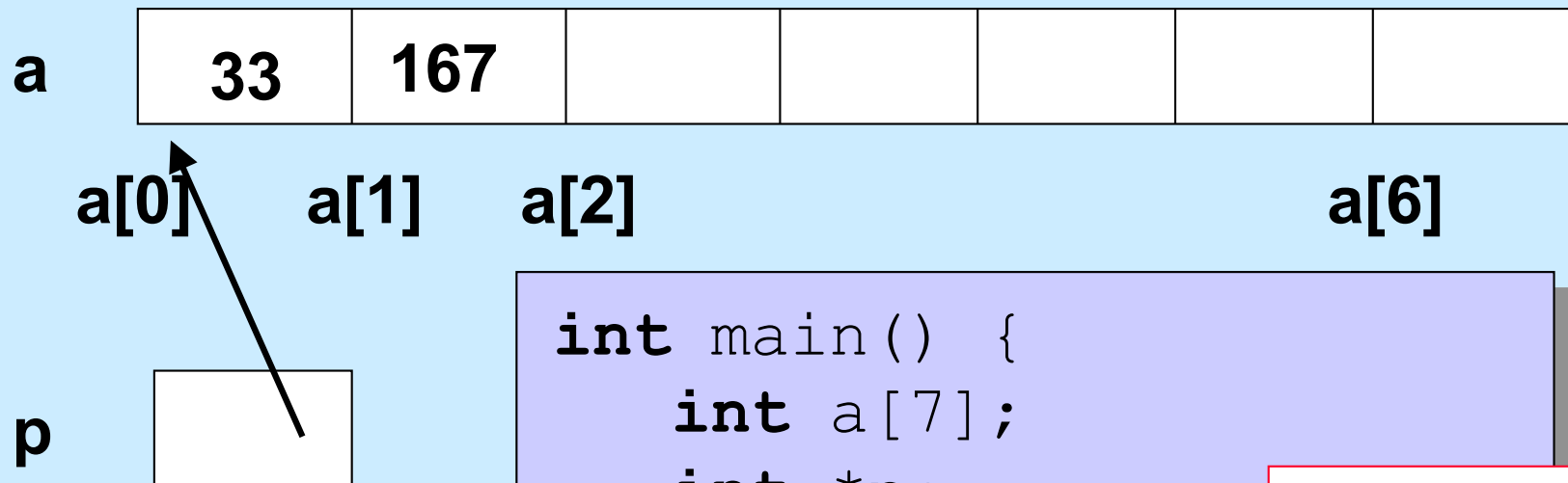
p

```
int main() {
    int a[7];
    int *p;
    p = &a[0];
}
```

Now `p` and `a` have the same value

Pointer Arithmetic

Pointers can be incremented/decremented

− **what this does depends on its type**

a | 33 | 167 | | | | | |

a[0] a[1] a[2]   a[6]

p

```
int main() {
    int a[7];
    int *p;
    p = a;
    *p = 33;
    p[1] = 167;
}
```

The array name represents a pointer to its first element

Pointers and Arrays

`p = &a[0];`   **can also be written as**   `p = a;`

`a[i];`   **really is**   `*(a+i)`

- **This makes sense, yet is weird ...**
  - `p` **is of type** `int *`
    - **it can be assigned to**
      `int *q;`
      `p = q;`
  - `a` **sort of behaves like an** `int *`
    - **but it can't be assigned to**
      ~~`a = q;`~~

Pointers and Arrays

- **An array name represents a pointer to the first element of the array**

- **Just like a literal represents its associated value**

  - **in**

    ```
    x = y + 2;
    ```

    » **"2" is a *literal* that represents the value 2**

  - **can't do**

    ```
    2 = x + y;
    ```

Literals and Functions

```
int func(int x) {
    x = x + 4;
    return x * 2;
}


int main() {
    result = func(2);
    printf("%d\n", result);
    return 0;
}
```

initialized with a copy of the argument

Arrays and Functions

initialized with a copy of the argument

```
int func(int *a, int nelements) {
    // sizeof(a) == sizeof(int *)
    int i;
    for (i=0; i<nelements-1; i++)
        a[i+1] += a[i];
    return a[nelements-1];
}

int main() {
    int array[50] = ... ;
    // sizeof(array) == 50*sizeof(int)
    printf("result = %d\n", func(array, 50));
    return 0;
}
```

Equivalently ...

```
int func(int a[], int nelements) {
    // sizeof(a) == sizeof(int *)
    ...

}
```

No need for array size, since all that's used is pointer to first element

```
int main() {
    int array[50] = ... ;
    // sizeof(array) == 50*sizeof(int)
    printf("result = %d\n", func(array, 50));
    return 0;
}
```

Parameter passing

Passing arrays to a function

```
int average(int a[], int size) {
    int i; int sum;
    for(i=0,sum=0; i<size; i++)
        sum += a[i];
    return sum/size;
}
int main() {
    int a[100];
    …
    printf("%d\n",average(a,100));
}
```

- **Note that I need to pass the size of the array**
- **This array has no idea how big it is**

Swapping

Write a function to swap two entries of an array

```
void swap(int a[], int i, int j) {
    int tmp;
    tmp = a[j];
    a[j] = a[i];
    a[i] = tmp;
}
```

Selection Sort

```c
void selectsort(int array[], int length){
  int i, j, min;
  for (i = 0; i < length; ++i){
    /* find the index of the smallest item from i onward */
    min = i;
    for (j = i; j < length; ++j)
      if (array[j] < array[min])
        min = j;
    /* swap the smallest item with the i-th item */
    swap(array, i, min);
  }
  /* at the end of each iteration, the first i slots have the i
     smallest items */
}
```

Quiz 2

```c
int func(int a[], int nelements) {
    int b[5] = {10, 11, 12, 13, 14};
    a = b;
    return a[1];
}


int main() {
    int array[50];
    array[1] = 0;
    printf("result = %d\n",
        func(array, 50));
    return 0;
}
```

This program prints:

a) 11
b) 0
c) 10
d) nothing: it doesn't compile because of a syntax error

Quiz 3

```c
int func(int a[], int nelements) {
    int b[5] = {10, 11, 12, 13, 14};
    a = b;
    return a[1];
}


int main() {
    int array[5] = {9, 8, 7, 6, 5};
    func(array, 5);
    printf("%d\n", array[1]);
    return 0;
}
```

This program prints:

a) 8
b) 7
c) 10
d) 11

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>` ——— **Contains declaration of *printf* (and other things)**

    - **look in a standard place**

Function Declarations

fact.h

main.c

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

```
#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

```c
#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
```