CS 33

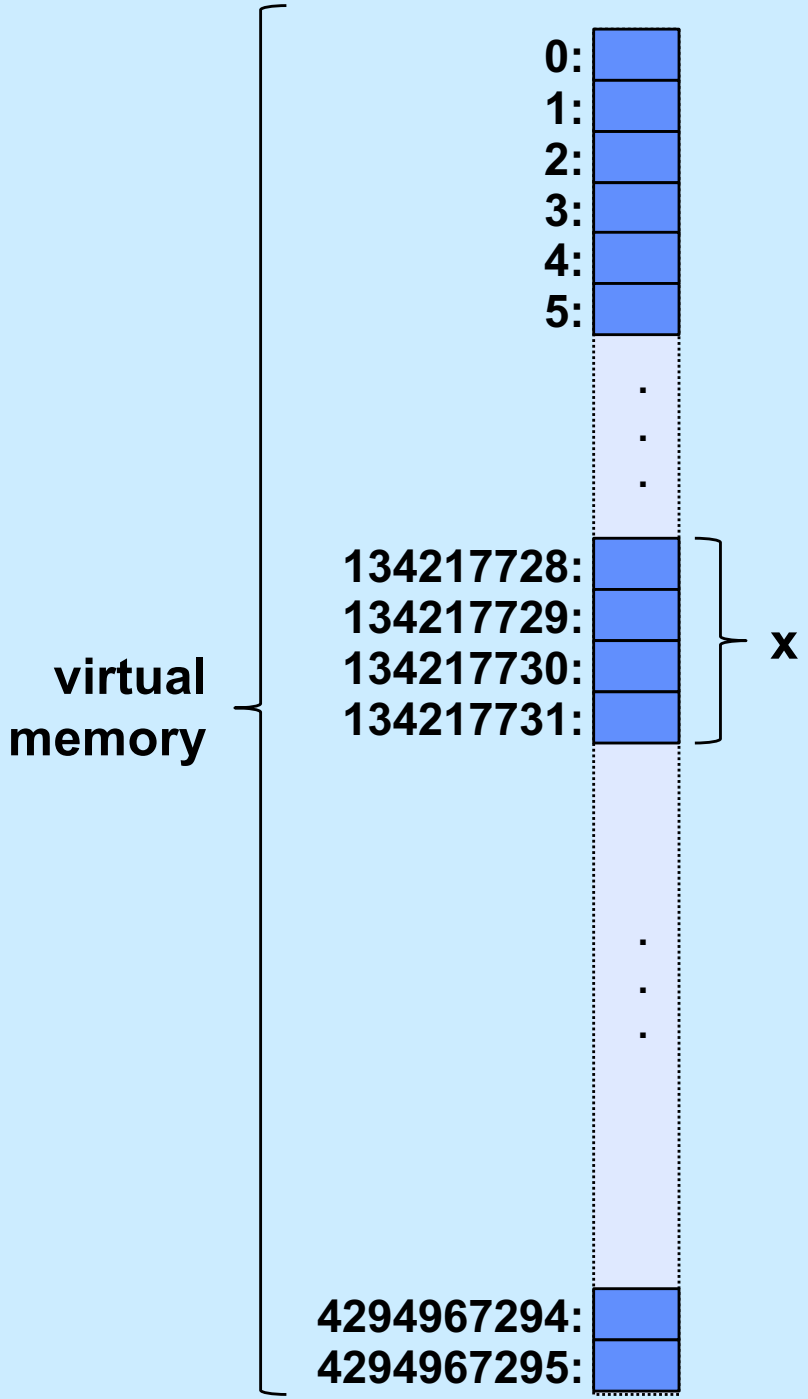
Introduction to C
Part 2

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)

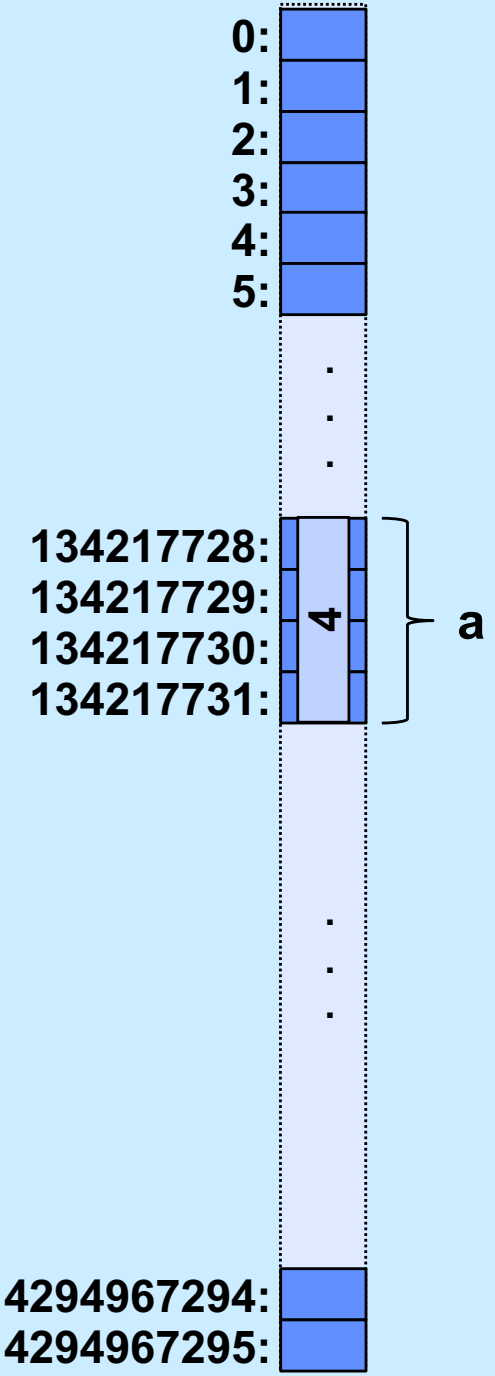
Virtual Memory

- 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



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
```

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

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

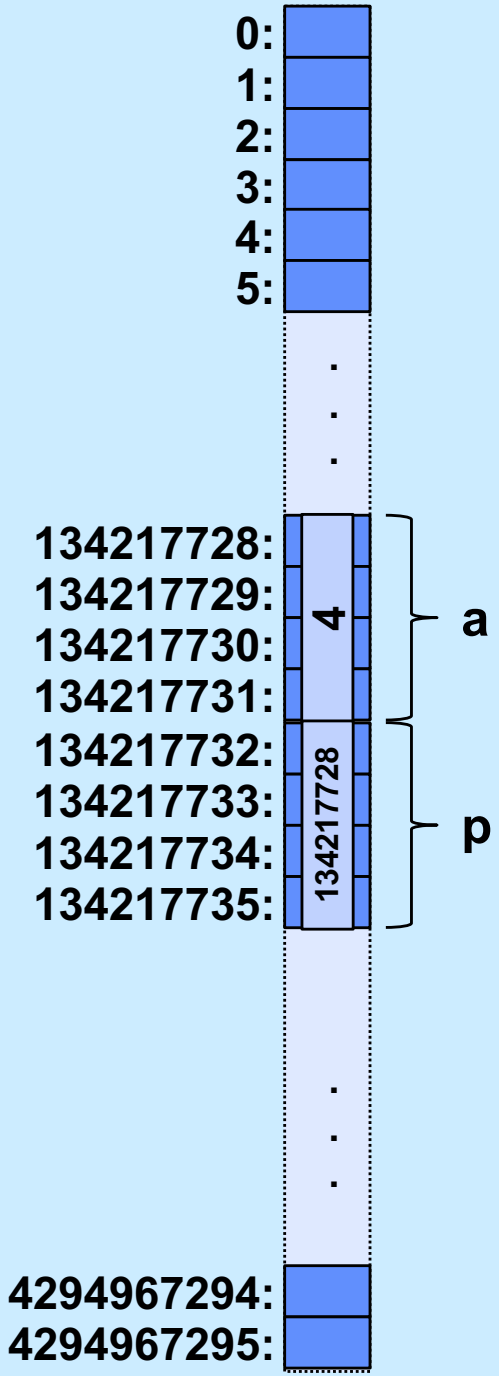
p is assigned the address of a

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

C Pointers

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

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



C Pointers

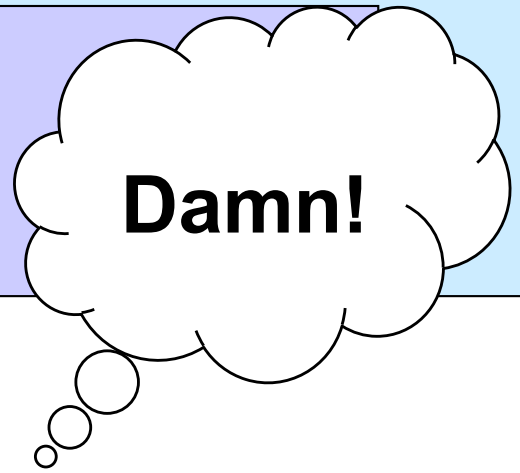
- Pointers are typed
  - the types of the objects they point to are known
  - there is one exception (discussed later)
- Pointers are first-class citizens
  - they can be passed to functions
  - they can be stored in arrays and other data structures
  - they can be returned by functions

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
```

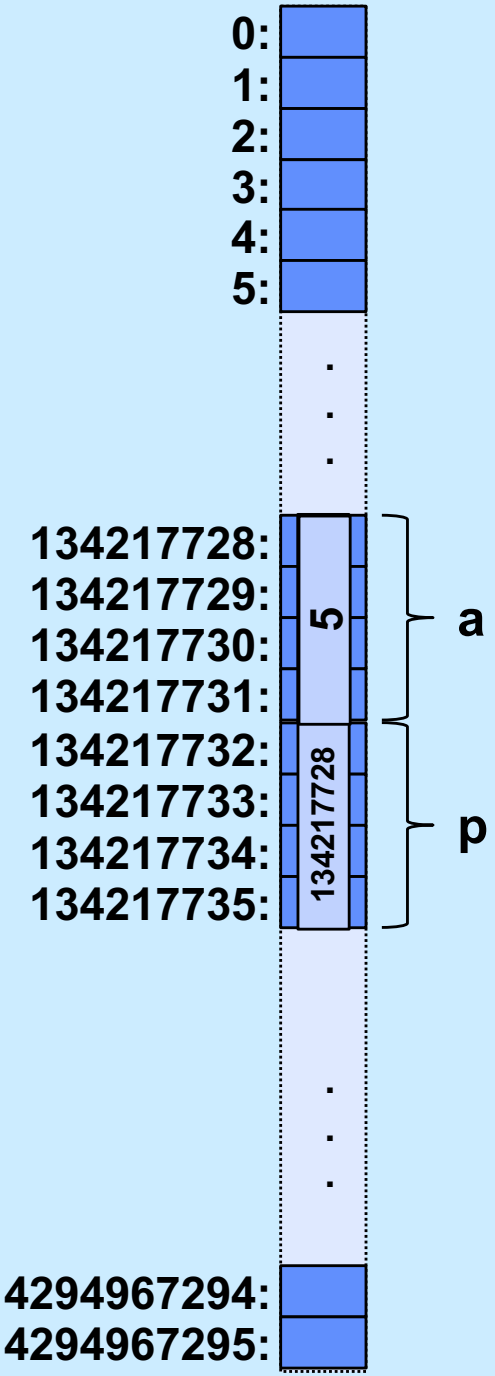


C Pointers

- **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
```



Dereferencing C Pointers

```
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
```

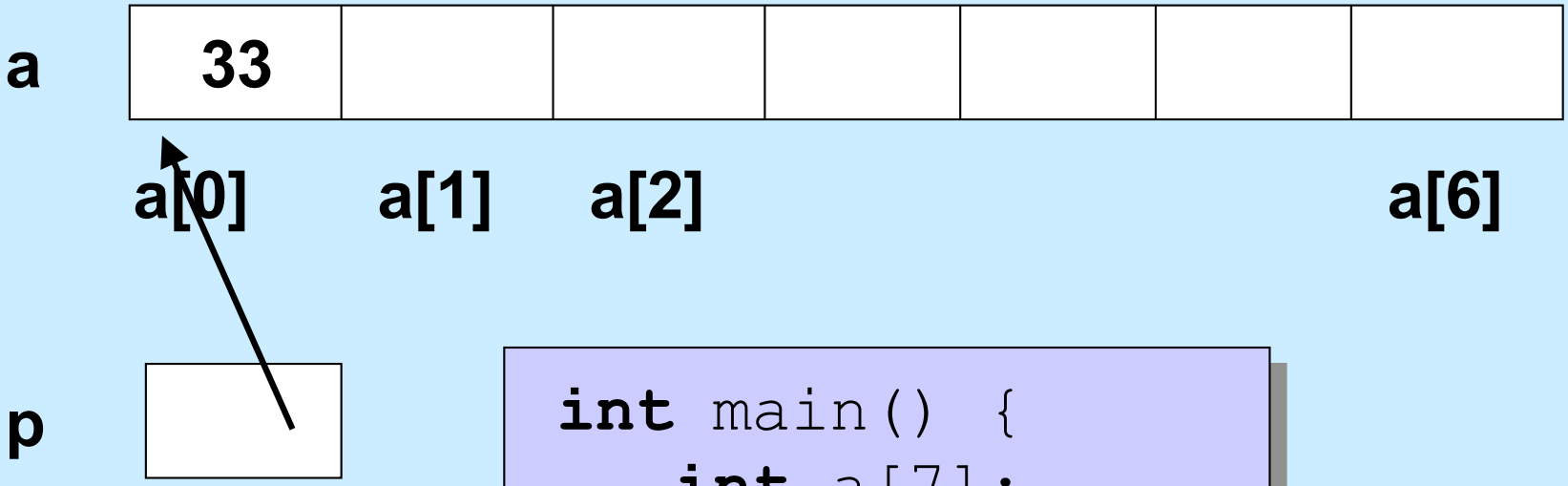
Quiz 1

```
int doubleit(int *p) {
    *p = 2*(*p);
    return *p;
}
int main() {
    int a = 3;
    int b;
    b = doubleit(&a);
    printf("%d\n", a*b);
}
```

What's printed?

a) 0
b) 12
c) 18
d) 36

Pointers and Arrays

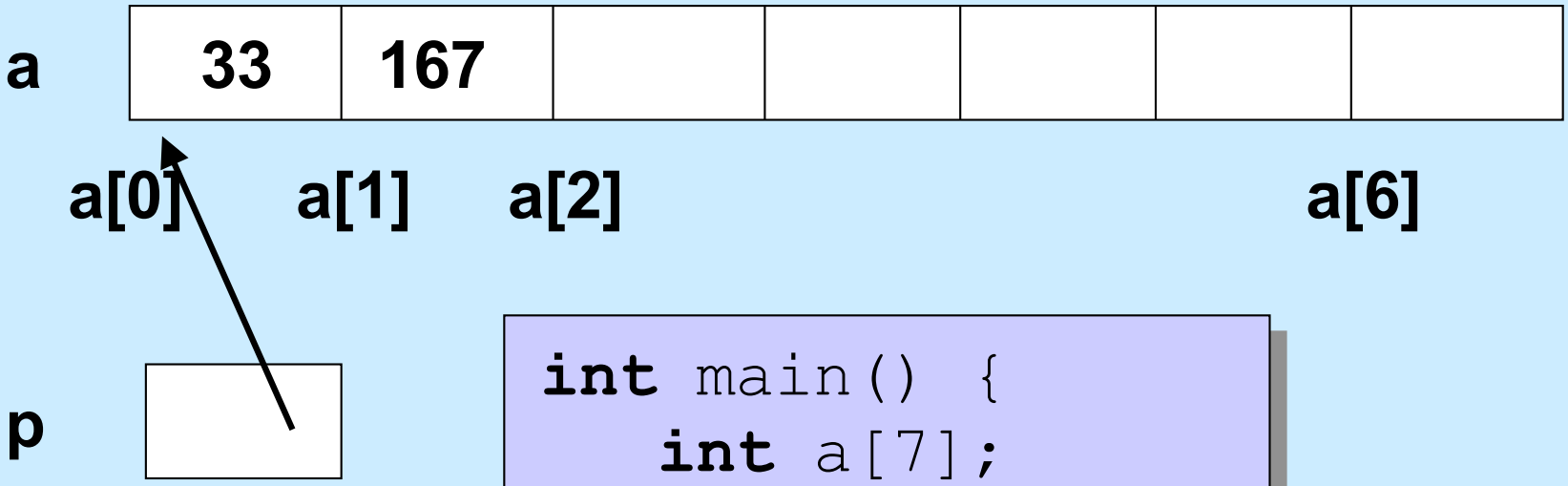



```
int main() {
    int a[7];
    int *p;
    p = &a[0];
    *p = 33;
}
```

Pointer Arithmetic

Pointers can be incremented/decremented

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

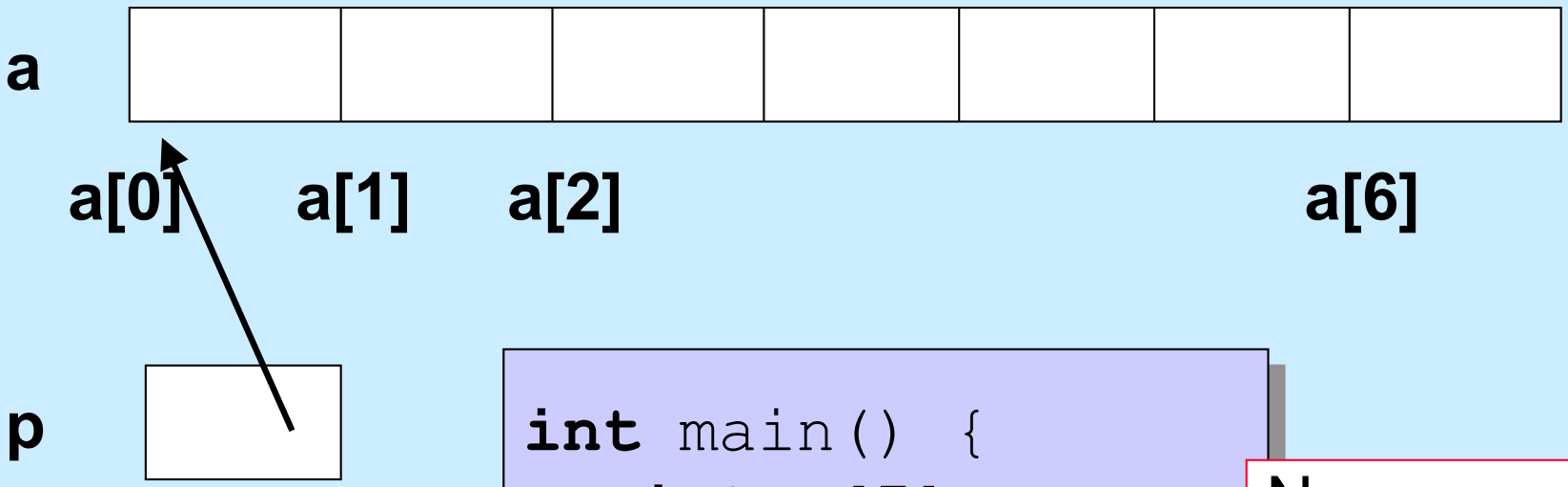



```
int main() {
    int a[7];
    int *p;
    p = &a[0];
    *p = 33;
    *(p+1) = 167;
}
```

Pointer Arithmetic

Pointers can be incremented/decremented

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



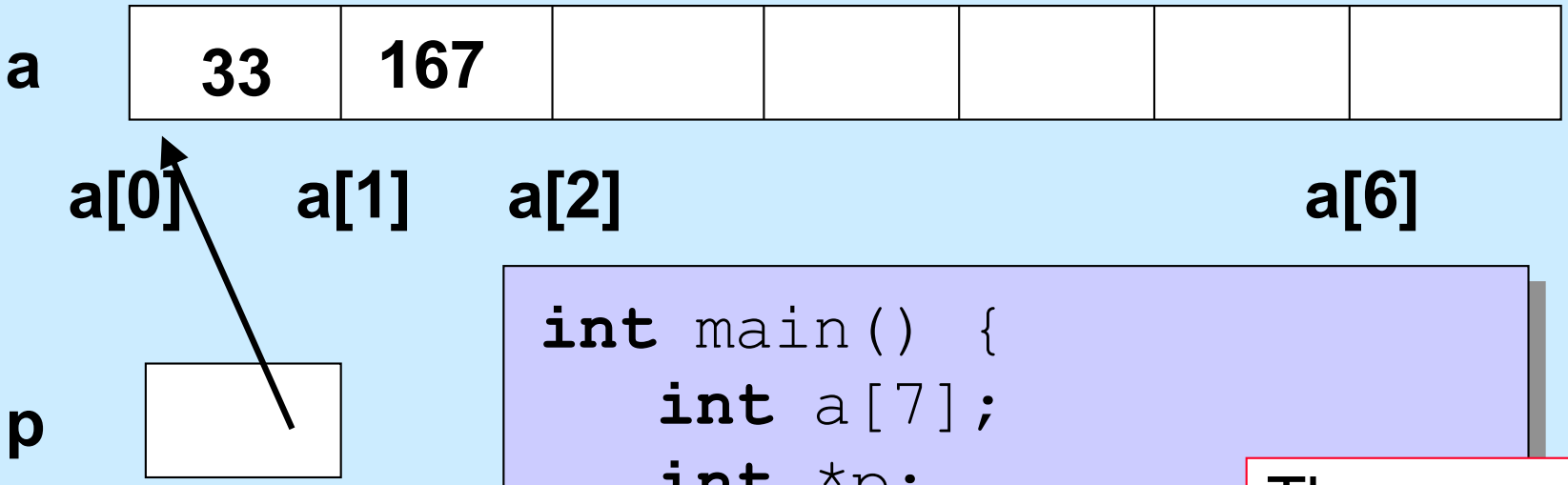

```
int main() {
    int a[7];
    int *p;
    p = &a[0];
}
```

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

Pointer Arithmetic

Pointers can be incremented/decremented

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




```
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

```
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;
}
```

initialized with a copy of the argument

Equivalently ...

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

}

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

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

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/s;
}
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

```
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

```
int func(int a[], int nelements) {
    int b[5] = {0, 1, 2, 3, 4};
    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) 0
b) 1
c) 2
d) nothing: it doesn't compile because of a syntax error

Quiz 3

```
int func(int a[], int nelements) {
    int b[5] = {0, 1, 2, 3, 4};
    a = b;
    return a[1];
}

int main() {
    int array[5] = {4, 3, 2, 1, 0};
    func(array, 5);
    printf("%d\n", array[1]);
    return 0;
}
```

This program prints:

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