Pointers

In the opposite direction to `&`, given a pointer we can get at the value at that address using the `*` operator

```
int n = 1234, *pn = &n; // declaration with initialisation
printf("n has value %d, pn has value %p\n", n, pn);
printf("the value at pn is %d\n", *pn);
*pn = 23;
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```

Produces

```
n has value 1234, pn has value 0x7fff81aa38d4
the value at pn is 1234
n has value 23, pn has value 0x7fff81aa38d4
```

Pointers

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So if the variable has type pointer to integer, it will fetch 4 bytes of integer; if the variable has type pointer to double, it will fetch 8 bytes of double; and so on

This is one reason why pointers to different types are distinguished: to determine how many bytes of value to access

Pointers

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So `*pn = 99` means “get the value of `pn`; store 99 at that address”

Pointers

As `pn` is a perfectly normal variable, it will be associated with some memory location

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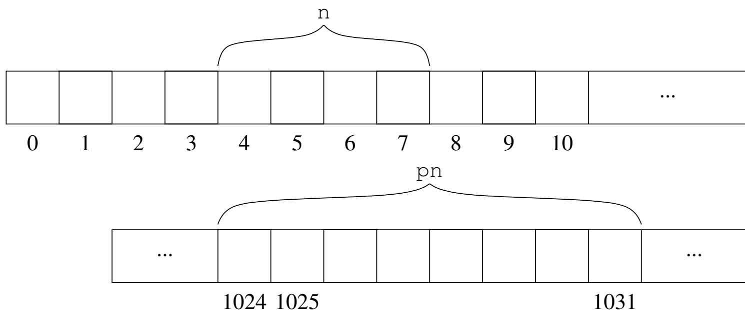

8 bytes of pointer on this 64-bit machine

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A major gotcha when porting poorly-written programs from 32 to 64 bit architectures

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declares `ppn` to be of type pointer to pointer to integer, and initialises it with a value, namely the address of the variable `pn`

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Use multiple `*`s as appropriate to the number of “pointer to”s

Pointers

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**ppn = 100;
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Now `pn` no longer points at `n` but another place in memory

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In fact, most useful applications of pointers are *not* pointing at variables

Pointers

Exercise (harder). The following does not work. Explain why and fix it using pointers.

```
void swap(int a, int b)
{
  int tmp = a;
  a = b;
  b = tmp;
}
...
int n = 1, m = 2;
swap(n, m);
printf("n = %d m = %d\n", n, m);
```

Pointers

One of Java's design principles was to eliminate pointers. In reality, it *does* have pointers, it just hides the fact from the naive programmer. And makes it harder for experienced programmers

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Exercise. Is it possible to write a (primitive) integer swap function in Java?

Exercise. Find out how Java manages pointers

Arrays and Pointers

Pointers are intimately associated with arrays in C

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Consider an array `int a[4];`

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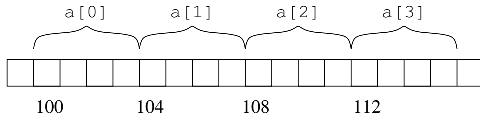
Consider an array `int a[4];`

In memory, C arrays are laid out simply



To be definite, we fix on using 4 byte (32 bit) integers

Arrays and Pointers

Adjacent members of the array are adjacent in memory

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If the array starts at address 100, so `a[0]` is at address 100,
then `a[1]` is at address $100 +$ `sizeof(int)`;
`a[2]` is at address $100 + 2 \times$ `sizeof(int)`;
and so on

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Adjacent members of the array are adjacent in memory

If the array starts at address 100, so `a[0]` is at address 100, then `a[1]` is at address $100 + \texttt{sizeof(int)}$;
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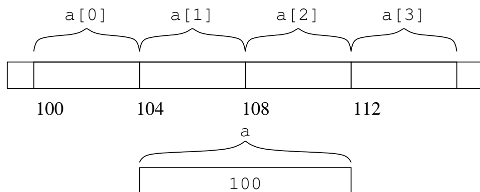
and so on

Array element n is at address

$$100 + n \times \texttt{sizeof(int)}$$

Arrays and Pointers

In fact the variable `a` contains the address of the start of the array



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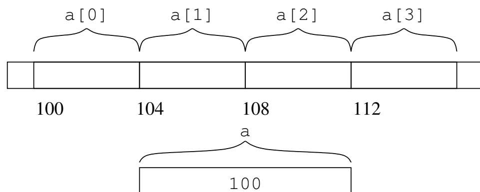

So `a` actually has type `int*` (with a caveat)

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For an integer pointer `a` the expression `a + 3` is not simply the address 3 along from the value in `a`, but instead is the address of the *3rd integer* along

If the value in `a` is 100, and integers are of size 4, then `a + 3` is the address $100 + 3 \times 4 = 112$

Arrays and Pointers

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Giving the address of the nth item along

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Giving the address of the *n*th item along

Pointer arithmetic counts in items, not bytes

Arrays and Pointers

The result is that for an array `a[]`

- the value of `a` is the address of the start of the array
- `a + 3` is the address of the item 3 further along (the 4th item)
- so `*(a + 3)` is the value there; just like `a[3]`
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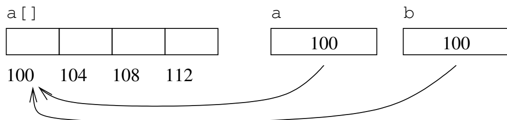
And exactly the same is true for a pointer variable, though this may or may not be pointing at the memory for an array

Arrays and Pointers

Also ++ works well. If we define an integer pointer

```
int *b;
b = a;
```

then `*b` (equivalently, `b[0]`) is the same as `a[0]`



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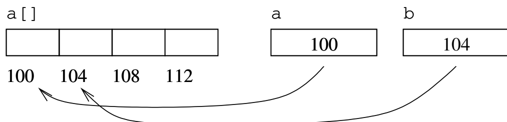

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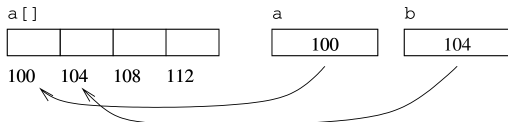

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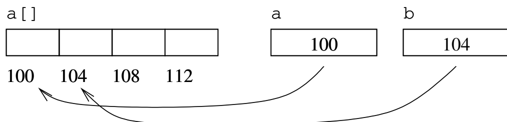

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The increment operator is an array iteration operator (as well as the normal increase-by-one on usual integers)

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for (b = a; ...  ; b++) { ...  }
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is a common sight in C programs

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The `x[n]` syntax really is just a short way of writing `*(x + n)` so is equally useful for both arrays and pointers

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Not necessarily a useful point of view, though!

Arrays and Pointers

Exercise. Explain

```
void copy(int *dst, int *src, int len)
{
  while (len--) {
    *dst++ = *src++;
  }
}
...
int a[128], b[128];
...
copy(b, a, 128);
```

Arrays and Pointers

Exercise. Then explain

```
copy(a, a + 64, 64);
```

Arrays and Pointers

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As long as you understand what you are doing

Except for a few subtleties

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Array types are a special subset of pointer types

Arrays and Pointers

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What is `a[10]` in the above example?

Arrays and Pointers

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What is `a[10]` in the above example?

It is the value stored at address $100 + 10 \times 4 = 140$, regarded as an integer

Arrays and Pointers

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- successfully return some integer value from whatever happens to be at that memory location
- this might be unused and initialised memory, or it might be where some other value (not necessarily an integer) is currently placed
- or it might refer to an unmapped memory location (think about virtual memory and unmapped pages), when the OS will cause an interrupt and likely terminate your program

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If this happens you need to look carefully at your program to find the error

Arrays and Pointers

Under Linux there is a useful checking program called `valgrind` that is good at finding memory mis-access errors

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```
valgrind ./myprog
```

will run the program `./myprog` checking *all* the program's accesses to memory

This will slow execution horribly, of course, but it will highlight when you do something stupid

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As mentioned, usually C does not check for these kids of errors as

- the high cost of checking memory accesses
- sometimes the programmer *does* want to write code that accesses off the nominal ends of an array; you can sometimes find code like `a[-1]`. This is valid C, and the programmer will get everything they deserve

Arrays and Pointers

In the declaration of an array and a pointer

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int a[4]
int *b;
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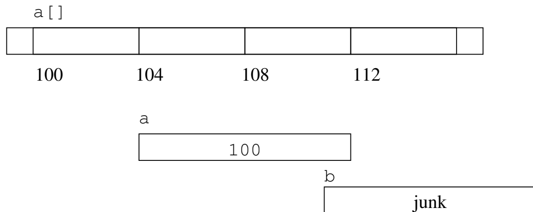
`a` is a variable of type pointer to integer **and** a chunk of memory (e.g., 16 bytes) is reserved somewhere for the array; the value of the variable `a` will be the address of that chunk of memory

`b` is a variable of type pointer to integer, with no particular value, and no chunk of memory is reserved

Arrays and Pointers



`int a[4]` sets up both `a` and the space for the array; `int *b` just sets up `b`

Arrays and Pointers

`b` is a pointer variable, so we can set its value: `b = a;`

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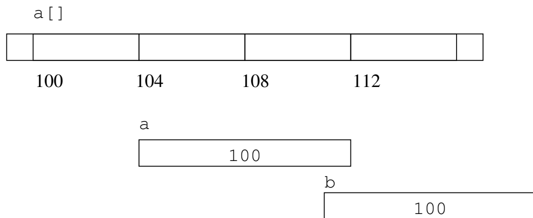

And now `b[1]` makes sense; it is the same as `a[1]`
`b[1]` is at address $100 + 1 \times 4 = 104$

Arrays and Pointers

We could equally do `b = a + 2`

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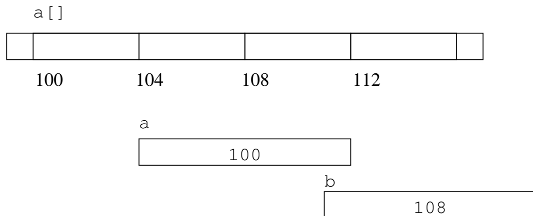

And now `b[1]` makes sense; it is the same as `a[3]`

`b[1]` is at address $108 + 1 \times 4 = 112$

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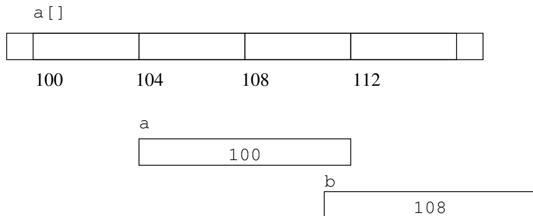

And now `b[1]` makes sense; it is the same as `a[3]`
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And now `b[-1]` makes sense; it is the same as `a[1]`
`b[-1]` is at address $108 + (-1) \times 4 = 104$

Arrays and Pointers

Another difference in this declaration is that `a` is a *constant* variable (!)

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We can't change the value of `a`

This is what we usually want from arrays; while `b` is explicitly a variable pointer

Arrays and Pointers

```
void foo(void)
{
  int a[4];
  a++;
}
```

gives an error message in the compiler

```
const.c: In function 'foo':
const.c:5:3: error: lvalue required as increment operand
```

An “lvalue” is a thing that can appear on the left side of an assignment, e.g., an updatable variable

Arrays and Pointers

```
void foo(void)
{
  int a[4], *b = a;
  b++;
}
```

is OK as `b` is allowed to vary

Arrays and Pointers

This may seem trivial but the following is very popular, particularly from Java-trained “programmers”

```
void foo(void)
{
  int a[4], *b;
  ...
  b = ...
  ...
  a = b;
  ...
}
```

Bad!

Strings and Pointers

Strings are just arrays of `char`; string variables thus have type pointer to `char`, i.e., `char *`

We can have

```
char a[4] = "xyz", *b;
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just as before; `a` has type `char *`

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We can have

```
char a[4] = "xyz", *b;
```

just as before; `a` has type `char *`

Now the value of `a` is a (constant) pointer to an array of 4 characters; the value of `b` is nothing in particular

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Note there is no copying of characters involved

Strings and Pointers

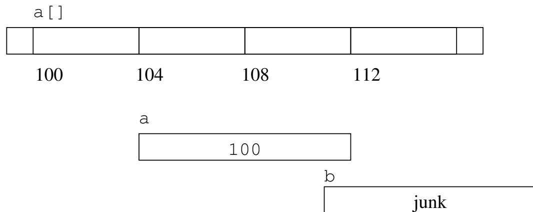
What happens with `b = a`?

Just as before, the variable `b` now points to the same memory as `a`

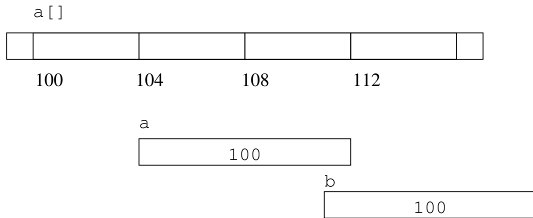
Note there is no copying of characters involved

Just the value in `a` (an address) is copied into `b`, nothing more

Strings and Pointers



Strings and Pointers

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b = a;
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The characters are `a[0]`, `a[1]`, etc.

To copy the characters we can go

```
b[0] = a[0]; b[1] = a[1]; ...
```

more likely using a `for` loop

Strings and Pointers

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And `strcpy` will copy characters up to and including the terminating 0 byte of the string at `a`

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Forgetting these is a popular source of bugs

Strings and Pointers

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char a[] = "hello world", b[4];
strcpy(b, a);
```

will likely not do what you want

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Exercise. What is the output from the following?

```
char a[] = "the cat sat on the mat", *b;
b = a;
b[4] = 'r';
printf("a is '%s'\nb is '%s'\n", a, b);
```

Exercise. What is the bug here?

```
char a[] = "the cat sat on the mat", *b;
strcpy(b, a);
```

Strings and Pointers

Exercise. What about

```
char a[] = "hello", b[5];
strcpy(b, a);
```

Strings and Pointers

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```
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```

Look up the function `strlen`. Reimplement it yourself

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When we run a program we often want to pass some values to that program: `./summit 23 42`

The arguments passed to the program are presented to the `main` function

Strings and Pointers

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

int main(int argc, char **argv)
{
  int n, m;

  if (argc < 3) {
    printf("Not enough arguments!\n");
    return 1;
  }

  n = atoi(argv[1]);
  m = atoi(argv[2]);
  printf("sum is %d\n", n + m);

  return 0;
}
```

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- The length of this array is `argc`, of course
- Some people declare `argv` as `char *argv[]` to emphasise it is an array of strings

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- `if (argc < 3) ...` remember the program name is included in the count
- The function `atoi` converts a string containing an integer to an integer. See `man atoi`

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You will have to just explore!

Arrays and Pointers

Exercise. Look up `strncpy` (extra 'n' in there)

Exercise. What about `3[a]`? Or `0[a+3]`?

Exercise. For `int a[4], *b;` compare `sizeof(a)`, `sizeof(*a)`, `sizeof(b)`, `sizeof(*b)`

Exercise. Read the specification for `atoi` and implement it for yourself (give your version a different name!)

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One more thing about pointers: the `void` pointer

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This allows us to write functions that act on arbitrary pointers: `memcpy` copies arbitrary blocks of objects, be it `int`s, `double`s, or `struct` whatevers

Pointers

```
int a[10], b[10];
double x[5], y[5];
...
memcpy(b, a, 10*sizeof(int));
memcpy(y, x, 5*sizeof(double));
```

copies 10 integers-worth of bytes from where `a` points to where `b` points; and 5 doubles-worth of bytes from `x` points to where `y` points

Pointers

Exercise. What is the error here?

```
int a[5];
void *b;
...
b = a;
b[0] = b[1] + b[2];
```