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Then `str[4]` is the character `'o'`

Which, of course, is just some integer value

In `printf` use `%s` for strings

```
printf("str is '%s'\n", str);
```

And `%c` for `chars`

```
printf("char is '%c'\n", str[4]);
```

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char str[] = { 'h', 'e', 'l', 'l', 'o', ' ', 'w',
'o', 'r', 'l', 'd' };
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char str[] = { 'h', 'e', 'l', 'l', 'o', ' ', 'w',
'o', 'r', 'l', 'd' };
```

There are two reasons why you wouldn't normally write code like this:

- it's easier to use normal quoted string syntax
- this code is semantically **incorrect**

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Thus, in C, all strings are conventionally terminated by a (character value/byte) 0

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char str[] = { 'h', 'e', 'l', 'l', 'o', ' ', 'w',
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The double quote syntax includes the terminating 0; standard string functions expect the terminating 0

Exercise. Look up the ASCII encoding for characters

Exercise. Characters really are integers. What about the following?

```
char message[] = { 104, 101, 108, 108, 111, 32, 119,
  111, 114, 108, 100, 0 };
```

Exercise. And what about

```
printf("A has value %d\n", 'A');
printf("A has value %c\n", 'A');
```

Types

Strings

Exercise. `sizeof` gives the size in bytes of a C value. Compare

```
sizeof("cat")
```

against

```
strlen("cat")
```

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Exercise. Look up the various library functions that operate on strings, e.g., `strlen`, `strcpy`, `strcat`, `strcmp` and lots more

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However, there are a couple of ways of combining types into compound types for the convenience of programming

And for the convenience of the thought processes of the programmers

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Structures

C has a simple *structure* type constructor, used when we need to manage more complicated combinations of values

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struct rational {
  int num, den;
};

...

struct rational r;
r.num = 1;
r.den = 2;
```

- Don't forget the `;` at the end of the declaration

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- There are no classes, no objects, no methods in C
- The type declaration can only contain names of values, as **there are no methods in C**

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struct rational numbers[10];
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We can declare structs containing arrays
`struct numb { int nums[10]; int dens[10]; }`

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We can declare structs containing arrays

```
struct numb { int nums[10]; int dens[10]; }
```

Then

```
struct numb n;
n.nums[7] = 42;
```

Structs of structs, and so on

```
struct inner {
  double first[10];
  char rest;
};

struct complicated {
  int sign;
  struct rational r;
  struct inner blob;
};
...
struct complicated c;
c.sign = -1;
c.r.num = 5;
c.blob.first[3] = 7.0;
```

Types

Structures

We can also declare structs "on the fly" as we are using them

```
struct complicated {
  int sign;
  struct rational r;
  struct inner {
    double first[10];
    char rest;
  } blob;
};
...
struct complicated c;
c.sign = -1;
c.r.num = 5;
c.blob.first[3] = 7.0;
```

Compound Types

In summary: the two main ways in C of collecting things together to make compound things are

- arrays: collections of the same type of things
- structures: collections of different types of things

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Exercise. Read up on `union` types, another way of making compound types in C

Exercise. Read up on `typedef`, a convenient way of abbreviating type names

Compound Types

Exercise for geeks. What is the difference (at the machine level) between

```
int a[2];
```

and

```
struct {
  int a1, a2;
} a;
```

?

Pointers

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Recall that (thanks to the universal adoption of von Neumann's model) memory can be regarded as a big array of bytes; conventionally numbered from 0 upwards

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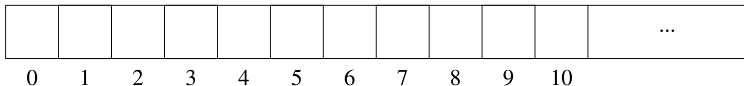
We start by reviewing the way memory is laid out in hardware

Recall that (thanks to the universal adoption of von Neumann's model) memory can be regarded as a big array of bytes; conventionally numbered from 0 upwards



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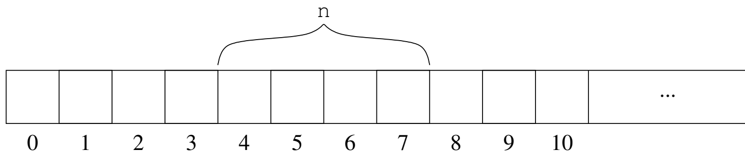
When a program is compiled, variables are mapped in some useful way to memory location by the system (compiler and OS program loader)

So if we have a (4 byte) integer `n` in our code, the system might choose to place it at memory address 4 (a very unlikely place in real systems)



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Then every access of `n` in our code becomes a read or write of bytes 4–7 of memory

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It's where the variable lives in memory

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But for low-level programs that manipulate bits and bytes of memory this is just what they need

To get the address of a variable use the `&` operator

Pointers

```
#include <stdio.h>

int main(void)
{
  int n = 1234;

  printf("n has value %d and address %p\n", n, &n);

  return 0;
}
```

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  int n = 1234;

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Produces

```
n has value 1234 and address 0x7fff251f6d5c
```

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The value of `n` will always be 1234; the address (this example: 140732877607788 in decimal) will likely be different on different OSs, different on different compilers, possibly different on different runs on the same machine

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It all depends on where in memory `n` happens to be placed when the program is loaded to be run

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Exercise. Compare `%x` with `%p`

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Variables that hold addresses are called *pointer variables*

(Though it's not the variables that are pointers, but their values. . .)

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And both are treated as different from a ordinary integer

This is a bit subtle: they are all simple integers underneath; it's just how the compiler *manipulates* those integers that will be different for different types

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Now, memory doesn't "know" what kind of data is being stored at a particular address; memory is just a bunch of bytes

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The type of a variable or the type of a pointer encodes the information as to what bits they refer to “mean”

Thus `int n = 99;` says “allocate four bytes of memory somewhere and (while we access these bytes through this `n`) interpret the bits in those bytes as an integer”

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Note: while C makes this quite plain, the same is true for all computer languages

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We can declare pointer variables, e.g., `pn`

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int n;
int *pn;
pn = &n;
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The `*` is read as "pointer to"; the variable `pn` has type "pointer to `int`"

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"pointer to" and "reference to" are the same as "address of"

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Convention

Note: the convention is to write

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int *pn;
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means an `int` `n` and a pointer to `int` `pn`

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means an `int` `n` and a pointer to `int` `pn`

You can read the above as “`n` is an `int` and `pn` is an `int` pointer”

Pointers

Convention

Exercise. What are the types of the variables in the following?

```
int* a, b;
```