Pointers

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

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int n = 1234, *pn = &n; // declaration with initialisation

printf("n has value %d, pn has value %p\n", n, pn);
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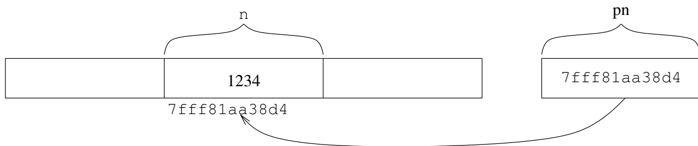
Produces

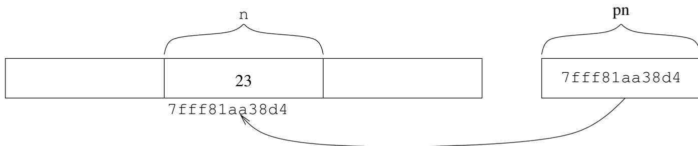
```
n has value 1234, pn has value 0x7fff81aa38d4
the value pn points to is 1234
n has value 23, pn has value 0x7fff81aa38d4
```

Pointers



Initial values

Pointers



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

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

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

Pointers

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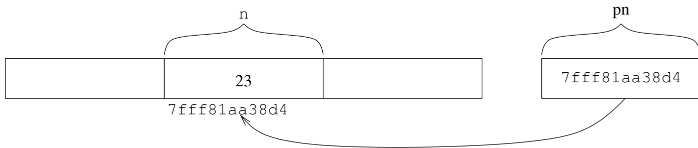
And modifying `pn` does not move `n` in memory; just that `pn` now points to somewhere else

Pointers



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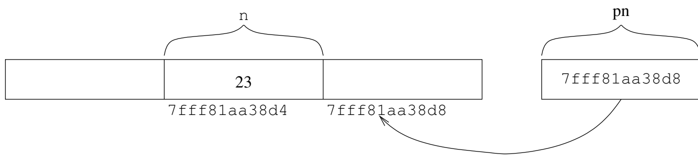
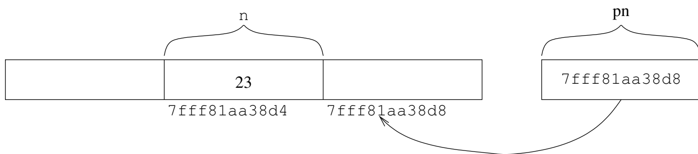


After `pn = 0x7fff81aa38d8`

Pointers



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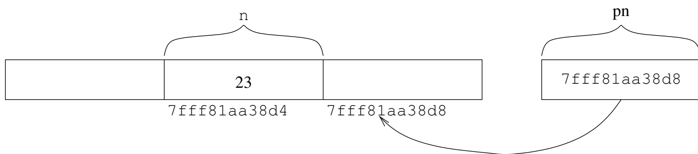
Now accessing `*pn` will access the four bytes at the address 0x7fff81aa38d8 (four bytes, as `pn` is an `int` pointer)

Pointers



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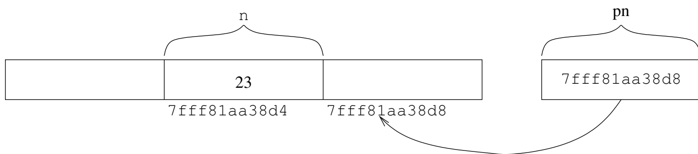

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C does not stop you messing with *any* bytes in memory!

Pointers

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

Pointers

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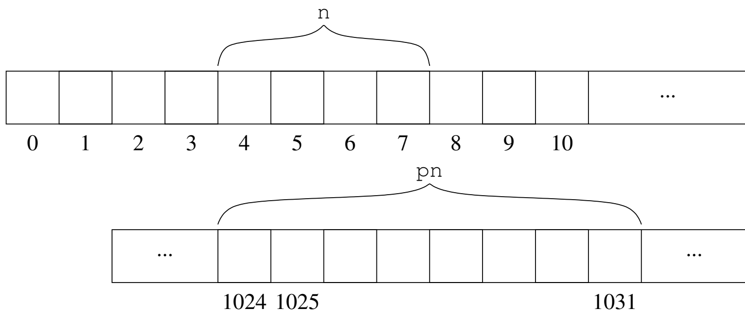

8 bytes of address on this 64-bit machine

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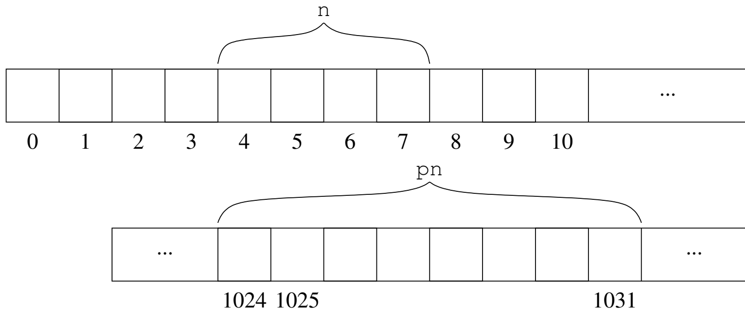
A major gotcha when porting poorly-written programs from 32 to 64 bit architectures

Some versions of C on early computers had 2 byte (16 bit) pointers: they didn't have enough memory to make 4 byte pointers necessary!

Pointers

On a 64-bit architecture:



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

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Now `pn` no longer points at `n` but another place in memory

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);
```

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Exercise. Find out how Java manages pointers

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

Arrays and Pointers

Pointers are intimately associated with arrays in C

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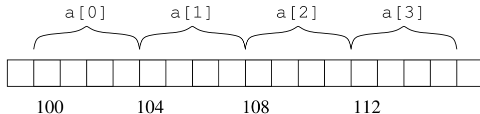
In memory, C arrays are laid out simply



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

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If the array starts at address 100, so `a[0]` is at address 100, then `a[1]` is at address $100 + \texttt{sizeof(int)} = 104$; `a[2]` is at address $100 + 2 \times \texttt{sizeof(int)} = 108$; and so on

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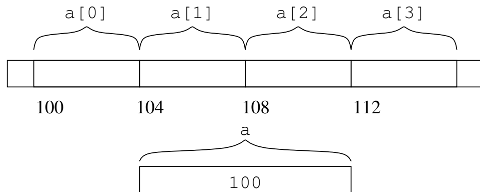
Array element n is at address

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

Arrays and Pointers

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



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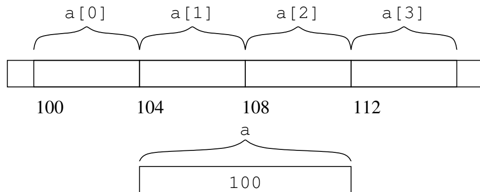

So `a` actually has type `int*` (with a caveat)

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

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This is another reason to distinguish types of pointers. For a variable `v` of type `T*`, the expression `v + ` n is computed as

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Pointer arithmetic counts in items, not bytes

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

- the value of `a` is the address of the start of the array
- `*a` is the same as `a[0]`
- `a + 3` is the address of the item 3 further along (the 4th item)
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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

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int *b;
b = a;
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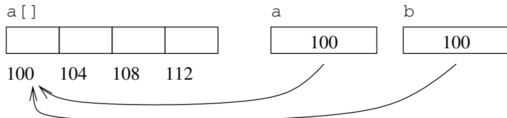

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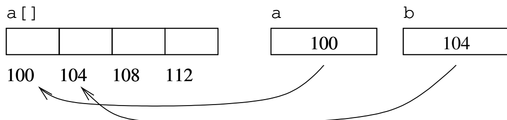

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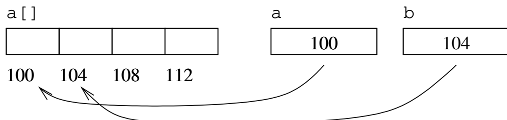

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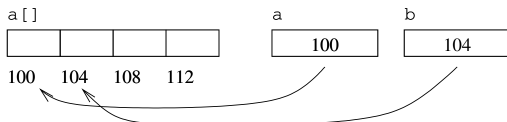

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The increment operator is an array iteration operator (as well as the normal increase-by-one on usual integers)

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for (b = a; ...  ; b++) {
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expr1[expr2] is the same as *(expr1 + expr2)

Arrays and Pointers

Exercise.

```
int n = 7;
int *p = &n;
```

Is `p[0]` meaningful?

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Just integers, floating point, and pointers (which are integers)

And `[]` and `""` are just some convenient syntax

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 think through

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

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As long as you understand what you are doing

Except for a few subtleties

Array types and pointer types are interchangeable

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Array types are a special subset of pointer types: they are pointers that point at pre-allocated blocks of memory

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This is beyond the end of the memory reserved by the system for the array `a`

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- this might be previously unused and uninitialised 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 might cause an interrupt and likely terminate your program

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Occasionally you will see *bus error* for the same kind of thing

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

Exercise for geeks. Read up on value *alignment*

Arrays and Pointers

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Thus `valgrind` is a way of inserting that slow checking that other languages do all the time

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Clang users can use `-fsanitize=address` when compiling to insert code that does something similar

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- the significant overhead 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

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In the declarations of an array and a pointer

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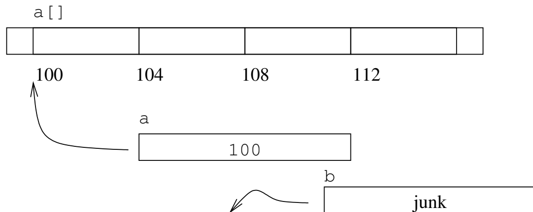
`b` is a variable of type pointer to integer, with no particular value, and no chunk of memory is reserved

Arrays and Pointers



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

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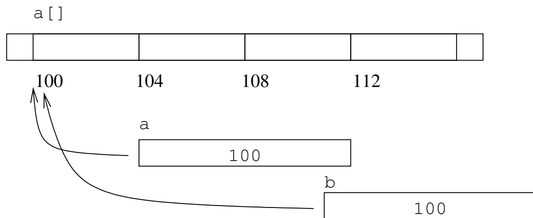

And now `b[1]` makes sense; it is the same as `a[1]`
`b[1]` is at address $100 + 1 \times 4 = 104$

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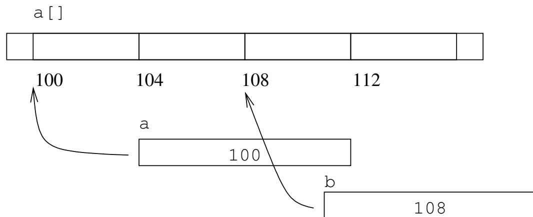

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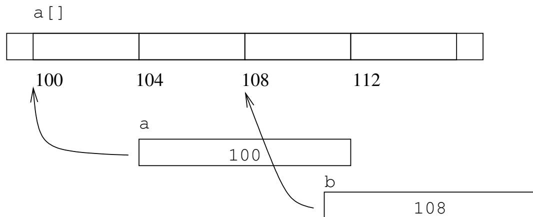

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And now `b[-1]` makes sense; it is the same as `a[1]`
`b[-1]` is at address $108 + (-1) \times 4 = 104$