Chapter Seven: Pointers, Part I

Slides by Evan Gallagher

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Chapter Goals

- To be able to declare, initialize, and use pointers
- To understand the relationship between arrays and pointers
- To become familiar with dynamic memory allocation and deallocation

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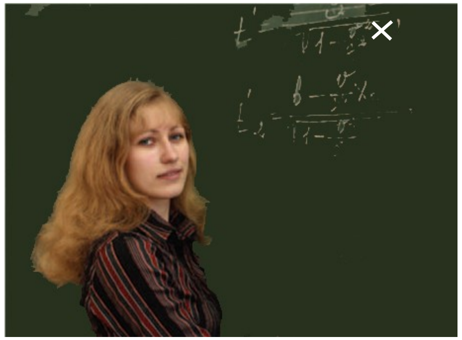
Pointers



What's stored in that variable?

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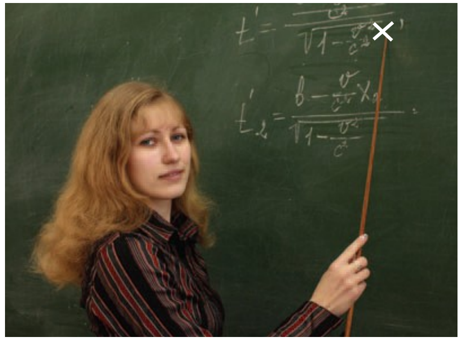
Pointers



that one – the one I'm ***pointing*** at!

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Pointers

A variable *contains* a value,

but a *pointer* specifies *where* a value is located.

A pointer denotes the
memory location of a variable

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Pointers

- In C, pointers are important for several reasons.
  - ***Pointers allow sharing of values stored in variables in a uniform way***
  - ***Pointers can refer to values that are allocated on demand (dynamic memory allocation)***
  - ***Pointers are necessary for implementing polymorphism, an important concept in object-oriented programming (later for C++)***

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A Banking Problem

Consider a person.

(Harry)

Harry has more than one bank account.

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Harry Needs a Banking Program

Harry wants a program for making
bank deposits and withdrawals.

```
… balance += depositAmount …
… balance -= withdrawalAmount …
```

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Harry Needs a Multi-Bank Banking Program

But not all deposits and withdrawals
should be from the *same* bank.

```
… balance += depositAmount …
… balance -= withdrawalAmount …
```

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Good Design

But withdrawing is withdrawing
– no matter which bank it is.

Same with depositing.

Same problem – same code, right?

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Pointers to the Rescue

By using a *pointer*,
it is possible to *switch* to a different account
without modifying the code for
deposits and withdrawals.

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Pointers to the Rescue

Harry starts with a variable for storing an account balance.
It should be initialized to 0 since there is no money yet.

```
double harrys_account = 0;
```

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Pointers to the Rescue

If Harry anticipates that he may someday use other accounts, he can use a pointer to access any accounts.

So Harry also declares a pointer variable named **`account_pointer`** :

```
double* account_pointer
```

The type of this variable is "*pointer to double*".

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Addresses and Pointers

A *pointer to double* type can hold the address of a **`double`**.

So what's an address?

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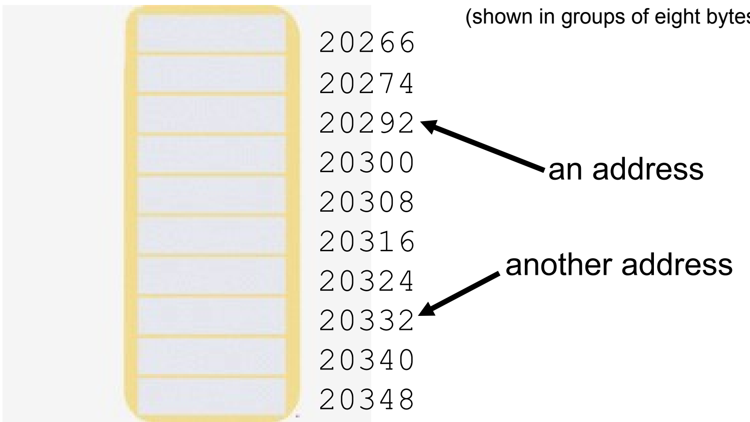
Addresses and Pointers

Here's a picture of RAM.

Every byte in RAM has an *address*.

(shown in groups of eight bytes)



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Addresses and Pointers

Here's how we have pictured a variable in the past:

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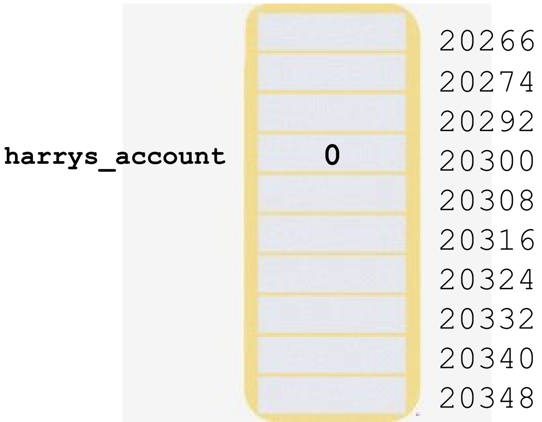
Addresses and Pointers

But really it's been like this all along:



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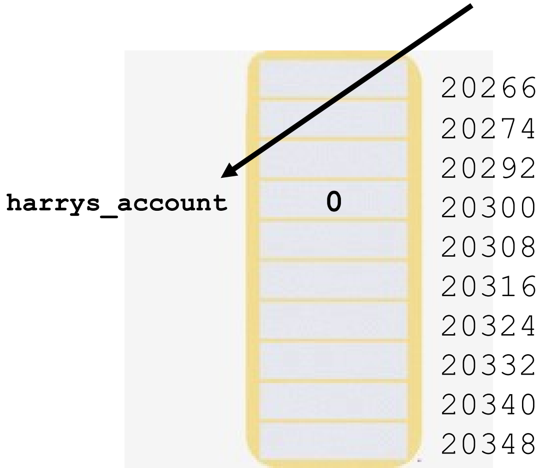
Addresses and Pointers

The address of the variable named **`harrys_account`**



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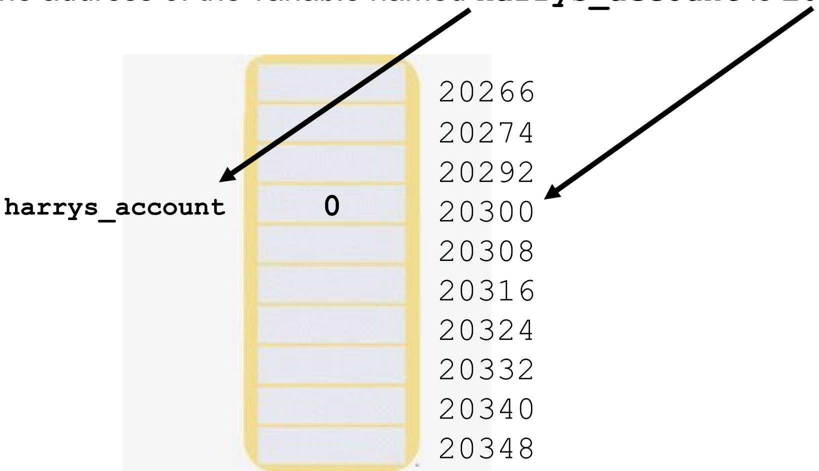
Addresses and Pointers

The address of the variable named **`harrys_account`** is **`20300`**



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Pointers to the Rescue

So when Harry declares a pointer variable,
he also initializes it to point to **`harrys_account`**:

```
double harrys_account = 0;
double* account_pointer = &harrys_account;
```

The **`&`** operator yields the location (or address) of a variable.

Taking the address of a **`double`** variable yields a value of type **`double*`** so everything fits together nicely.

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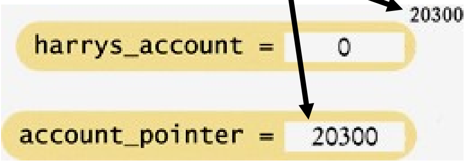
Pointers to the Rescue

`account_pointer` now *contains* the *address* of `harrys_account`

```
double harrys_account = 0;
double* account_pointer = &harrys_account;
```



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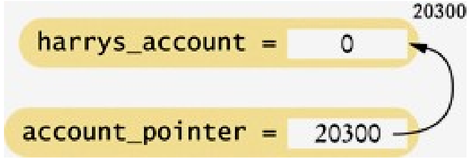
Pointers to the Rescue

`account_pointer` now "points to" `harrys_account`

```
double harrys_account = 0;
double* account_pointer = &harrys_account;
```



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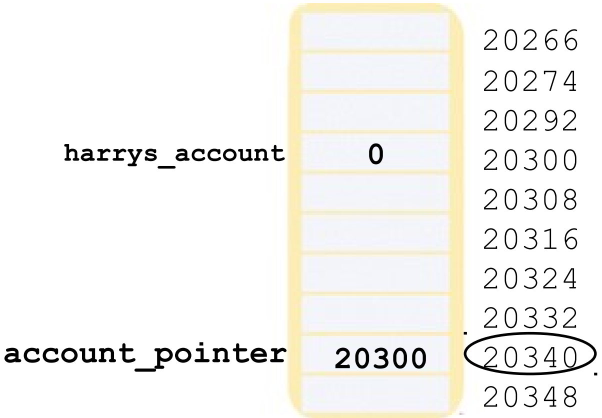
Addresses and Pointers

And, of course, `account_pointer` is *somewhere* in RAM:



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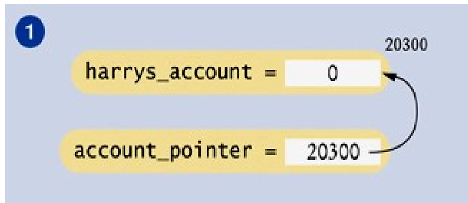
Addresses and Pointers

To access a different account, you would change the pointer value stored in `account_pointer`:

```
double harrys_account = 0;
account_pointer = &harrys_account;
```



use `account_pointer` to access `harrys_account`

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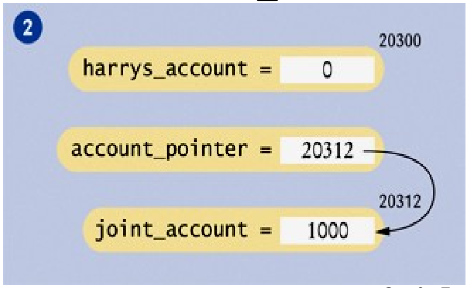
Addresses and Pointers

To access a different account, like `joint_account`, change the pointer value stored in `account_pointer` and similarly use `account_pointer`.

```
double harrys_account = 0;
account_pointer = &harrys_account;
double joint_account = 1000;
account_pointer = &joint_account;
```



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Addresses and Pointers – and ARROWS

Do note that the computer stores numbers,

not arrows.

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Accessing the Memory Pointed to by A Pointer Variable

When you have a pointer to a variable,
you will want to access the value to which it points.

```
... *account_pointer ...
```

In C, the * operator is used to indicate

the memory location associated with a pointer.

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Accessing the Memory Pointed to by A Pointer Variable

An expression such as `*account_pointer` can be used wherever a variable name of the same type can be used:

```
// display the current balance
printf("%f\n", *account_pointer);
```

It can be used on the left or the right of an assignment:

```
// withdraw $100
*account_pointer = *account_pointer - 100;
```

(or both)

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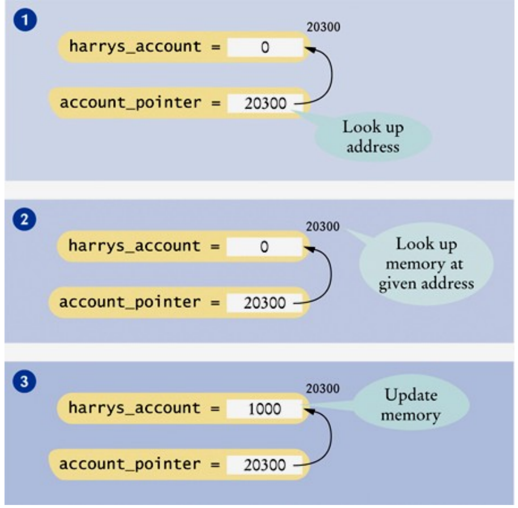
Harry Makes the Deposit

```
// deposit $1000
  *account_pointer = *account_pointer + 1000;
```



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Accessing the Memory Pointed to by A Pointer Variable

Of course, this only works
if **`account_pointer`** is pointing
to **`harrys_account`*!***

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Errors Using Pointers – Uninitialized Pointer Variables

When a pointer variable is first defined,
it contains a random address.

Using that random address is an error.

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Errors Using Pointers – Uninitialized Pointer Variables

In practice, your program will likely crash or mysteriously misbehave if you use an uninitialized pointer:

```
double* account_pointer; // No initialization

*account_pointer = 1000;
```

NO!
`account_pointer` contains an *unpredictable* value!

`Where is the 1000 going?`

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NULL

There is a special value
that you can use
to indicate a pointer
that doesn't point anywhere:

NULL

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NULL

If you define a pointer variable
and are not ready to initialize it quite yet,
it is a good idea to set it to **NULL**.

You can later test whether the pointer is **NULL**.
If it is, don't use it:

```
double* account_pointer = NULL; // Will set later
if (account_pointer != NULL) {  // OK to use
   printf("%f\n", *account_pointer);
}
```

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NULL

Trying to access data through a NULL pointer is still illegal,
and
it will cause your program to crash.

```
double* account_pointer = NULL;
printf("%f\n", *account_pointer);
```

CRASH!!!

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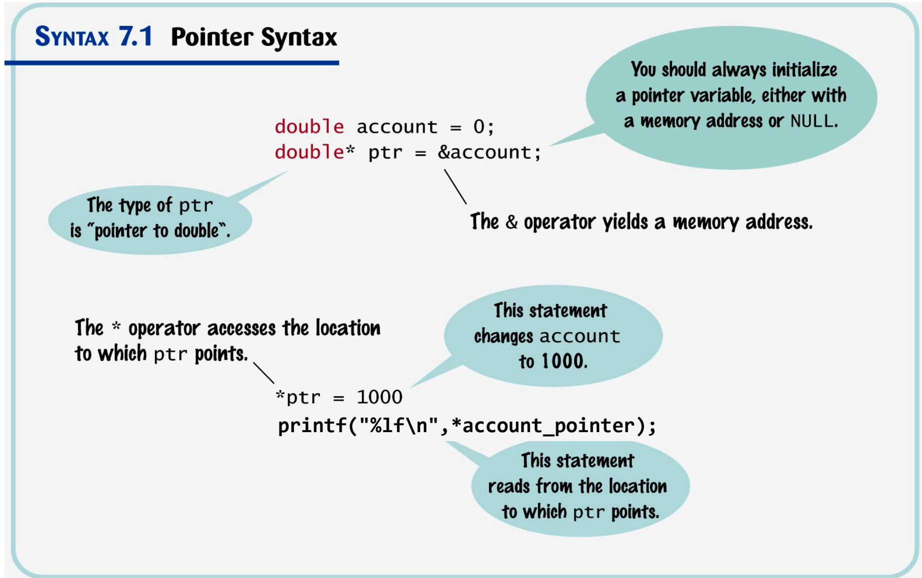
Syntax of Pointers



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Pointer Syntax Examples

Table 1 Pointer Syntax Examples

Assume the following declarations:
```
int m = 10; // Assumed to be at address 20300
int n = 20; // Assumed to be at address 20304
int* p = &m;
```

Expression	Value	Comment
`p`	20300	The address of `m`.
`*p`	10	The value stored at that address.
`&n`	20304	The address of `n`.
`p = &n;`		Set `p` to the address of `n`.
`*p`	20	The value stored at the changed address.
`m = *p;`		Stores 20 into `m`.
`m = p;`	**Error**	`m` is an `int` value; `p` is an `int*` pointer. The types are not compatible.
`&10`	**Error**	You can only take the address of a variable.
`&p`	The address of `p`, perhaps 20308	This is the location of a pointer variable, not the location of an integer.
`double x = 0;` `p = &x;`	**Error**	`p` has type `int*`, `&x` has type `double*`. These types are incompatible.

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Harry's Banking Program

Here is the complete banking program.

It demonstrates the use of a pointer variable to allow *uniform access* to variables.

```
#include <stdio.h>

int main()
{
   double harrys_account = 0;
   double joint_account = 2000;
   double* account_pointer = &harrys_account;
   *account_pointer = 1000; // Initial deposit
```

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Harry's Banking Program

ch07/accounts.cpp

```
   // Withdraw $100
   *account_pointer = *account_pointer - 100;

   // Print balance
   printf("Balance: %lf\n", *account_pointer);

   // Change the pointer value so that the same
   // statements now affect a different account
   account_pointer = &joint_account;

   // Withdraw $100
   *account_pointer = *account_pointer - 100;

   // Print balance
   printf("Balance: %lf\n", *account_pointer);

   return 0;
}
```

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Common Error: Confusing Data And Pointers

A pointer is a memory address

– a number that tells where a value is located in memory.

It is a common error to confuse the pointer with the variable to which it points.

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Common Error: Where's the *?

```
double* account_pointer = &joint_account;
account_pointer = 1000;
```

The assignment statement does *not* set the joint account balance to 1000.

It sets the pointer variable, **`account_pointer`**, to point to memory address 1000.

ERROR

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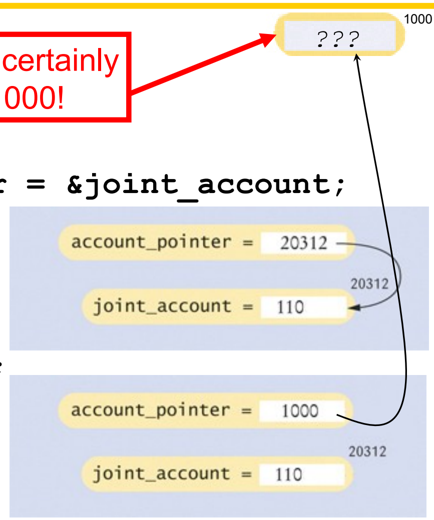
Common Error: Where's the *?

`joint_account` is almost certainly *not* located at address 1000!

```
double* account_pointer = &joint_account;
```

```
account_pointer = 1000;
```



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Common Error: Where's the *?

Most compilers will report an error for this kind of error.

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Confusing Definitions

It is legal in C to define multiple variables together, like this:

```
int i = 0, j = 1;
```

This style is confusing when used with pointers:

```
double* p, q;
```

The **`*`** associates only with the first variable.
That is, **`p`** is a **`double*`** pointer, and **`q`** is a **`double`** value.

To avoid any confusion, it is best to define each pointer variable separately:

```
double* p;
double* q;
```

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Pointers and References

Changing value of parameter:

```
void withdraw(double* balance, double amount)
{
    if (*balance >= amount)
    {
        *balance = *balance - amount;
    }
}
```

but the call will have to be:

```
withdraw(&harrys_checking, 1000);
```

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Arrays and Pointers

In C, there is a deep relationship between pointers and arrays.

This relationship explains a number of special properties and limitations of arrays.

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Arrays and Pointers

Pointers are particularly useful for understanding the peculiarities of arrays.

The *name* of the array denotes a pointer to the starting element.

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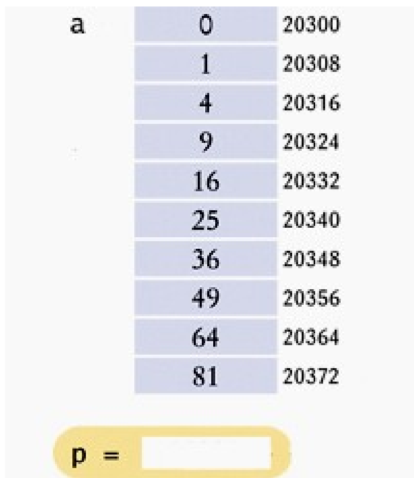
Arrays and Pointers

Consider this declaration:

`int a[10];`

(Assume we have filled it as shown.)

You can capture the pointer to the first element in the array in a variable:



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Arrays and Pointers

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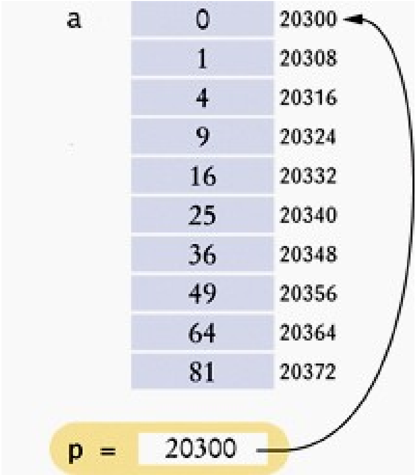


```
int* p = a; // Now p points to a[0]
```

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Arrays and Pointers – Same Use

You can use the array name **a** as you would a pointer:

These output statements are equivalent:

```
printf("%d", *a);
printf("%d", a[0]);
```

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Pointer Arithmetic

Pointer arithmetic allows you to add an integer to an array name.

```
int* p = a;
```

`p + 3` is a pointer to the array element with index `3`

The expression: `*(p + 3)`

.

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The Array/Pointer Duality Law

The *array/pointer duality law* states:

`a[n]` is identical to `*(a + n)`,

where **a** is a pointer into an array and **n** is an integer offset.

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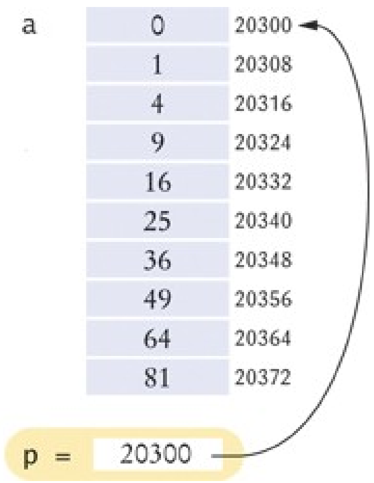
The Array/Pointer Duality Law

This law explains why all C arrays start with an index of zero.

The pointer **`a`** (or **`a + 0`**) points to the starting element of the array.

That element must therefore be **`a[0]`**.

You are adding 0 to the start of the array, thus *correctly going nowhere!*



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The Array/Pointer Duality Law

Now it should be clear why array parameters are different from other parameter types.

(if not, we'll show you)

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The Array/Pointer Duality Law

Consider this function that computes the sum of all values in an array:

Look at this

```
double sum(double a[], int size)
{
   double total = 0;
   for (int i = 0; i < size; i++) {
      total = total + a[i];
   }
   return total;
}
```

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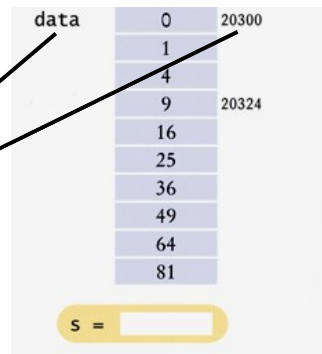
The Array/Pointer Duality Law

Here is a call to the function.

```
double data[10];
... // Initialize data

double s = sum(data, 10);
```



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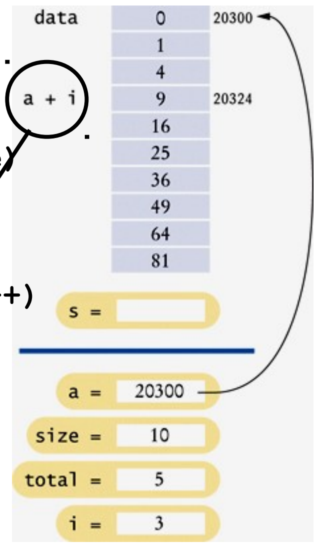
The Array/Pointer Duality Law

After the loop has run
to the point when **`i`** is 3:

```
double sum(double a[], int size)
{
   double total = 0;
   for (int i = 0; i < size; i++)
   {
      total = total + a[i];
   }
   return total;
}
```



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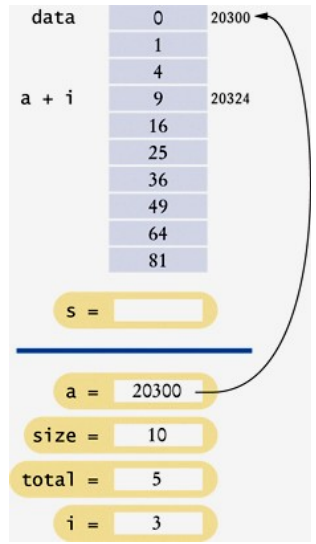
The Array/Pointer Duality Law

The C compiler considers
`a` to be a pointer, not an array.

The expression **`a[i]`**
is *syntactic sugar*
for **`*(a + i)`**.



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Syntactic Sugar

Computer scientists use the term

"*syntactic sugar*"

to describe a notation that is easy to read for humans
and that masks a complex implementation detail.

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Syntactic Sugar

That masked complex implementation detail:

`double sum(double* a, int size)`
is how we *should* define the first parameter

but
`double sum(double a[], int size)`
looks a lot more like we are passing an array.

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Arrays and Pointers

Table 2 Arrays and Pointers

Expression	Value	Comment
`a`	20300	The starting address of the array, here assumed to be 20300.
`*a`	0	The value stored at that address. (The array contains values 0, 1, 4, 9, ...)
`a + 1`	20308	The address of the next `double` value in the array. A `double` occupies 8 bytes.
`a + 3`	20324	The address of the element with index 3, obtained by skipping past 3 × 8 bytes.
`*(a + 3)`	9	The value stored at address 20324.
`a[3]`	9	The same as `*(a + 3)` by array/pointer duality.
`*a + 3`	3	The sum of `*a` and 3. Since there are no parentheses, the `*` refers only to `a`.
`&a[3]`	20324	The address of the element with index 3, the same as `a + 3`.

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Using a Pointer to Step Through an Array

Watch variable p as this code is executed.

```
double sum(double* a, int size)
{
   double total = 0;
   double* p = a;
   // p starts at the beginning of the array
   for (int i = 0; i < size; i++) {
      total = total + *p;
      // Add the value to which p points
      p++;
      // Advance p to the next array element
   }
   return total;
}
```

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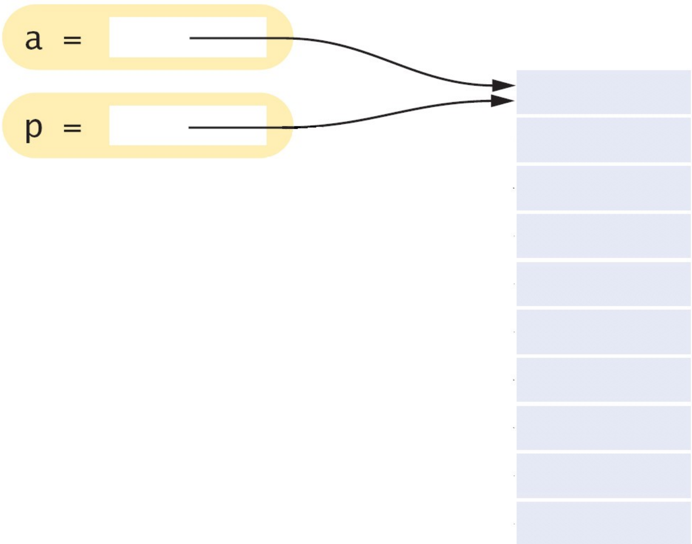
Using a Pointer to Step Through an Array



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Using a Pointer to Step Through an Array

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{
   double total = 0;
   double* p = a;
   // p starts at the beginning of the array
   for (int i = 0; i < size; i++)
   {
      total = total + *p;
      // Add the value to which p points
      p++;
      // Advance p to the next array element
   }
   return total;
}
```

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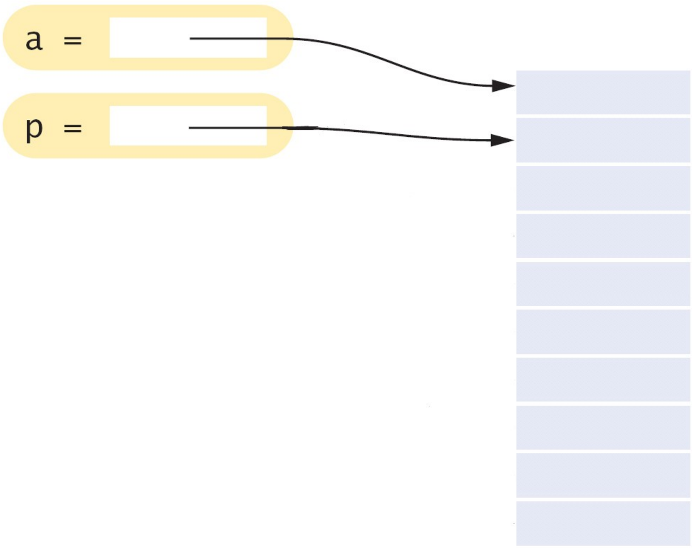
Using a Pointer to Step Through an Array



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Using a Pointer to Step Through an Array

Watch variable p as this code is executed.

```
double sum(double* a, int size)
{
   double total = 0;
   double* p = a;
   // p starts at the beginning of the array
   for (int i = 0; i < size; i++)
   {
      total = total + *p;
      // Add the value to which p points
      p++;
      // Advance p to the next array element
   }
   return total;
}
```

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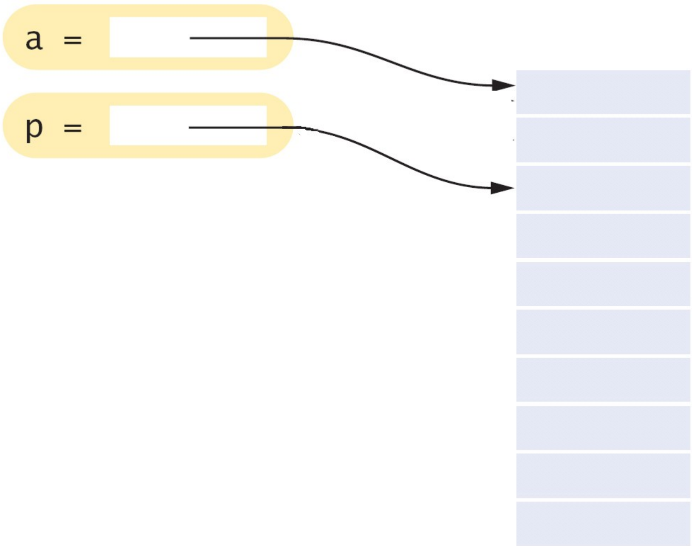
Using a Pointer to Step Through an Array



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Using a Pointer to Step Through an Array

Add, then move **p** to the next position by incrementing.

```
double sum(double* a, int size)
{
   double total = 0;
   double* p = a;
   // p starts at the beginning of the array
   for (int i = 0; i < size; i++)
   {
      total = total + *p;
      // Add the value to which p points
      p++;
      // Advance p to the next array element
   }
   return total;
}
```

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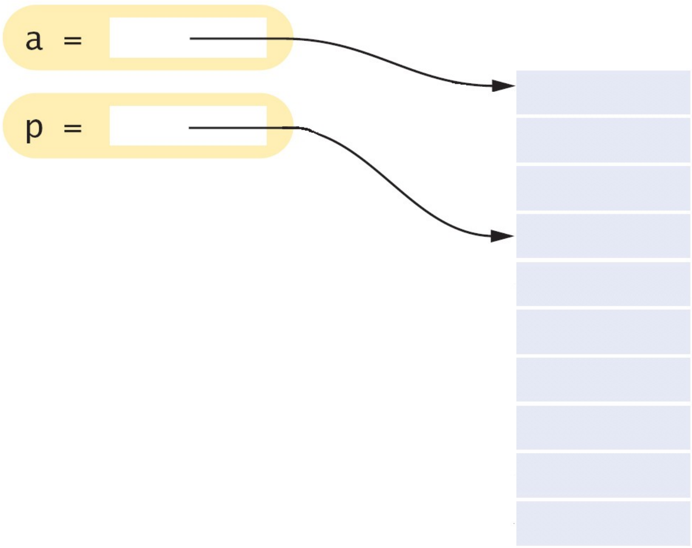

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Using a Pointer to Step Through an Array

Add, then again move **p** to the next position by incrementing.

```
double sum(double* a, int size)
{
   double total = 0;
   double* p = a;
   // p starts at the beginning of the array
   for (int i = 0; i < size; i++)
   {
      total = total + *p;
      // Add the value to which p points
      p++;
      // Advance p to the next array element
   }
   return total;
}
```

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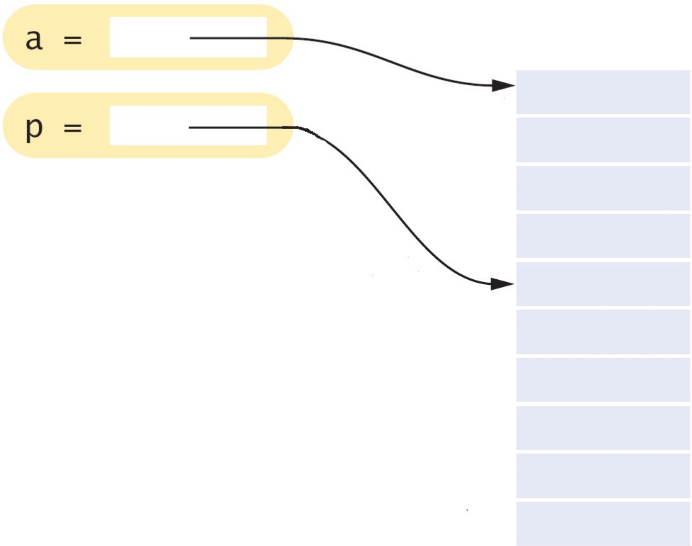

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Using a Pointer to Step Through an Array

Add, then move **p**.

```
double sum(double* a, int size)
{
   double total = 0;
   double* p = a;
   // p starts at the beginning of the array
   for (int i = 0; i < size; i++)
   {
      total = total + *p;
      // Add the value to which p points
      p++;
      // Advance p to the next array element
   }
   return total;
}
```

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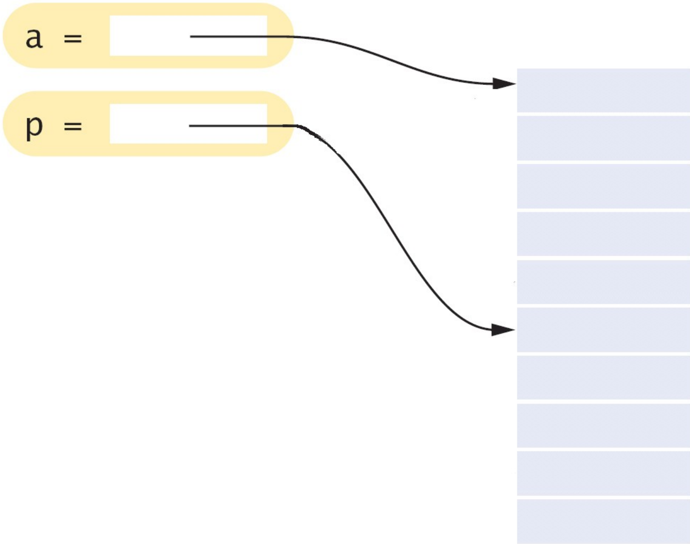
Using a Pointer to Step Through an Array



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Using a Pointer to Step Through an Array

Again...

```
double sum(double* a, int size)
{
   double total = 0;
   double* p = a;
   // p starts at the beginning of the array
   for (int i = 0; i < size; i++)
   {
      total = total + *p;
      // Add the value to which p points
      p++;
      // Advance p to the next array element
   }
   return total;
}
```

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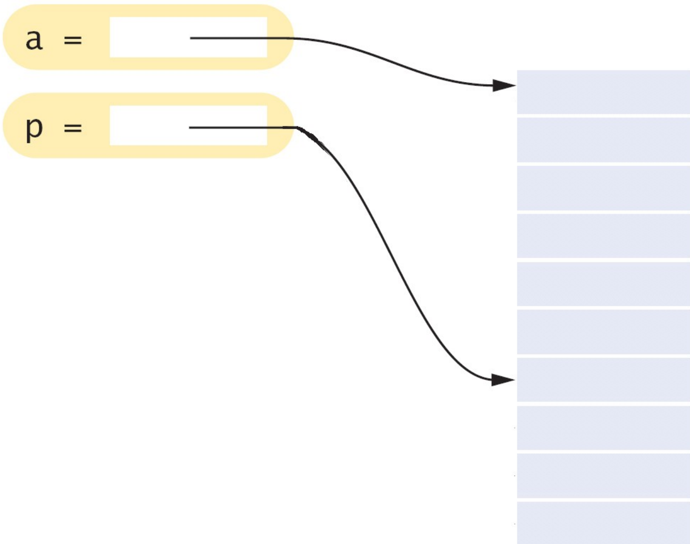
Using a Pointer to Step Through an Array



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Using a Pointer to Step Through an Array

And so on until every single position in the array has been added.

```
double sum(double* a, int size)
{
   double total = 0;
   double* p = a;
   // p starts at the beginning of the array
   for (int i = 0; i < size; i++)
   {
      total = total + *p;
      // Add the value to which p points
      p++;
      // Advance p to the next array element
   }
   return total;
}
```

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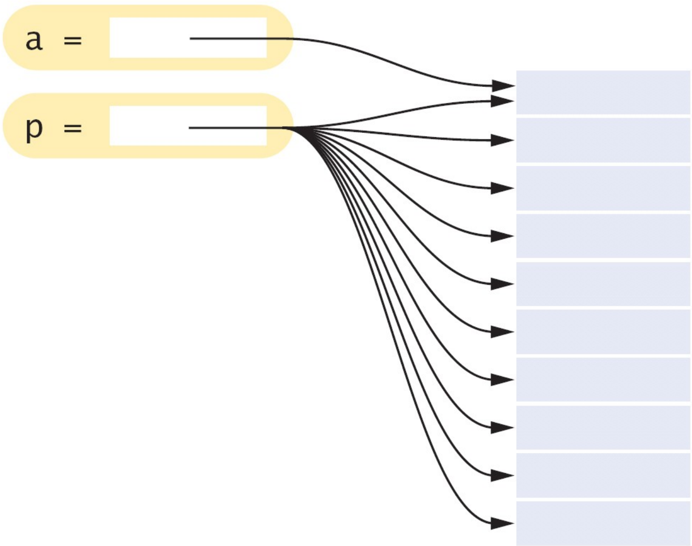
Using a Pointer to Step Through an Array



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Using a Pointer to Step Through an Array

It is a tiny bit more efficient to use and increment a pointer than to access an array element.

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Program Clearly, Not Cleverly

Some programmers take great pride
in minimizing the number of instructions,
even if the resulting code is hard to understand.

```
while (size-- > 0) // Loop size times
{
   total = total + *p;
   p++;
}
```

could be written as:

```
total = total + *p++;
```

Ah, so much better?

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Program Clearly, Not Cleverly

```
while (size > 0)
{
   total = total + *p;
   p++;
   size--;
}
```

could be written as:

```
while (size-- > 0)
    total = total + *p++;
```

Ah, so much better?

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Program Clearly, Not Cleverly

Please do not use this programming style.

Your job as a programmer is not to dazzle other programmers
with your cleverness,
but to write code that is easy
to understand and maintain.

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Common Error: Returning a Pointer to a Local Variable

What would it mean to
"return an array"
?

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Common Error: Returning a Pointer to a Local Variable

Consider this function that tries to return
a pointer to an array containing two elements,
the first and last values of an array:

```
double* firstlast(double a[], int size)
{
   double result[2];
   result[0] = a[0];
   result[1] = a[size - 1];
   return result;
}
```

Local memory is invalid after the function call has ended!

What would the value the caller gets be pointing to?

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Common Error: Returning a Pointer to a Local Variable

A solution would be to pass
in an array to hold the answer:

```
void firstlast(double a[], int size,
               double result)
{
   result[0] = a[0];
   result[1] = a[size - 1];
}
```

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Strings

- Are represented as arrays of `char` values.

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`char` Type and Some Famous Characters

The type `char` is used to store an individual character.

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`char` Type and Some Famous Characters

Some of these characters are plain old letters and such:

```
char yes = 'y';
char no = 'n';
char maybe = '?';
```


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`char` Type and Some Famous Characters

Some are numbers masquerading as digits:

```
char theThreeChar = '3';
```

That is not the number three – it's the *character* 3.

`'3'` is what is actually stored in a disk file when you write the `int` 3.

Writing the variable `theThreeChar` to a file would put the same `'3'` in a file.

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`char` Type and Some Famous Characters

So some characters are literally what they are:

`'A'`

Some represent digits:

`'3'`

Some are other things that can be typed:

`'C'`

`'+'`

`'+'`

but…

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Some Famous Characters

Some of these characters are "special":

`'\n'`

`'\t'`

These are still single (individual) characters:
the ***escape sequence*** characters.

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Some Famous Characters

And there is one special character that
is especially special to C strings:

The null terminator character:

`'\0'`

That is an escaped zero.
It's in ASCII position zero.
It is the value `0` (not the character zero, `'0'`)
If you output it to screen nothing will appear.

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Some Famous Characters

Table 3 Character Literals

`'y'`	The character `y`
`'0'`	The character for the digit `0`. In the ASCII code, `'0'` has the value 48.
`' '`	The space character
`'\n'`	The newline character
`'\t'`	The tab character
`'\0'`	The null terminator of a string
🚫 `"y"`	**Error:** Not a `char` value

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The Null Terminator Character and C Strings

The null character is special to C strings because it is always the last character in them:

"**CAT**" is really this sequence of characters:

'C' 'A' 'T' '\0'

The null terminator character indicates the end of the C string

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The Null Terminator Character and C Strings

The literal C string **"CAT"** is actually an array of ***four*** **char**s stored somewhere in the computer.

In the C programming language, literal strings are always stored as character arrays.

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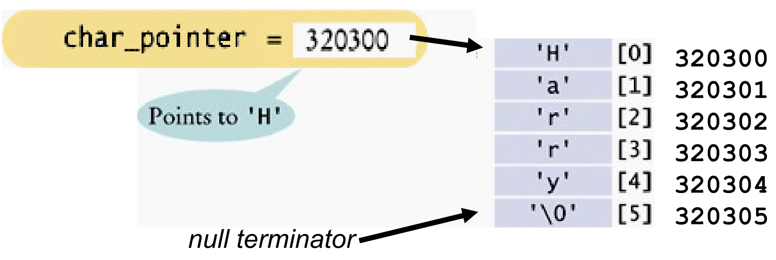
Character Arrays as Storage for C Strings

As with all arrays, a string literal can be assigned to a pointer variable that points to the initial character in the array:

```
char* char_pointer = "Harry";
      // Points to the 'H'
```



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Using the Null Terminator Character

Functions that operate on C strings rely on this terminator.
The strlen function returns the length of a C string.

```
int strlen(const char s[])
{
   int i = 0;
   // Count characters before
   // the null terminator
   while (s[i] != '\0') {
      i++;
   }
   return i;
}
```

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Using the Null Terminator Character

The call `strlen("Harry")` returns 5.

The null terminator character is not counted as part of the “length” of the C string – but it’s there.

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Character Arrays

Literal C strings are considered constant.

You are not allowed to modify its characters.

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Character Arrays

If you want to modify the characters in a C string, define a character array to hold the characters instead.

For example:

```
// An array of 6 characters
char char_array[] = "Harry";
```

Isn’t something missing?

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Character Arrays

The compiler counts the characters in the string that is used for initializing the array, including the null terminator.

```
char char_array[] = "Harry";
```

(6)

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Character Arrays

You can modify the characters in the array:

```
char char_array[] = "Harry";
char_array[0] = 'L';
```

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C String Functions

Table 4 C String Functions

In this table, s and t are character arrays; n is an integer.

Function	Description
`strlen(s)`	Returns the length of s.
`strcpy(t, s)`	Copies the characters from s into t.
`strncpy(t, s, n)`	Copies at most n characters from s into t.
`strcat(t, s)`	Appends the characters from s after the end of the characters in t.
`strncat(t, s, n)`	Appends at most n characters from s after the end of the characters in t.
`strcmp(s, t)`	Returns 0 if s and t have the same contents, a negative integer if s comes before t in lexicographic order, a positive integer otherwise.

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