Pointers

EECS 211

Winter 2019
Initial code setup

$ cd eecs211
$ curl $URL211/lec/05pointer.tgz | tar zx
... 
$ cd 05pointer
Road map

- What’s a pointer?
- What can it do?
- What’s the point?
What is a pointer?
Review: variables, objects, values

```c
int main()
{
    int a = 5, b = 10;
    a = 12;
}
```

• Variables name objects, which contain values
• Assignment changes the value in an object
• Each object has an address
Review: variables, objects, values

```c
int main()
{
    int a = 5, b = 10;
    a = 12;
}
```

- Variables name objects, which contain values
Review: variables, objects, values

```c
int main()
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    int a = 5, b = 10;
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- Variables name objects, which contain values
- Assignment changes the value in an object
Review: variables, objects, values

```c
int main()
{
    int a = 5, b = 10;
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}
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- Variables name objects, which contain values
- Assignment changes the value in an object
- Each object has an address
Memory is a huge array,
and addresses are indices into it.
Memory is a huge array, and addresses are indices into it.

Array of **char**s: 

<table>
<thead>
<tr>
<th>100</th>
<th>101</th>
<th>102</th>
<th>103</th>
<th>104</th>
<th>105</th>
<th>106</th>
<th>107</th>
<th>108</th>
<th>109</th>
<th>110</th>
<th>111</th>
</tr>
</thead>
<tbody>
<tr>
<td>48</td>
<td>65</td>
<td><strong>6C</strong></td>
<td>6C</td>
<td><strong>6F</strong></td>
<td>20</td>
<td>77</td>
<td><strong>6F</strong></td>
<td>72</td>
<td><strong>6C</strong></td>
<td>64</td>
<td>00</td>
</tr>
</tbody>
</table>

Array of **short**s: (little endian)

<table>
<thead>
<tr>
<th>100</th>
<th>102</th>
<th>104</th>
<th>106</th>
<th>108</th>
<th>...</th>
</tr>
</thead>
<tbody>
<tr>
<td>65</td>
<td>6C</td>
<td>20</td>
<td>77</td>
<td><strong>6F</strong></td>
<td>...</td>
</tr>
</tbody>
</table>

Array of **int**s: (big endian)

<table>
<thead>
<tr>
<th>100</th>
<th>104</th>
<th>108</th>
<th>...</th>
</tr>
</thead>
<tbody>
<tr>
<td>48</td>
<td>65</td>
<td><strong>6C</strong></td>
<td>6C</td>
</tr>
</tbody>
</table>

Mixed! double and 4 chars:

<table>
<thead>
<tr>
<th>100</th>
<th>108</th>
<th>109</th>
<th>110</th>
<th>111</th>
<th>...</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td><strong>6C</strong></td>
<td><strong>6F</strong></td>
<td>20</td>
<td>77</td>
<td>...</td>
</tr>
</tbody>
</table>
Memory is a huge array, and addresses are indices into it.

Array of **chars**: (hexadecimal)

<table>
<thead>
<tr>
<th>...</th>
<th>100</th>
<th>101</th>
<th>102</th>
<th>103</th>
<th>104</th>
<th>105</th>
<th>106</th>
<th>107</th>
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<tr>
<td>...</td>
<td>6548</td>
<td>6C6C</td>
<td>206F</td>
<td>6F77</td>
<td>6C72</td>
<td>0064</td>
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Array of *ints*: (big endian)

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<th>108</th>
<th>...</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>48656C6C</td>
<td>6F20776F</td>
<td>726C6400</td>
<td>...</td>
</tr>
</tbody>
</table>
Memory is a huge array, and addresses are indices into it.

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<td>... 100 101 102 103 104 105 106 107 108 109 110 111 ...</td>
<td></td>
</tr>
<tr>
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<td></td>
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<td></td>
</tr>
</tbody>
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</tr>
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<tr>
<td>... 100 108 109 110 111 ...</td>
</tr>
<tr>
<td>... 1.56C6C6F20776Fp+135 72 6C 64 00 ...</td>
</tr>
</tbody>
</table>
Let’s see some real addresses

We can get the address of a variable using the & operator, and format it with printf’s "%p" (after casting it to the “universal” pointer type void*):

```c
int main()
{
    int a = 5, b = 7, c = 9;

    printf("a: \%d\n", a);
    printf("b: \%d\n", b);
    printf("c: \%d\n", c);

    printf("&a: \%p\n", (void*) &a);
    printf("&b: \%p\n", (void*) &b);
    printf("&c: \%p\n", (void*) &c);
}
```
Output from previous slide

$ build/addresses
a: 5
b: 7
c: 9
&a: 0x7ffee536816c
&b: 0x7ffee5368168
&c: 0x7ffee5368164
$ build/addresses
a: 5
b: 7
c: 9
&a: 0x7ffee536816c
&b: 0x7ffee5368168
&c: 0x7ffee5368164

Note that the addresses (in hexadecimal) are 4 bytes apart, which must by `sizeof(int)` on my system.
Pointers

- We can store the address of one object in another object

```c
int main()
{
    int a = 5, b = 7;
    int* ip;
    ip = &a;
    ip = &b;
}
```
Pointers

- We can store the address of one object in another object
- A object containing an address is called a *pointer*
Pointers

- We can store the address of one object in another object
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- A pointer to an object of any type $T$ has type $T*$
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```c
int main()
{
    int a = 5, b = 7;
    int* ip;
    ip = &a;
    ip = &b;
}
```

```
a @100  b @104
5       7
```
Pointers

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```c
int main()
{
    int a = 5, b = 7;
    int* ip;
    ip = &a;
    ip = &b;
}
```

```
a @100  b @104  ip @108
5  7  
```
Pointers

- We can store the address of one object in another object
- A object containing an address is called a pointer
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```c
int main()
{
    int a = 5, b = 7;
    int* ip;
    ip = &a;
    ip = &b;
}
```

<table>
<thead>
<tr>
<th>$a$</th>
<th>$b$</th>
<th>$ip$</th>
</tr>
</thead>
<tbody>
<tr>
<td>@100</td>
<td>@104</td>
<td>@108</td>
</tr>
<tr>
<td>5</td>
<td>7</td>
<td>100</td>
</tr>
</tbody>
</table>
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- A pointer to an object of any type $T$ has type $T*$

```c
int main()
{
    int a = 5, b = 7;
    int* ip;
    ip = &a;
    ip = &b;
}
```

```
a @100  b @104  ip @108
5        7         104
```
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```c
int main()
{
    int a = 5, b = 7;
    int* ip;
    ip = &a;
    ip = &b;
}
```

a @100     b @104     ip @108
5           7

Pointers

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```c
int main()
{
    int a = 5, b = 7;
    int* ip;
    ip = &a;
    ip = &b;
}
```

```
5 7 0
```
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• We can store the address of one object in another object
• A object containing an address is called a pointer
• A pointer to an object of any type $T$ has type $T*$

```c
int main()
{
    int a = 5, b = 7;
    int* ip;
    ip = &a;
    ip = &b;
}
```

```
5 @100  b @104  ip @108
```

Try on C Tutor
What’s with the syntax?

```c
int* p;
```
What’s with the syntax?

```c
int* p;
int *p;
```
What’s with the syntax?

```c
int* p;
int *p;
int * p;
int* p;
int*p;
```
What’s with the syntax?

```c
int* p;
int *p;
int * p;
int* p;
int*p;
    int
    *
    *
p  ;
```
What’s with the syntax?

```c
int* p;
int *p;
int * p;  // don’t
int*p;    // don’t
        int

*      
p    ;
```
What’s with the syntax?

```c
int* p;
int *p;
int *p;  // don’t
int*p;   // don’t
    int
    // o_o
    *
    p ;
```
What’s with the syntax?

```c
int* p;     // “p is an int*”
int *p;     // “*p is an int”
int * p;    // don’t
int*p;      // don’t

int
    // o_o
*    
* p ;
```
Beware!

What does this mean?

```
int* p, q;
```
Beware!

What does this mean?

\texttt{int* p, q;} \equiv \texttt{int *p, q;}

Beware!

What does this mean?

```c
int* p, q;  \equiv  int *p, q;  \equiv  int *p; int q;
```
Beware!

What does this mean?

```c
int* p, q;  ≡  int *p, q;  ≡  int *p; int q;
```

So you gotta write:

```c
int* p;
int* q;
```
Beware!

What does this mean?

\[ \text{int* p, q; } \equiv \text{ int *p, q; } \equiv \text{ int *p; int q;} \]

So you gotta write:

\[ \text{int* p;} \]
\[ \text{int* q;} \quad \text{or int *p, *q;} \]
Beware!

What does this mean?

\[ \text{int* p, q; } \equiv \text{ int *p, q; } \equiv \text{ int *p; int q;} \]

So you gotta write:

\[ \text{int* p;} \]
\[ \text{int* q; or int *p, *q; (but please not int* p,* q;)} \]
What can it do?
What can you do with a pointer?

You can dereference (or “follow”) it, using the \* operator:

```c
int main()
{
    int y = 5, z = 7;
    int* ip = &y;  // referent is y
    z = *ip + 1;  // use value of referent
    *ip = 9;      // assign to referent
}
```
What can you do with a pointer?

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}
```

<table>
<thead>
<tr>
<th>y @100</th>
<th>z @104</th>
</tr>
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<tbody>
<tr>
<td>5</td>
<td>7</td>
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    *ip = 9;       // assign to referent
}
```

```
y  z  ip
@100 @104 @108
5  7  
```
What can you do with a pointer?

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int main()
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    int y = 5, z = 7;
    int* ip = &y;    // referent is y
    z = *ip + 1;     // use value of referent
    *ip = 9;         // assign to referent
}
```

```
y @100  z @104  ip @108
  5      6
```
What can you do with a pointer?

You can dereference (or “follow”) it, using the * operator:

```c
int main()
{
    int y = 5, z = 7;
    int* ip = &y;  // referent is y
    z = *ip + 1;  // use value of referent
    *ip = 9;      // assign to referent
}
```

y @100  z @104  ip @108
9 6 0
FAQ

Can a struct contain a struct? *Yes.
Can a struct contain an array? *Yes, but declaring it looks weird.
Can a struct contain a pointer? *Yes.
Can you have an array of structs? *Yes.
Can you have an array of arrays? †Can you not have an array?
Can you have an array of pointers? *Yes.
Can you have a pointer to a struct? *Yes.
Can you have a pointer to an array? ‡Can you have a pointer to a pointer?
Can you have a pointer to a field of a struct? *Yes.
Can you have a pointer to an element of an array? *Yes.
Can you have a pointer to a field of struct which is an element of an array which is a field of a struct? *Yes.
FAQ

Can a struct contain a struct?

Yes.
FAQ

Can a struct contain a struct? Can a struct contain an array?
FAQ

Can a struct contain a struct?  Can a struct contain an array?  Can a struct contain a pointer?
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Can a struct contain a struct? Can a struct contain an array? Can a struct contain a pointer? Can you have an array of structs? Can you have an array of arrays? Can you have an array of pointers?
FAQ

Can a struct contain a struct?  Can a struct contain an array?  Can a struct contain a pointer?  Can you have an array of structs?  Can you have an array of arrays?  Can you have an array of pointers?  Can you have a pointer to a struct?  Can you have a pointer to an array?  Can you have a pointer to a pointer?
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Can a struct contain a struct? Can a struct contain an array? Can a struct contain a pointer? Can you have an array of structs? Can you have an array of arrays? Can you have an array of pointers? Can you have a pointer to a struct? Can you have a pointer to an array? Can you have a pointer to a pointer? Can you have a pointer to a field of a struct?
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* Yes.
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* Yes.

† Yes, but declaring it looks weird.
FAQ

Can a struct contain a struct?* Can a struct contain an array?* Can a struct contain a pointer?* Can you have an array of structs?* **Can you have an array of arrays?**† Can you have an array of pointers?* Can you have a pointer to a struct?* **Can you have a pointer to an array?**‡ Can you have a pointer to a pointer?* Can you have a pointer to a field of a struct?* Can you have a pointer to an element of an array?* Can you have a pointer to a field of struct which is an element of an array which is a field of a struct?*

* Yes.
† Yes, but declaring it looks weird.
‡ Can you not have a pointer to an array?
Everything is compositional

typedef struct { short h, k; } entry;
Everything is compositional

typedef struct { short h, k; } entry;

struct matrix
{
    entry data[3][6];
    entry *some_entry;
    short *some_subentry;
    entry *some_entries[12];
    entry (*some_row)[6];
    entry **some_ptr;
}

typedef struct { short h, k; } entry;

struct matrix
{
    entry data[3][6]; // array of 3 arrays of 6 structs
    entry *some_entry;
    short *some_subentry;
    entry *some_entries[12];
    entry (*some_row)[6];
    entry **some_ptr;
}
typedef struct { short h, k; } entry;

struct matrix
{
    entry data[3][6];       // array of 3 arrays of 6 structs
    entry *some_entry;      // pointer to struct
    short *some_subentry;
    entry *some_entries[12];
    entry (*some_row)[6];
    entry **some_ptr;
}
Everything is compositional

typedef struct { short h, k; } entry;

struct matrix {
    entry data[3][6]; // array of 3 arrays of 6 structs
    entry *some_entry; // pointer to struct
    short *some_subentry; // pointer to field of struct
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    entry (*some_row)[6];
    entry **some_ptr;
}

Everything is compositional

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struct matrix
{
    entry data[3][6]; // array of 3 arrays of 6 structs
    entry *some_entry; // pointer to struct
    short *some_subentry; // pointer to field of struct
    entry *some_entries[12]; // array of 12 pointers to structs
    entry (*some_row)[6];
    entry **some_ptr;
}
Everything is compositional

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    entry data[3][6]; // array of 3 arrays of 6 structs
    entry *some_entry; // pointer to struct
    short *some_subentry; // pointer to field of struct
    entry *some_entries[12]; // array of 12 pointers to structs
    entry (*some_row)[6]; // pointer to array of 6 structs
    entry **some_ptr;
}

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    entry data[3][6]; // array of 3 arrays of 6 structs
    entry *some_entry; // pointer to struct
    short *some_subentry; // pointer to field of struct
    entry *some_entries[12]; // array of 12 pointers to structs
    entry (*some_row)[6]; // pointer to array of 6 structs
    entry **some_ptr; // pointer to pointer to struct
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Everything is compositional

typedef struct { short h, k; } entry;

struct matrix
{
    entry data[3][6];                       // array of 3 arrays of 6 structs
    entry *some_entry;                      // pointer to struct
    short *some_subentry;                   // pointer to field of struct
    entry *some_entries[12];                // array of 12 pointers to structs
    entry (*some_row)[6];                   // pointer to array of 6 structs
    entry **some_ptr;                       // pointer to pointer to struct
}
    m;
typedef struct { short h, k; } entry;

struct matrix
{
    entry data[3][6]; // array of 3 arrays of 6 structs
    entry *some_entry; // pointer to struct
    short *some_subentry; // pointer to field of struct
    entry *some_entries[12]; // array of 12 pointers to structs
    entry (*some_row)[6]; // pointer to array of 6 structs
    entry **some_ptr; // pointer to pointer to struct
}

m;

m.data[2][5].h = 6;
Everything is compositional

typedef struct { short h, k; } entry;

struct matrix
{
    entry data[3][6]; // array of 3 arrays of 6 structs
    entry *some_entry; // pointer to struct
    short *some_subentry; // pointer to field of struct
    entry *some_entries[12]; // array of 12 pointers to structs
    entry (*some_row)[6]; // pointer to array of 6 structs
    entry **some_ptr; // pointer to pointer to struct
} m;

m.some_entry = &m.data[row][col];
m.some_subentry = &m.data[row][col].k;
Everything is compositional

typedef struct { short h, k; } entry;

struct matrix
{
    entry data[3][6]; // array of 3 arrays of 6 structs
    entry *some_entry; // pointer to struct
    short *some_subentry; // pointer to field of struct
    entry *some_entries[12]; // array of 12 pointers to structs
    entry (*some_row)[6]; // pointer to array of 6 structs
    entry **some_ptr; // pointer to pointer to struct
}
m;

m.some_entry = &(((m.data)[row])[col]);
m.some_subentry = &(((m.data)[row])[col]).k;
Everything is compositional

typedef struct { short h, k; } entry;

struct matrix
{
    entry data[3][6]; // array of 3 arrays of 6 structs
    entry *some_entry; // pointer to struct
    short *some_subentry; // pointer to field of struct
    entry *some_entries[12]; // array of 12 pointers to structs
    entry (*some_row)[6]; // pointer to array of 6 structs
    entry **some_ptr; // pointer to pointer to struct
} m;

m.some_entry = &(m.data[row][col]);
m.some_subentry = &(m.data[row][col].k);
Everything is compositional

typedef struct { short h, k; } entry;

struct matrix
{
    entry data[3][6];          // array of 3 arrays of 6 structs
    entry *some_entry;         // pointer to struct
    short *some_subentry;      // pointer to field of struct
    entry *some_entries[12];   // array of 12 pointers to structs
    entry (*some_row)[6];      // pointer to array of 6 structs
    entry **some_ptr;          // pointer to pointer to struct
} m;

m.some_entry->k = 7;
*m.some_subentry = 7;
typedef struct { short h, k; } entry;

struct matrix
{
    entry data[3][6]; // array of 3 arrays of 6 structs
    entry *some_entry; // pointer to struct
    short *some_subentry; // pointer to field of struct
    entry *some_entries[12]; // array of 12 pointers to structs
    entry (*some_row)[6]; // pointer to array of 6 structs
    entry **some_ptr; // pointer to pointer to struct
}
m;

m.some_entry->k = 7;
*(m.some_subentry) = 7;
Everything is compositional

typedef struct { short h, k; } entry;

struct matrix
{
    entry data[3][6]; // array of 3 arrays of 6 structs
    entry *some_entry; // pointer to struct
    short *some_subentry; // pointer to field of struct
    entry *some_entries[12]; // array of 12 pointers to structs
    entry (*some_row)[6]; // pointer to array of 6 structs
    entry **some_ptr; // pointer to pointer to struct
} m;

m.some_entries[1] = &m.data[1][2];
m.some_entries[1]->h = 8;
typedef struct { short h, k; } entry;

struct matrix {
    entry data[3][6]; // array of 3 arrays of 6 structs
    entry *some_entry; // pointer to struct
    short *some_subentry; // pointer to field of struct
    entry *some_entries[12]; // array of 12 pointers to structs
    entry (*some_row)[6]; // pointer to array of 6 structs
    entry **some_ptr; // pointer to pointer to struct
} m;

m.some_row = &m.data[row];
(*m.some_row)[col].h = 9; // necessary parentheses!
typedef struct { short h, k; } entry;

struct matrix
{
    entry data[3][6]; // array of 3 arrays of 6 structs
    entry *some_entry; // pointer to struct
    short *some_subentry; // pointer to field of struct
    entry *some_entries[12]; // array of 12 pointers to structs
    entry (*some_row)[6]; // pointer to array of 6 structs
    entry **some_ptr; // pointer to pointer to struct
} m;

m.some_ptr = &m.some_entries[cur];
*m.some_ptr = m.some_entry;
Okay, but why?
What’s the point?

- “Talk about” objects
- Avoid copying
- They’re super general
- Unnamed objects (next time)
Let’s talk about objects

```c
void swap(int* ip, int* jp)
{
    int temp = *ip;
    *ip = *jp;
    *jp = temp;
}

int x = 5, y = 7;
swap(&x, &y);
```
Let’s talk about objects

void swap(int* ip, int* jp)
{
    int temp = *ip;
    *ip = *jp;
    *jp = temp;
}

int x = 5, y = 7;
swap(&x, &y);

x @100  y @104
5       7
Let’s talk about objects

```c
void swap(int* ip, int* jp)
{
    int temp = *ip;
    *ip = *jp;
    *jp = temp;
}

int x = 5, y = 7;
swap(&x, &y);
```

(x @100 5

y @104 7

ip @200 100

jp @208 104

(caller’s stack frame)

(swarm’s stack frame)
Let’s talk about objects

```c
void swap(int* ip, int* jp)
{
    int temp = *ip;
    *ip = *jp;
    *jp = temp;
}

int x = 5, y = 7;
swap(&x, &y);
```

(caller’s stack frame)

(ip @200)

(temp @216)

(jp @208)

(x @100)

(100)

(5)

(y @104)

(104)

(7)

(caller’s stack frame)

(swap’s stack frame)
Let’s talk about objects

```c
void swap(int* ip, int* jp)
{
    int temp = *ip;
    *ip = *jp;
    *jp = temp;
}
```

```c
int x = 5, y = 7;
swap(&x, &y);
```

(x @100  y @104
7 7
ip @200  jp @208
temp @216
100 104 5
(caller’s stack frame)

(swaps stack frame)
Let’s talk about objects

```c
void swap(int* ip, int* jp)
{
    int temp = *ip;
    *ip = *jp;
    *jp = temp;
}
```

```c
int x = 5, y = 7;
swap(&x, &y);
```

(caller’s stack frame)

(x @100)

(y @104)

(ip @200)

(jp @208)

(temp @216)

(swap’s stack frame)
Let’s talk about objects

```c
void swap(int* ip, int* jp)
{
    int temp = *ip;
    *ip = *jp;
    *jp = temp;
}
```

```c
int x = 5, y = 7;
swap(&x, &y);
```

```
x @100    y @104
7          5
```

(caller’s stack frame)
Avoiding copying

#define N 1024

struct intvec
{
    size_t count;
    int    data[N];
};

void push(struct intvec r, int v)
{
    r.data[r.count] = v;
    ++r.count;
}
Avoiding copying

#define N 1024

struct intvec
{
    size_t count;
    int data[N];
};

struct intvec push(struct intvec r, int v)
{
    r.data[r.count] = v;
    ++r.count;
    return r;
}
Avoiding copying

#define N 1024

struct intvec
{
    size_t count;
    int data[N];
};

void push(struct intvec* r, int v)
{
    ++(*r).count;
}
Avoiding copying

#define N 1024

struct intvec
{
    size_t count;
    int data[N];
};

void push(struct intvec* r, int v)
{
    r->data[r->count] = v;
    ++r->count;
}

Syntactic sugar: ⟨ptr⟩->⟨field⟩ means (⋆⟨ptr⟩).⟨field⟩
Arrays decay to pointers

```c
int a[] = { 2, 3, 4, 5, 6 };

put_ptr(&a[0]); // ⇒ 0x7ffee5c6e2f0
put_ptr(a);
put_int(a[0]);
put_int(*a);
```

20
Arrays decay to pointers

```c
int a[] = { 2, 3, 4, 5, 6 };

put_ptr(&a[0]); // ⇒ 0x7ffee5c6e2f0
put_ptr(a);     // ⇒ 0x7ffee5c6e2f0
put_int(a[0]);  // ⇒ 0x7ffee5c6e2f0
put_int(*a);    // ⇒ 2
```
Arrays decay to pointers

```c
int a[] = { 2, 3, 4, 5, 6 };

put_ptr(&a[0]); //⇒ 0x7ffee5c6e2f0
put_ptr(a);     //⇒ 0x7ffee5c6e2f0
put_int(a[0]);  //⇒ 2
put_int(*a);    //⇒ 2
```

Arrays decay to pointers

```c
int a[] = { 2, 3, 4, 5, 6 };

put_ptr(&a[0]);     // ⇒ 0x7ffee5c6e2f0
put_ptr(a);         // ⇒ 0x7ffee5c6e2f0
put_int(a[0]);      // ⇒ 2
put_int(*a);        // ⇒ 2
```

Arrays decay to pointers

```c
int a[] = { 2, 3, 4, 5, 6 };

put_ptr(&a[0]);    // ⇒ 0x7ffee5c6e2f0
put_ptr(a);        // ⇒ 0x7ffee5c6e2f0
put_int(a[0]);     // ⇒ 2
put_int(*a);        // ⇒ 2

put_ptr(&a[1]);
put_ptr(a + 1);
put_int(a[1]);
put_int(*(a + 1));
```
Arrays decay to pointers

```c
int a[] = { 2, 3, 4, 5, 6 };

put_ptr(&a[0]);       // ⇒ 0x7ffee5c6e2f0
put_ptr(a);           // ⇒ 0x7ffee5c6e2f0
put_int(a[0]);        // ⇒ 2
put_int(*a);          // ⇒ 2

put_ptr(&a[1]);       // ⇒ 0x7ffee5c6e2f4
put_ptr(a + 1);       // ⇒ 0x7ffee5c6e2f4
put_int(a[1]);        // ⇒ 3
put_int(*(a + 1));    // ⇒ 3
```

put_size(sizeof a);  // ⇒ 20
put_size(sizeof (a + 0)); // ⇒ 8
Arrays decay to pointers

```c
int a[] = { 2, 3, 4, 5, 6 };

put_ptr(&a[0]); // ⇒ 0x7fffee5c6e2f0
put_ptr(a); // ⇒ 0x7fffee5c6e2f0
put_int(a[0]); // ⇒ 2
put_int(*a); // ⇒ 2

put_ptr(&a[1]); // ⇒ 0x7fffee5c6e2f4
put_ptr(a + 1);
put_int(a[1]);
put_int(*(a + 1));
```
Arrays decay to pointers

```c
int a[] = { 2, 3, 4, 5, 6 };

put_ptr(&a[0]);  // ⇒ 0x7ffee5c6e2f0
put_ptr(a);      // ⇒ 0x7ffee5c6e2f0
put_int(a[0]);   // ⇒ 2
put_int(*a);     // ⇒ 2

put_ptr(&a[1]);  // ⇒ 0x7ffee5c6e2f4
put_ptr(a + 1);  // ⇒ 0x7ffee5c6e2f4
put_int(a[1]);   // ⇒ 3
put_int(*(a + 1));
```
Arrays decay to pointers

```c
int a[] = { 2, 3, 4, 5, 6 };

put_ptr(&a[0]);          // ⇒ 0x7ffee5c6e2f0
put_ptr(a);              // ⇒ 0x7ffee5c6e2f0
put_int(a[0]);           // ⇒ 2
put_int(*a);             // ⇒ 2

put_ptr(&a[1]);          // ⇒ 0x7ffee5c6e2f4
put_ptr(a + 1);          // ⇒ 0x7ffee5c6e2f4
put_int(a[1]);           // ⇒ 3
put_int(*(a + 1));       // ⇒ 3
```

Arrays decay to pointers

```c
int a[] = { 2, 3, 4, 5, 6 };

put_ptr(&a[0]); // ⇒ 0x7ffee5c6e2f0
put_ptr(a);     // ⇒ 0x7ffee5c6e2f0
put_int(a[0]);  // ⇒ 2
put_int(*a);    // ⇒ 2

put_ptr(&a[1]); // ⇒ 0x7ffee5c6e2f4
put_ptr(a + 1); // ⇒ 0x7ffee5c6e2f4
put_int(a[1]);  // ⇒ 3
put_int(*(a + 1)); // ⇒ 3
```
Arrays *decay* to pointers

```c
int a[] = { 2, 3, 4, 5, 6 };

put_ptr(&a[0]); // ⇒ 0x7ffee5c6e2f0
put_ptr(a); // ⇒ 0x7ffee5c6e2f0
put_int(a[0]); // ⇒ 2
put_int(*a); // ⇒ 2

put_ptr(&a[1]); // ⇒ 0x7ffee5c6e2f4
put_ptr(a + 1); // ⇒ 0x7ffee5c6e2f4
put_int(a[1]); // ⇒ 3
put_int(*(a + 1)); // ⇒ 3

put_size(sizeof a);
put_size(sizeof (a + 0));
```
Arrays *decay* to pointers

```c
int a[] = { 2, 3, 4, 5, 6 };

put_ptr(&a[0]); // ⇒ 0x7ffee5c6e2f0
put_ptr(a);     // ⇒ 0x7ffee5c6e2f0
put_int(a[0]);  // ⇒ 2
put_int(*a);    // ⇒ 2

put_ptr(&a[1]); // ⇒ 0x7ffee5c6e2f4
put_ptr(a + 1); // ⇒ 0x7ffee5c6e2f4
put_int(a[1]);  // ⇒ 3
put_int(*(a + 1)); // ⇒ 3

put_size(sizeof a);   // ⇒ 20
put_size(sizeof (a + 0)); // ⇒ 8
```
Array indexing is pointer arithmetic

\[ \langle aexpr \rangle [\langle iexpr \rangle] \quad \text{means} \quad *(\langle aexpr \rangle + \langle iexpr \rangle) \]
Array indexing is pointer arithmetic

\[
\langle aexpr \rangle [\langle iexpr \rangle] \quad \text{means} \quad *(\langle aexpr \rangle + \langle iexpr \rangle)
\]

\&\langle aexpr \rangle [\langle iexpr \rangle] \quad \text{means} \quad \langle aexpr \rangle + \langle iexpr \rangle
Strings are arrays of chars

```c
#include <stdio.h>

int main()
{
    char mystery[] = {
        71, 111, 32, 39, 67, 97, 116, 115, 33, 0
    };

    printf("%s\n", mystery);
}
```
Strings are arrays of chars

```c
#include <stdio.h>

int main()
{
    char mystery[] = {
        71, 'o', 32, 39, 67, 97, 116, 115, 33, 0
    };

    printf("%s\n", mystery);
}
```
Strings are arrays of chars

```c
#include <stdio.h>

int main()
{
    char mystery[] = {
        71, 'o', 32, 39, 67, 'a', 116, 115, 33, 0
    };

    printf("%s\n", mystery);
}
```
Strings are arrays of chars

```c
#include <stdio.h>

int main()
{
    char mystery[] = {
        71, 'o', 32, 39, 67, 'a', 't', 115, 33, 0
    };

    printf("%s\n", mystery);
}
```
Strings are arrays of chars

```c
#include <stdio.h>

int main()
{
    char mystery[] = {
        71, 'o', 32, 39, 67, 'a', 't', 's', 33, 0
    };

    printf("%s\n", mystery);
}
```
Strings are arrays of chars

```c
#include <stdio.h>

int main()
{
    char mystery[] = {
        71, 'o', 32, 39, 67, 'a', 't', 's', '!', 0
    };

    printf("%s\n", mystery);
}
```
Strings are arrays of chars

```c
#include <stdio.h>

int main()
{
    char mystery[] = {
        71, 'o', 32, 39, 67, 'a', 't', 's', '!', '\0'
    };

    printf("%s\n", mystery);
}
```
Strings are arrays of chars

#include <stdio.h>

int main()
{
    char mystery[] = {
        71, 'o', 32, '\', 67, 'a', 't', 's', '!', '\0'
    };

    printf("%s\n", mystery);
}

How long is a C string?

```c
int main()
{
    const char* cptr = "12345";
}
```
How long is a C string?

```c
int main()
{
    const char* cptr = "12345";
    printf("%zu\n", sizeof cptr); // ⇒ ?
}
```
How long is a C string?

```c
int main()
{
    const char* cptr = "12345";
    printf("%zu\n", sizeof cptr); // ⇒ 8
}
```
int main()
{
    const char* cptr = "12345";
    printf("%zu\n", sizeof cptr); // ⇒ 8
    printf("%zu\n", sizeof *cptr); // ⇒ ?
    const char carray[6] = "12345";
    printf("%zu\n", sizeof carray); // ⇒ ?
    printf("%zu\n", sizeof const char[6]); // ⇒ ?
    for (size_t i = 0; i < sizeof carray; ++i)
        printf("%d␣", (int) carray[i]); // ⇒ ?
How long is a C string?

```c
int main()
{
    const char* cptr = "12345";
    printf("%zu\n", sizeof cptr); // ⇒ 8
    printf("%zu\n", sizeof *cptr); // ⇒ 1
}
```
How long is a C string?

```c
int main()
{
    const char* cptr = "12345";
    printf("%zu\n", sizeof cptr);  // ⇒ 8
    printf("%zu\n", sizeof *cptr); // ⇒ 1
    printf("%zu\n", sizeof(const char*)); // ⇒ 8
    printf("%zu\n", sizeof(const char)); // ⇒ 1

}
```
How long is a C string?

```c
int main()
{
    const char* cptr = "12345";
    printf("%zu\n", sizeof cptr); // ⇒ 8
    printf("%zu\n", sizeof *cptr); // ⇒ 1
    printf("%zu\n", sizeof(const char*)); // ⇒ 8
    printf("%zu\n", sizeof(const char)); // ⇒ 1

    const char carray[] = "12345";
    printf("%zu\n", sizeof carray); // ⇒ ?
}
```
How long is a C string?

```c
int main()
{
    const char* cptr = "12345";
    printf("%zu\n", sizeof cptr); // ⇒ 8
    printf("%zu\n", sizeof *cptr); // ⇒ 1
    printf("%zu\n", sizeof(const char*)); // ⇒ 8
    printf("%zu\n", sizeof(const char)); // ⇒ 1

    const char carray[] = "12345";
    printf("%zu\n", sizeof carray); // ⇒ 6

    for (size_t i = 0; i < sizeof carray; ++i)
        printf("%d␣", (int) carray[i]); // ⇒ 12345

}
```
# How long is a C string?

```c
int main()
{
    const char* cptr = "12345";
    printf("%zu\n", sizeof cptr); // ⇒ 8
    printf("%zu\n", sizeof *cptr); // ⇒ 1
    printf("%zu\n", sizeof(const char*)); // ⇒ 8
    printf("%zu\n", sizeof(const char)); // ⇒ 1

    const char carray[] = "12345";
    printf("%zu\n", sizeof carray); // ⇒ 6
    printf("%zu\n", sizeof(const char[6])); // ⇒ 6
}
```
How long is a C string?

```c
int main()
{
    const char* cptr = "12345";
    printf("%zu\n", sizeof cptr);        // ⇒ 8
    printf("%zu\n", sizeof *cptr);       // ⇒ 1
    printf("%zu\n", sizeof(const char*)); // ⇒ 8
    printf("%zu\n", sizeof(const char));  // ⇒ 1

    const char carray[] = "12345";
    printf("%zu\n", sizeof carray);      // ⇒ 6
    printf("%zu\n", sizeof(const char[6])); // ⇒ 6

    for (size_t i = 0; i < sizeof carray; ++i)
        printf("%d\n", (int) carray[i]);   // ⇒ ?
}
```
How long is a C string?

```c
int main()
{
    const char* cptr = "12345";
    printf("%zu\n", sizeof cptr); // ⇒ 8
    printf("%zu\n", sizeof *cptr); // ⇒ 1
    printf("%zu\n", sizeof(const char*)); // ⇒ 8
    printf("%zu\n", sizeof(const char)); // ⇒ 1

    const char carray[] = "12345";
    printf("%zu\n", sizeof carray); // ⇒ 6
    printf("%zu\n", sizeof(const char[6])); // ⇒ 6

    for (size_t i = 0; i < sizeof carray; ++i)
        printf("%d␣", (int) carray[i]);
    // ⇒ 49 50 51 52 53 0
}
```
A string algorithm

```c
size_t count_chars(const char* s) {
    size_t result = 0;
    while (*s++) ++result;
    return result;
}
```
A string algorithm

size_t count_chars(const char* s)
{
    size_t result = 0;
    while (*s++) ++result;
    return result;
}

size_t count_chars(const char* s)
{
    size_t i = 0;
    while (s[i] != '\0') ++i;
    return i;
}
A string algorithm

def count_chars(s):  # count characters in string s
    result = 0
    while *s++:
        result += 1
    return result

def count_chars_optimized(s):  # count characters in string s
    t = s
    while *t:
        t = t + 1
    return t - s
Counting characters

```c
int main()
{
    const char carray[] = "12345",
    *cptr = "12345";

    printf("%zu\n", count_chars(carray));  // ⇒ ?
    printf("%zu\n", count_chars(cptr));   // ⇒ ?


    printf("%s\n", buf);  // ⇒ ?
}
```
Counting characters

```c
int main()
{
    const char carray[] = "12345",
                         *cptr     = "12345";

    printf("%zu\n", count_chars(carray));  // ⇒ 5
    printf("%zu\n", count_chars(cptr));    // ⇒ 5
```
Counting characters

```c
int main()
{
    const char carray[] = "12345",
                        *cptr = "12345";

    printf("%zu\n", count_chars(carray));  // ⇒ 5
    printf("%zu\n", count_chars(cptr));    // ⇒ 5

    char buf[800] = {'a'};
    printf("%zu\n", sizeof buf);          // ⇒ ?
    printf("%zu\n", count_chars(buf));    // ⇒ ?
}
```
Counting characters

int main()
{
    const char carray[] = "12345",
    *cptr = "12345";

    printf("%zu\n", count_chars(carray));  // ⇒ 5
    printf("%zu\n", count_chars(cptr));  // ⇒ 5

    char buf[800] = {'a'};
    printf("%zu\n", sizeof buf);  // ⇒ 800
    printf("%zu\n", count_chars(buf));  // ⇒ 1

}
Counting characters

```c
int main()
{
    const char carray[] = "12345",
    *cptr = "12345";

    printf("%zu\n", count_chars(carray)); // ⇒ 5
    printf("%zu\n", count_chars(cptr)); // ⇒ 5

    char buf[800] = {'a'};
    printf("%zu\n", sizeof buf); // ⇒ 800
    printf("%zu\n", count_chars(buf)); // ⇒ 1

    printf("%zu\n", count_chars(buf)); // ⇒ ?
    printf("%s\n", buf); // ⇒ ?
}
```
Counting characters

```c
int main()
{
    const char carray[] = "12345",
    *cptr = "12345";

    printf("%zu\n", count_chars(carray)); // ⇒ 5
    printf("%zu\n", count_chars(cptr));  // ⇒ 5

    char buf[800] = {'a'};
    printf("%zu\n", sizeof buf);        // ⇒ 800
    printf("%zu\n", count_chars(buf)); // ⇒ 1

    printf("%zu\n", count_chars(buf)); // ⇒ 3
    printf("%s\n", buf);              // ⇒ abb
}
```
– Next: More objects than you can name –