CS 241: Systems Programming
Lecture 15. Strings

Fall 2019

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Review of last lecture

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Arrays are contiguous sequences of objects

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- `long y = *p;` // sets y to the value of the long pointed to by p

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- `long *p;` // declares a pointer p that can point to a long
- `p = &x;` // sets the value of p to the address of x
- `long y = *p;` // sets y to the value of the long pointed to by p
- `*p = 5;` // sets the value of the long pointed to by p to be 5

```c
long x = 5;
long y = -10;
long *p = &x;
long *q = &y;
*p = *q + 2;
q = p;
p = 0;
printf("%ld\n", *q); // What is printed?
```

A. -10

B. -8

C. 0

D. 5

E. 7

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Array decay

C has array *objects* but not array *values*

When an array is used as an value, it **decays** into a pointer to its 0th element

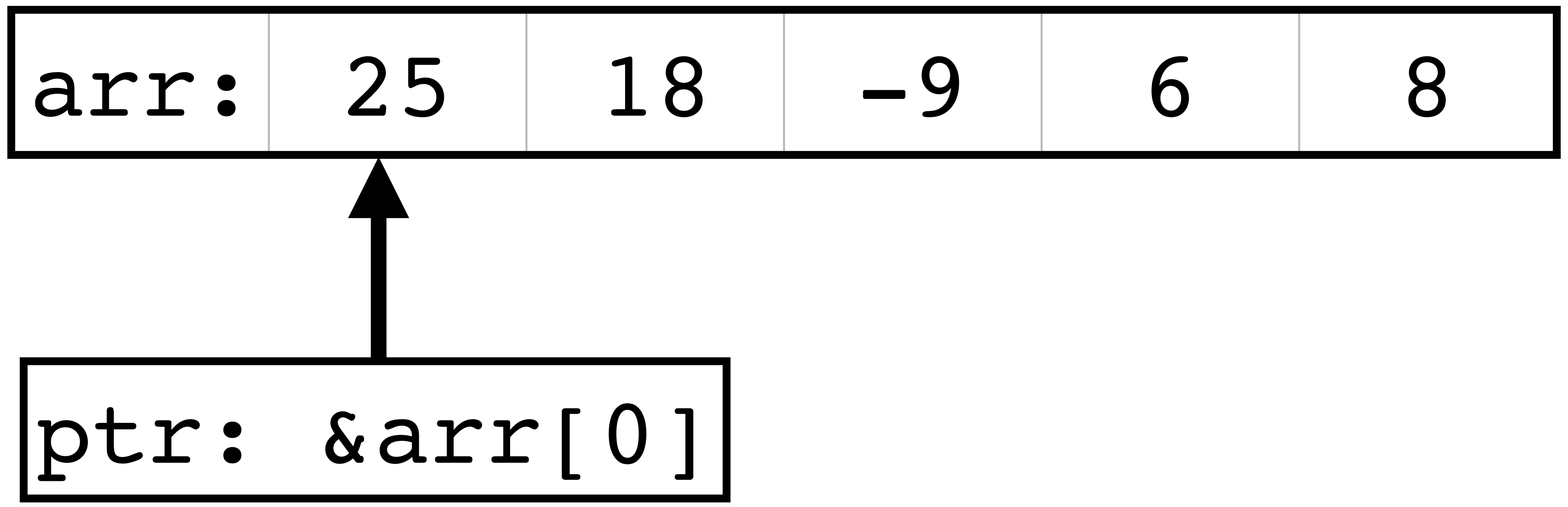
```
#include <stdio.h>

int main(void) {
  int arr[] = { 25, 18, -9 };
  int *ptr = arr; // decay to pointer, same as &arr[0]
  ptr[1] = 77;    // We can use [] syntax with pointers too!
  for (size_t idx = 0; idx < sizeof arr / sizeof arr[0]; ++idx) {
    printf("arr[%zu] = %d\n", idx, arr[idx]);
  }
  return 0;
}
```

Prints:

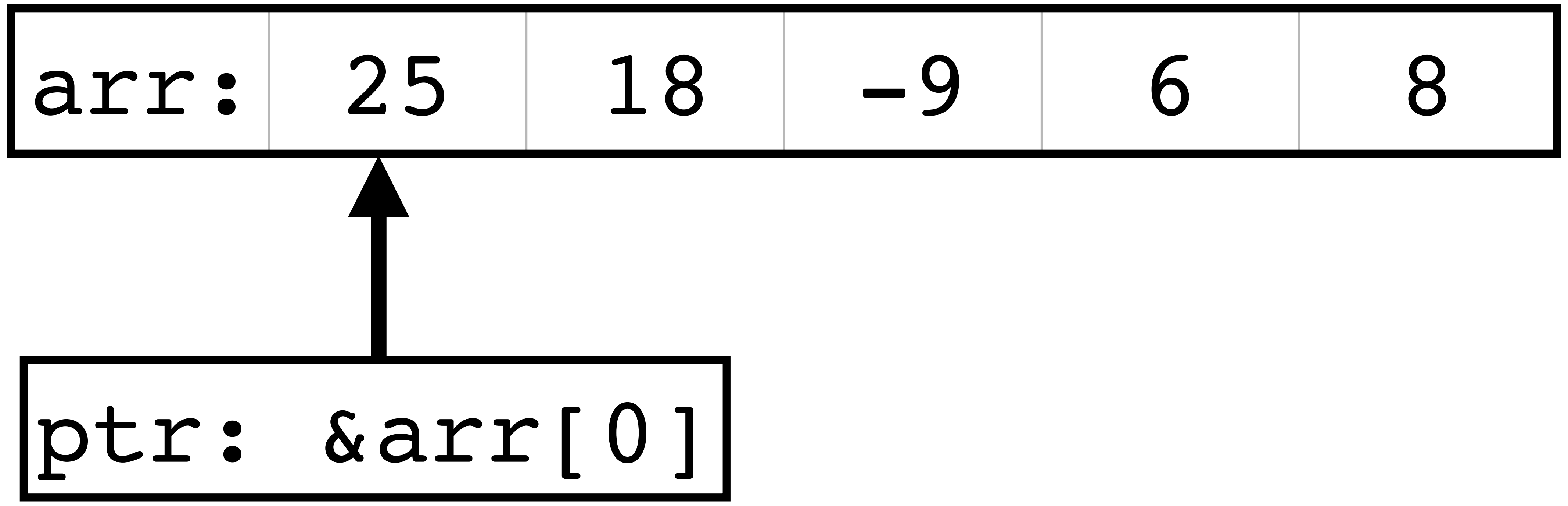
```
arr[0] = 25
arr[1] = 77
arr[2] = -9
```

Pointer arithmetic



Pointer arithmetic

```
int arr[] = { 25, 18, -9, 6, 8 };
int *ptr = arr;
```

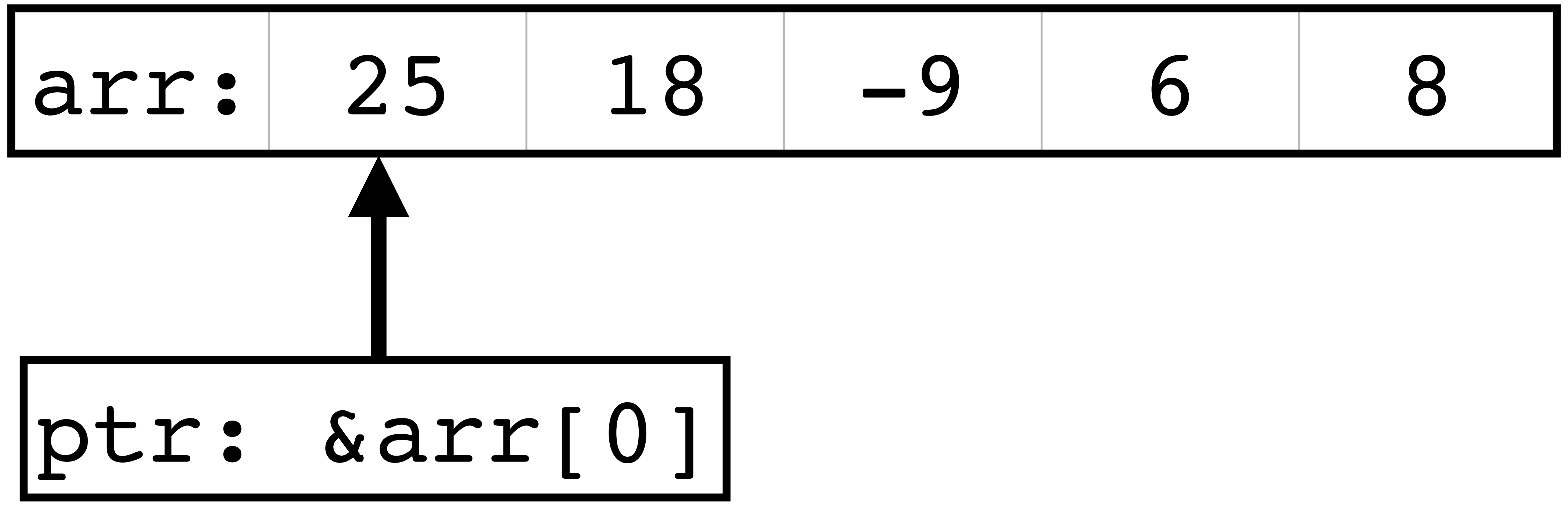


Pointer arithmetic

```
int arr[] = { 25, 18, -9, 6, 8 };
int *ptr = arr;
```

Adding pointers and integers

- `ptr` points to the 0th element of `arr`
- `ptr + 1` points to the 1st element of `arr`
- `ptr + 2` points to the 2nd element of `arr`
- …



Pointer arithmetic

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int arr[] = { 25, 18, -9, 6, 8 };
int *ptr = arr;
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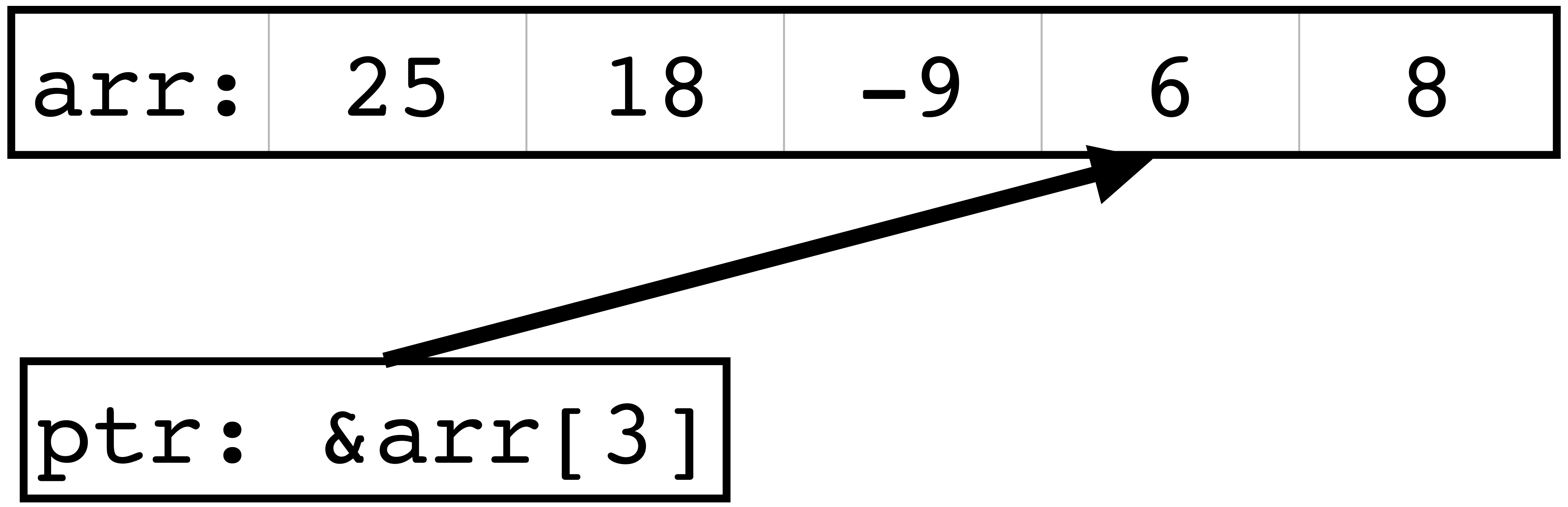
Adding pointers and integers

- `ptr` points to the 0th element of `arr`
- `ptr + 1` points to the 1st element of `arr`
- `ptr + 2` points to the 2nd element of `arr`
- ...

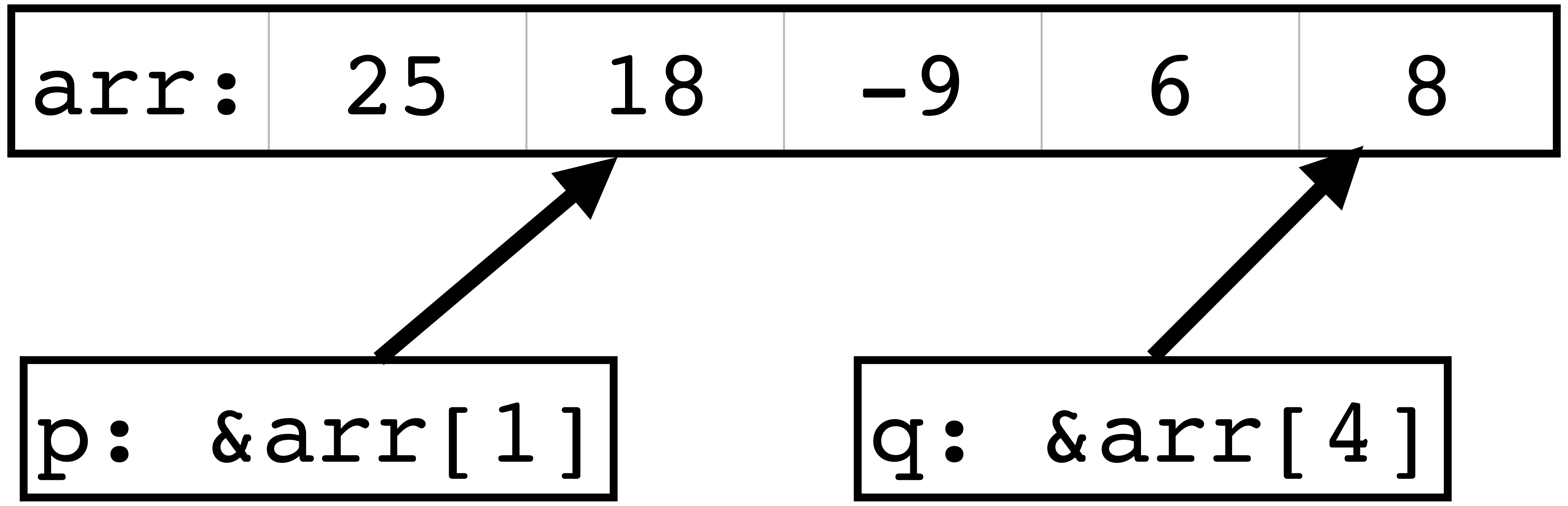
```
ptr += 3;
```



Pointer subtraction

Two pointers into the same array object may be subtracted

```
int arr[] = { 25, 18, -9, 6, 8 };
int *p = &arr[1];
int *q = &arr[4];
ptrdiff_t difference = q - p;
```



Pointer undefined behavior

Pointers into array objects can point at any element of the array *or* just beyond the end of the array

Doing pointer arithmetic to get a different value is UB

- This is a massive source of software vulnerability

> — Addition or subtraction of a pointer into, or just beyond, an array object and an integer type produces a result that does not point into, or just beyond, the same array object (6.5.6).
>
> — Addition or subtraction of a pointer into, or just beyond, an array object and an integer type produces a result that points just beyond the array object and is used as the operand of a unary * operator that is evaluated (6.5.6).

```c
void foo(size_t n, int *p) {
  for (int *end = p + n; p != end; ++p)
    printf("%d\n", *p);
}
void bar() {
  int arr[] = { 0, 5, 4, 8, -8, 100, 0x80 };
  foo(sizeof arr/sizeof arr[0], arr);
} // What does bar do?
```

A. Prints each element of the `arr` array

B. Prints `0` seven times

C. Prints all but the last element of the `arr` array

D. Undefined behavior because end points beyond the end of the array pointed to by `p`

E. Undefined behavior because `arr[0]` is `0` so it divides by 0

Fun pointer facts (read later)

If `x + y` is a pointer, then

- `x[y]` is `*(x + y)` which equals `*(y + x)` which is `y[x]`
- `&x[y]` is `&*(x + y)` [same as `x + y`] which equals `&*(y + x)` which is `&y[x]`

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```c
int arr[10];
for (int i = 0; i < 10; ++i)
  arr[i] = i;

int *p = &arr[4];
int *q = &4[arr];
int *r = &*(arr + 4);
printf("p = %p; *p = %d\n", p, *p);
printf("q = %p; *q = %d\n", q, *q);
printf("r = %p; *r = %d\n", r, *r);

int x = arr[8];
int y = 8[arr];
printf("x = %d; y = %d\n", x, y);
```

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  arr[i] = i;

int *p = &arr[4];
int *q = &4[arr];
int *r = &*(arr + 4);
printf("p = %p; *p = %d\n", p, *p);
printf("q = %p; *q = %d\n", q, *q);
printf("r = %p; *r = %d\n", r, *r);

int x = arr[8];
int y = 8[arr];
printf("x = %d; y = %d\n", x, y);
```

```
p = 0x7ffee6bf31a0; *p = 4
q = 0x7ffee6bf31a0; *q = 4
r = 0x7ffee6bf31a0; *r = 4
x = 8; y = 8
```

Strings

C has no string type

Strings are char arrays where the last byte is 0 (not '0')

- We say C strings are NUL-terminated (or null-terminated)

```
char x[] = "CS 241"; // identical to
char y[] = { 'C', 'S', ' ', '2', '4', '1', 0 };

char *str = "FOO";
  // str is a pointer to the { 'F', 'O', 'O', 0 } array
str = x; // now str points to the x array
```

String literals are read-only

```
// This is valid because it creates a new array object x
char x[] = "CS 2xx";
x[4] = '4';
x[5] = '1';

// This is invalid because the pointer points to a read-only object
char *y = "CS 2xx";
y[4] = '4';  // This will likely crash right here
y[5] = '1';
```

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char *strcat(char *dest, char const *src);
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- Concatenates the string src to dest
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```
int strcmp(char const *s1, char const *s2);
```

- Compares strings s1 and s2 character by character returning a negative if s1 is lexicographically less than, equal to, or greater than s2

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```
size_t strlcpy(char *dest, char const *src, size_t size);
```

- Copies up to `size-1` characters from `src` to `dest` and NUL-terminates
- Returns `strlen(src)` (and you can check that it is less than `size`)

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- Returns `strlen(src)` (and you can check that it is less than `size`)

```
size_t strlcat(char *dest, char const *src, size_t size);
```

- Appends up to `size-strlen(dest)-1` characters from `src` to `dest` and NUL-terminates
- Returns `strlen(dest) + strlen(src)`

Example

```
bool foo(char const *name) {
  char buffer[100];
  size_t size = strlcpy(buffer, "Hello ", sizeof buffer);
  if (size >= sizeof buffer)
    return false;
  size = strlcat(buffer, name, sizeof buffer);
  if (size >= sizeof buffer)
    return false;
  size = strlcat(buffer, "! Welcome.", sizeof buffer);
  if (size >= sizeof buffer)
    return false;
  // buffer now contains "Hello ${name}! Welcome."
}
```

const

We can tell the compiler that data should not be modified

```
int const x = 5;
x = 6; // Invalid because x is declared const
```

The address of non-const variable may be assigned to a pointer to a const but the variable may not be modified via that pointer

```
int y = 28;
int const *p = &y; // Valid
y = 15; // Valid because y isn't const
*p = 6; // Invalid because p is a pointer to const!
```

String literals aren't const (but should be)

Help the compiler help you: always use

```
char const *str = "Foo bar";
```

This makes modification illegal

`str[0] = 'T';` // Invalid because str points to const

Pointer function parameters

If a function has a pointer parameter and it does not modify the data pointed to, make it a pointer to const

- `printf(char const *format, ...);` // doesn't modify format
- `puts(char const *str);` // doesn't modify str
- `strcpy(char *dest, char const *src);` // doesn't modify src
- `strlen(char const *str);` // doesn't modify str

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- `int *const r = &x;` // const pointer to non-const int

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- `int x;`
- `int *p = &x;` // non-const pointer to non-const int
- `int const *q = &x;` // non-const pointer to int const
- `int *const r = &x;` // const pointer to non-const int
- `int const *const s = &x;` // const pointer to int const

In-class exercise

https://checkoway.net/teaching/cs241/2019-fall/exercises/Lecture-15.html

Grab a laptop and a partner and try to get as much of that done as you can!