CS61C

Great Ideas in Computer Architecture
(a.k.a. Machine Structures)

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C Pointers, Arrays, and Strings

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Computing in the News

Hackers Can Make Computers Destroy Their Own Chips with Electricity (New Scientist, 2023-01-19)

https://www.newscientist.com/article/2354844-hackers-can-make-computers-destroy-their-own-chips-with-electricity/

Zitai Chen and David Oswald at the U.K.'s University of Birmingham uncovered a bug in the control systems of server motherboards that could be exploited to compromise sensitive information or to destroy their central processing units (CPUs). The researchers found a feature in the Supermicro X11SSL-CF motherboard often used in servers that they could tap to upload their own control software. Chen and Oswald discovered a flash memory chip in the motherboard's baseboard management controller that they could remotely command to send excessive electrical current through the CPU, destroying it in seconds. After the researchers disclosed the flaw to Supermicro, the company said it has rated its severity as "high" and has patched the bug in its existing motherboards.

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Address vs. Value

- **Consider memory to be a single huge array:**
  - Each cell of the array has an address associated with it.
  - Each cell also stores some value.
  - Do you think they use signed or unsigned numbers? Negative address?!
- **Don't confuse the address referring to a memory location with the value stored in that location.**
- **For now, the abstraction lets us think we have access to ∞ memory, numbered from 0…**

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Pointers

- An address refers to a particular memory location. In other words, it points to a memory location.
- **Pointer**: A variable that contains the address of a variable.

Pointer Syntax

- `int *p;`
  - Tells compiler that variable `p` is address of an `int`
- `p = &y;`
  - Tells compiler to assign address of `y` to `p`
  - `&` called the "address operator" in this context
- `z = *p;`
  - Tells compiler to assign value at address in `p` to `z`
  - `*` called the "dereference operator" in this context

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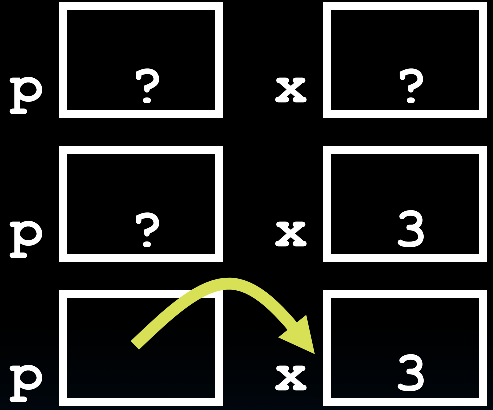
Pointers

- **How to create a pointer:**
  - & operator: get address of a variable

```
int *p, x;

x = 3;

p =&x;
```



Note the "*" gets used 2 different ways in this example. In the declaration to indicate that `p` is going to be a pointer, and in the `printf` to get the value pointed to by `p`.

- **How get a value pointed to?**
  - * "dereference operator": get value pointed to

```
printf("p points to %d\n",*p);
```

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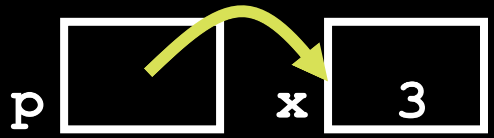
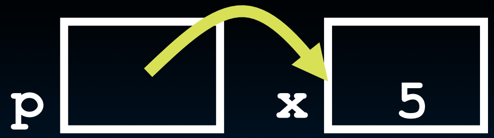
Pointers

- **How to change a variable pointed to?**
  - Use dereference * operator on left of =




```
*p = 5;
```



Pointers and Parameter Passing (1/2)

- **Java and C pass parameters "by value"**
  - procedure/function/method gets a copy of the parameter, so changing the copy cannot change the original

```
void addOne (int x) {
     x = x + 1;
 }
int y = 3;
addOne(y);
```

`y` is still = 3

Pointers and Parameter Passing (2/2)

- How to get a function to change a value?

```
void addOne (int *p) {
    *p = *p + 1;
}
int y = 3;
addOne(&y);
```

`y` is now = 4

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More C Pointer Dangers

- Declaring a pointer just allocates space to hold the pointer – it does not allocate something to be pointed to!
- Local variables in C are not initialized, they may contain anything.
- What does the following code do?

```
void f()
{
    int *ptr;
    *ptr = 5;
}
```


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Pointers in C … The Good, Bad, and the Ugly

- **Why use pointers?**
  - If we want to pass a large struct or array, it's easier / faster / etc. to pass a pointer than the whole thing
    - Otherwise we'd need to copy a huge amount of data
  - In general, pointers allow cleaner, more compact code
- **So what are the drawbacks?**
  - Pointers are probably the single largest source of bugs in C, so be careful anytime you deal with them
    - Most problematic with dynamic memory management—coming up next time
    - Dangling references and memory leaks

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Using Pointers Effectively

Pointers

- Pointers are used to point to **any** data type (`int`, `char`, a `struct`, etc.).
- Normally a pointer can only point to one type (`int`, `char`, a `struct`, etc.).
  - `void *` is a type that can point to anything (generic pointer)
  - Use sparingly to help avoid program bugs… and security issues… and a lot of other bad things!
- You can even have pointers to functions…
  - `int (*fn) (void *, void *) = &foo`
    - `fn` is a function that accepts two `void *` pointers and returns an `int` and is initially pointing to the function `foo`.
  - `(*fn)(x, y)` will then call the function

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Pointers and Structures

```c
typedef struct {
    int x;
    int y;
} Point;

Point p1;
Point p2;
Point *paddr;
```

```c
/* dot notation */
int h = p1.x;
p2.y = p1.y;

/* arrow notation */
int h = paddr->x;
int h = (*paddr).x;

/* This works too */
p1 = p2;
```

NULL pointers...

- The pointer of all 0s is special
  - The "NULL" pointer, like in Java, python, etc...
- If you write to or read a null pointer, your program should crash
- Since "0 is false", its very easy to do tests for null:
  - `if(!p) { /* P is a null pointer */ }`
  - `if(q) { /* Q is not a null pointer */ }`

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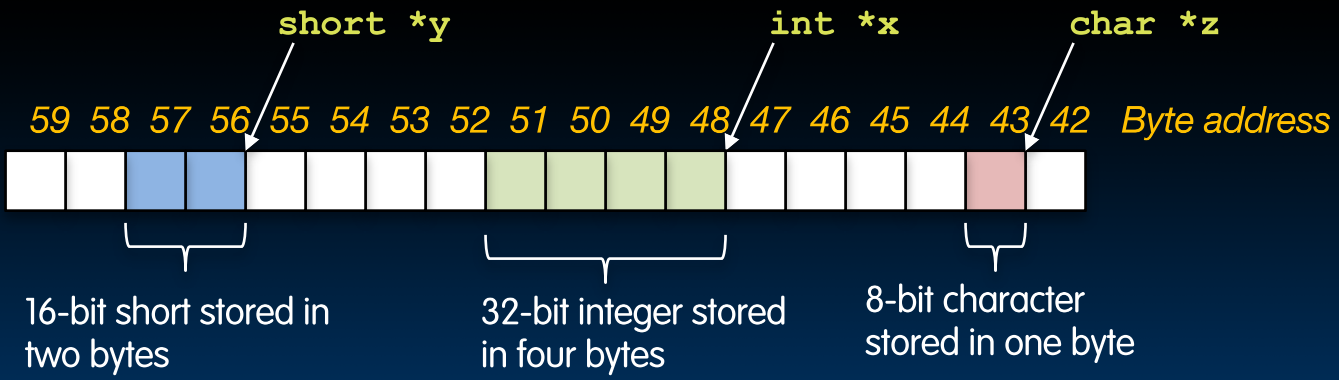
Pointing to Different Size Objects

- **Modern machines are "byte-addressable"**
  - Hardware's memory composed of 8-bit storage cells, each has a unique address
- **A C pointer is just abstracted memory address**
- **Type declaration tells compiler how many bytes to fetch on each access through ptr**
  - E.g., 32-bit integer stored in 4 consecutive 8-bit bytes
- **But we actually want "word alignment"**
  - Some processors will not allow you to address 32b values without being on 4-byte boundaries
  - Others will just be very slow if you try to access "unaligned" memory.



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Arrays

Arrays (1/5)

- **Declaration:**
  - `int ar[2];`
  - …declares a 2-element integer array
  - An array is really just a block of memory
- **Declaration and initialization**
  - `int ar[] = {795, 635};`
  - declares and fills a 2-elt integer array
- **Accessing elements:**
  - `ar[num]`
  - returns the numth element.

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Arrays (2/5)

- Arrays are (almost) identical to pointers
  - `char *string` and `char string[]` are nearly identical declarations
  - They differ in very subtle ways: incrementing, declaration of filled arrays
- **Key Concept**: An array variable is a "pointer" to the first element.

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Arrays (3/5)

- **Consequences:**
  - `ar` is an array variable but looks like a pointer in many respects (though not all)
  - `ar[0]` is the same as `*ar`
  - `ar[2]` is the same as `*(ar+2)`
  - We can use pointer arithmetic to access arrays more conveniently.
- **Declared arrays are only allocated while the scope is valid**

```
char *foo() {
   char string[32]; ...;
   return string;
}
```
is incorrect

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Arrays (4/5)

- Array size n; want to access from 0 to n-1, so you should use counter AND utilize a variable for declaration & incr
  - Wrong

```
int i, ar[10];
for(i = 0; i < 10; i++){ ... }
```

  - Right

```
int ARRAY_SIZE = 10;
int i, a[ARRAY_SIZE];
for(i = 0; i < ARRAY_SIZE; i++){ ... }
```

- Why? SINGLE SOURCE OF TRUTH
  - You're utilizing indirection and avoiding maintaining two copies of the number 10

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Arrays (5/5)

- **Pitfall: An array in C does not know its own length, & bounds not checked!**
  - Consequence: We can accidentally access off the end of an array.
  - Consequence: We must pass the array and its size to a procedure which is going to traverse it.
- **Segmentation faults and bus errors:**
  - These are VERY difficult to find; be careful!
  - You'll learn how to debug these in lab…

Pointer Arithmetic

- **pointer + n**
  - Adds `n*sizeof` ("whatever pointer is pointing to") to the memory address

- **pointer – n**
  - Subtracts `n*sizeof` ("whatever pointer is pointing to") from the memory address

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Pointers (1/4) …review…

- **Java and C pass parameters "by value"**
  - procedure/function/method gets a copy of the parameter, so changing the copy cannot change the original

```
void addOne (int x) {
     x = x + 1;
 }
int y = 3;
addOne(y);
```

`y` is still = 3

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Pointers (2/4) …review…

- How to get a function to change a value?

```
void addOne (int *p) {
    *p = *p + 1;
 }
int y = 3;
addOne(&y);
```

`y` is now = 4

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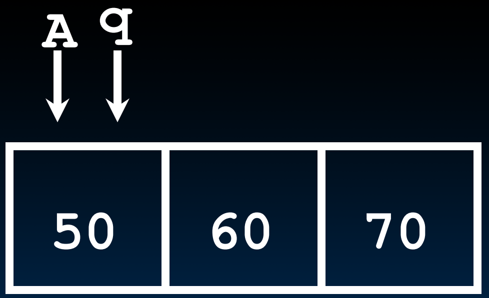
Pointers (3/4)

- **But what if you want to change a pointer?**
  - What gets printed?

```
void IncrementPtr(int  *p)
{    p =  p + 1;    }

int A[3] = {50, 60, 70};
int *q = A;
IncrementPtr( q);
printf("*q = %d\n", *q);
```

*q = 50



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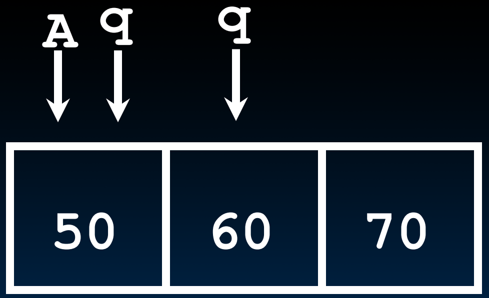
Pointers (4/4)

- **Idea! Pass a pointer to a pointer!**
  - Declared as `**h`
  - Now what gets printed?

```
void IncrementPtr(int **h)
{    *h = *h + 1;    }

int A[3] = {50, 60, 70};
int *q = A;
IncrementPtr(&q);
printf("*q = %d\n", *q);
```

*q = 60



Clicker

Respond at **pollev.com/ddg**

Text **DDG** to **22333** once to join, then **A, B, C, D, E...**

L04 How many syntax+logic errors in this C18 code?

```
void main(); {
  int *p, x=5, y; // init
  y = *(p = &x) + 1;
  int z;
  flip-sign(p);
  printf("x=%d,y=%d,p=%d\n",x,y,p);
}
flip-sign(int *n){*n = -(*n)}
```

0	A
1	B
2	C
3	D
4	E
5	F
6	G

Function Pointer Example

map (actually mutate_map easier)

```
#include <stdio.h>

int x10(int), x2(int);
void mutate_map(int [], int n, int(*)(int));
void print_array(int [], int n);

int x2  (int n) {    return 2*n;     }
int x10(int n) {    return 10*n;    }

void mutate_map(int A[], int n, int(*fp)(int)) {
    for (int i = 0; i < n; i++)
        A[i] = (*fp)(A[i]);
}

void print_array(int A[], int n) {
    for (int i = 0; i < n; i++)
        printf("%d ",A[i]);
    printf("\n");
}
```

```
% ./map
3 1 4
6 2 8
60 20 80
```

```
int main(void)
{
    int A[] = {3,1,4}, n = 3;
    print_array(A, n);
    mutate_map (A, n, &x2);
    print_array(A, n);
    mutate_map (A, n, &x10);
    print_array(A, n);
}
```

And In Conclusion, …

- All data is in memory. Each memory location has an address to use to refer to it and a value stored in it.
- A pointer is a C version of the address.
  - * "follows" a pointer to its value
  - & gets the address of a value
  - Use handles to change pointers
- Arrays don't know their own size and bounds are not checked, careful!

☑

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