# C PROGRAMMING CRASH COURSE

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CS537

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# THE C LANGUAGE IN A NUTSHELL

A statically-typed **systems programming language**.

Developed with (and for) the UNIX operating system.
- Exactly 50 years old this year!

Can be compiled into machine code and executes without a runtime or garbage collector.

Note that there are **different C standards**
- The example code is in “modern” C11
- Some code you encouter in the class might use a different version

# A BASIC C PROGRAM

The main function is invoked at the start of a program

```
int main() {
    char *str = “World”;
    printf(“Hello %s!\n”, str);
    return 0;
}
```

Functions can return a value

The return value of the main function is the exit code of the programs

# Basic Dev Workflow

| **Edit** | **Compile** | **Run** |
|---|---|---|
| `vim mycode.c` | `gcc mycode.c -o mybin` | `./mybin` |

- More complex codebases also need to link binaries together
- Use Makefiles (or similar tools) for bigger projects

# C TYPES AND TYPE CONVERSION

**Variable Declaration**
[type] [name], e.g.:

- `int foo;`
- `char bar;`
- `float xyz;`
- `unsigned long var;`

**Explicit Type Conversion**
Put new type in brackets

```
int a = 5;
char b = (char)a;
```

*Similar style as in Java and C#, which both derived their syntax from C/C++*

# Function Declartion and Definition

```c
int my_func();

int main() {
    return my_func();
}

int my_func() {
    return 0;
}
```

Declares the function **signature** so it can be called

`main` can use `my_func` before it is fully defined*

Defines the actual behavior of the function

*in older C standards functions could be used without being declared but that caused all sorts of issues and is not allowed in modern C

# IMPLICIT TYPE CONVERSION

C automically converts variable types if the new type is larger*

```
char c = 5; // usually 1 byte
int i = 2;  // usually 4 bytes
int result = i+c; // c gets converted to ‘int’
```

**it is a little more nuanced than that but "larger" should be sufficient to understand the behavior in most cases*

# POINTERS

Pointers are references to an address in memory

- Can point to values on the heap, the stack, **or** the program's data segment

**Be careful:** Pointers can be invalid!

- Can point to uninitialized values
- Can point to values outside of the bounds of the processes virtual memory

# POINTER SYNTAX

**Operators**

`&var` - Get the address of a variable

`*var` - De-reference a pointer (get the value the pointer points to)

**Variable Declaration**

- Regular integer: `int i;`
- Pointer to integer: `int *i;`
- Declaring multiple variables: `int *i, j, *k;`
  - i and k are pointers
  - j is a regular integer

# MEMORY ALLOCATION

```
int main() {
    int a = 5;

    int *b = malloc(sizeof(int));

    *b = 5;

    printf("Value is %i", (a + *b));

    free(b);

    return 0;
}
```

variables on the stack stay alive while in scope

malloc() reserves space on the heap

allocated heap space stays reserved until free() is called (or the program terminates)

# POINTERS EXAMPLE

## Code


```c
void func() {
    int a, *b, c, *d;
    a = 3;
    b = &a;
    *b = 4;
    c = *b;
    d = &c;
    *d = *b + 1;
    d = b;
}
```

## Stack

| | |
|---|---|
| a | ?? |
| b | ?? |
| c | ?? |
| d | ?? |

All variables start unitialized with a random value

# POINTERS EXAMPLE

## Code

PC

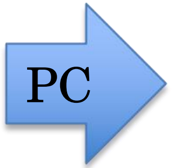
```
void func() {
   int a, *b, c, *d;
   a = 3;
   b = &a;
   *b = 4;
   c = *b;
   d = &c;
   *d = *b + 1;
   d = b;
}
```

## Stack

| | |
|---|---|
| a | 3 |
| b | ?? |
| c | ?? |
| d | ?? |

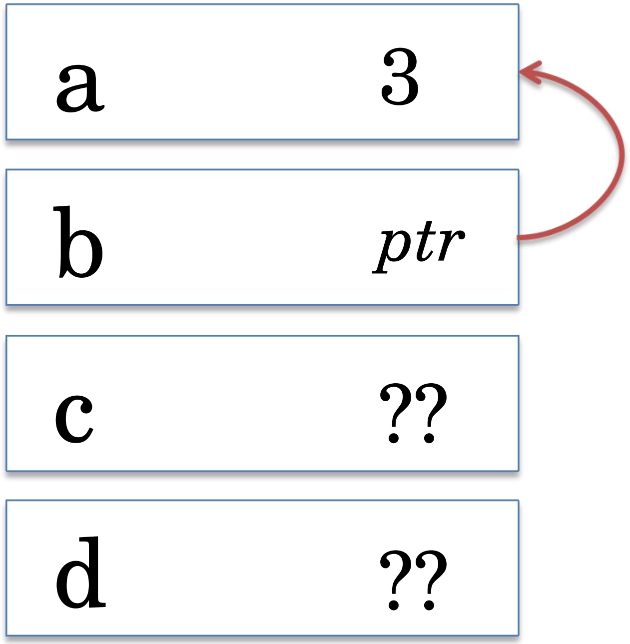
# POINTERS EXAMPLE

## Code




```
void func() {
    int a, *b, c, *d;
    a = 3;
    b = &a;
    *b = 4;
    c = *b;
    d = &c;
    *d = *b + 1;
    d = b;
}
```

## Stack



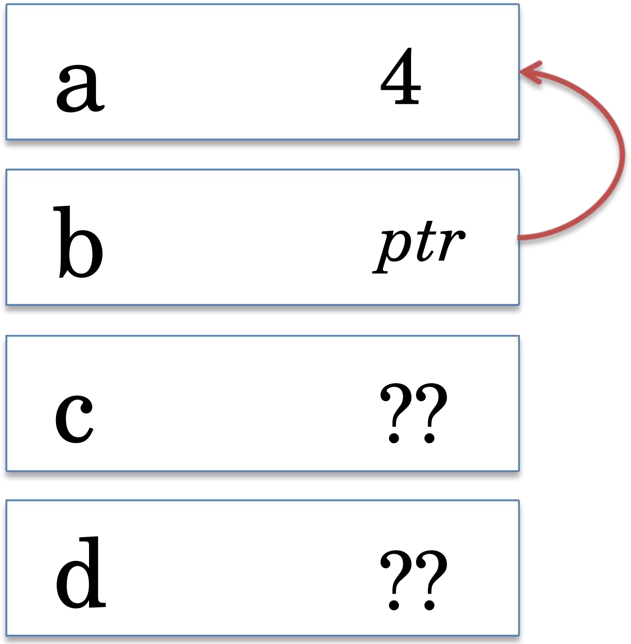

- The & operator gets variable's address
- `b` is now a pointer to `a` (its value is the address of `a`)

# POINTERS EXAMPLE

## Code


```
void func() {
   int a, *b, c, *d;
   a = 3;
   b = &a;
   *b = 4;
   c = *b;
   d = &c;
   *d = *b + 1;
   d = b;
}
```

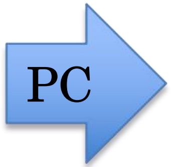
## Stack




The * operater allows modifying the pointers underlying value

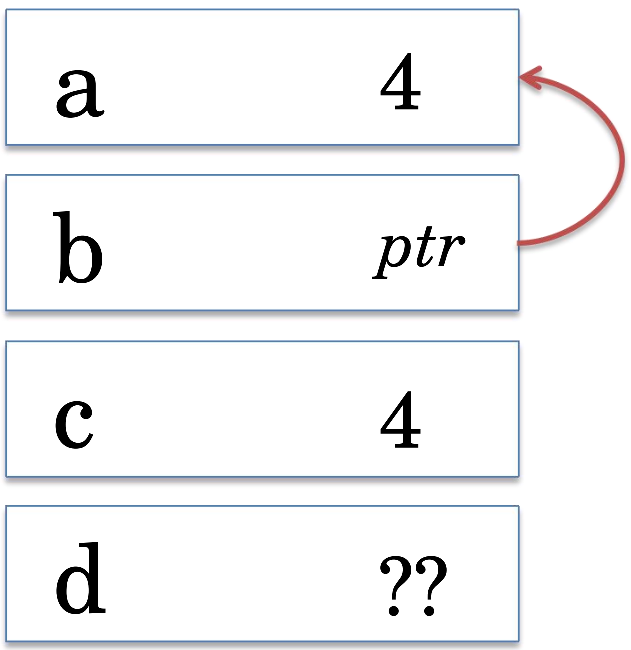
# POINTERS EXAMPLE

## Code




```
void func() {
   int a, *b, c, *d;
   a = 3;
   b = &a;
   *b = 4;
   c = *b;
   d = &c;
   *d = *b + 1;
   d = b;
}
```

## Stack



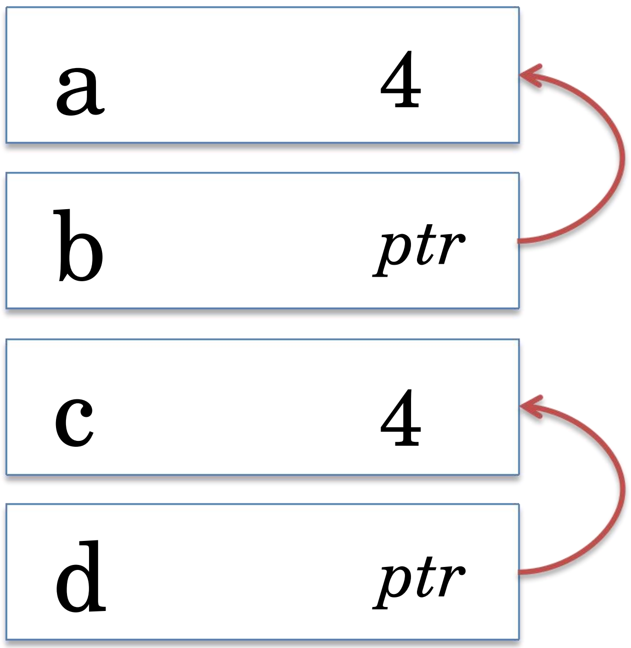

The * operater allows accessing the pointers underlying value

# POINTERS EXAMPLE

## Code


```
void func() {
    int a, *b, c, *d;
    a = 3;
    b = &a;
    *b = 4;
    c = *b;
    d = &c;
    *d = *b + 1;
    d = b;
}
```

## Stack

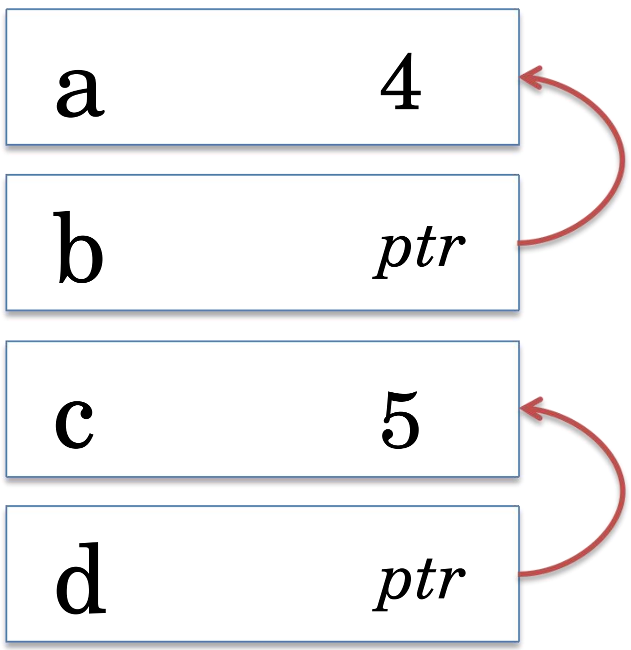


# POINTERS EXAMPLE

## Code


```
void func() {
   int a, *b, c, *d;
   a = 3;
   b = &a;
   *b = 4;
   c = *b;
   d = &c;
   *d = *b + 1;
   d = b;
}
```

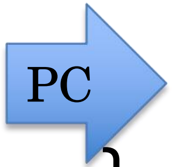
## Stack



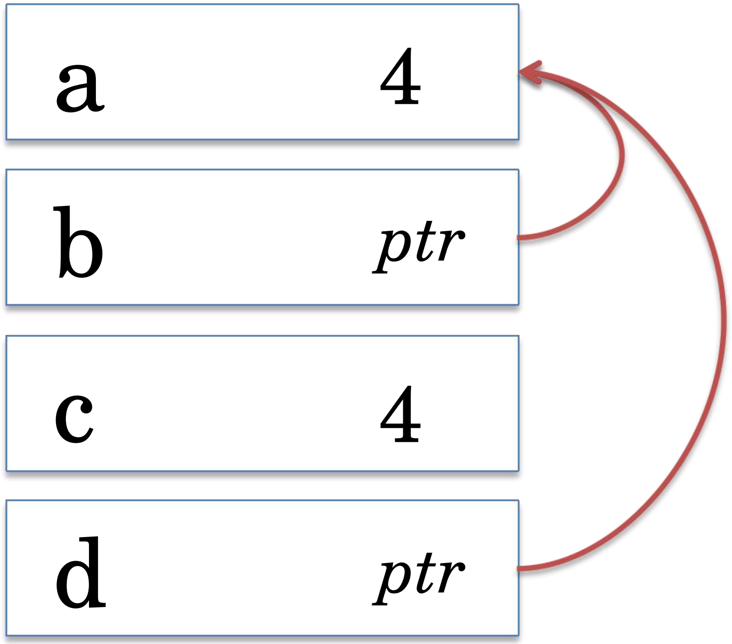
# POINTERS EXAMPLE

## Code

```
void func() {
   int a, *b, c, *d;
   a = 3;
   b = &a;
   *b = 4;
   c = *b;
   d = &c;
   *d = *b + 1;
   d = b;
}
```




## Stack




- You can always change pointers to point to something else
- d now points to a instead of c

# ARRAYS

Arrays on the stack:

```
bool array1[42];
```

Arrays on the heap:

```
bool *array2 = malloc(sizeof(bool)*42);
```

Both arrays are accessed the same way:

```
array1[5] = true;
array2[3] = false;
```

# ARRAYS (CONT.)

```
int *i = {5, 3, 7};
```

is the same as

```
int i[] = {5, 3, 7};
```

and the same as

```
int i[3] = {5, 3, 7};
```

# COMMON ERROR 1

Call free on an array stored on the stack

```
void func() {
   int *i = {1, 2, 3};
   [...]
   free(i);
}
```

i will automatically be deallocated when `func` terminates

every `malloc()` must have a matching `free()` and vice-versa

# MEMORY MANIPULATION

```
int memcmp(const void *p1, const void *p2, size_t n)
```

- Compares the content of two memory regions of size n
- Make sure both pointers are valid and the memory regions are at least `n` bytes long

```
void* memcpy(void *dest, const void *src, size_t n)
```

- Compies the first `n` bytes of `src` to `dest`
- Make sure you allocate a memory region for `dest` before calling this function

# POINTER MANIPULATION

```
char *mystring = “foobar”;

char first_char = *mystring

// move pointer by sizeof(char)
mystring = mystring+1;

char second_char = *mystring;
```

# PROBLEM 1: POINTER MANIPULATION

```
int numbers[] = {1, 2, 3, 4};

int *ptr = &numbers[1];
      var = *(ptr+2) + 1;
```

What is the type and value of var?

What is the type and value of var?

`var == 5`

# Problem 2: Memory Manipulation

```
float numbers1[] = {1.0, 2.0, 3.0, 4.0};
float numbers2[2];

memcpy(numbers2, numbers1, 2*sizeof(float));
numbers1[1] += 5.0f;
```

What is the final value of `numbers2`?

`{1.0, 2.0}`
the increment only affects the value in `numbers1`

# COMMON ERROR 2

Call free() on pointer with non-zero offset

```
int *ptr = malloc(16);
int *ptr2 = ptr+1;

free(ptr2); // wrong

free(&ptr[1]); // wrong

free(ptr); // correct
```

# EXPLICIT POINTER CONVERSION

```
float f = 1.0f;

// Converts float pointer to char pointer
char *float_ptr = (char*)&f;

// Gets the first byte of the float
char first_byte = float_ptr[0];

// Gets the second byte of the float
char second_byte = *(float_ptr + 1);
```

# IMPLICIT POINTER CONVERSION

- `void*` can be implicitly converted to any pointer
  - `malloc` returns `void*`!
- Useful if the type of the underlying data is not known

```
// does not compile
int i = 0;
bool *ptr = &i;
```

```
// compiles
int i = 0;
void *ptr2 = (void*) &i;
bool *ptr = ptr2;
```

# COMMON ERROR 3

Casting integer to pointers

```
int i = 0;
char *ptr = (char*)i;

// might crash
ptr[0] = ‘a’;
// will definitely crash
free(ptr);
```

There are some legitimate reasons for this, but most projects should not need it

# POINTER ARGUMENTS

```c
void set_value(int *var) {
    *var = 1;
}

int main() {
    int my_var = 0;
    set_value(&my_var);
    [...]
    return 0;
}
```

C always passes arguments **by value**

- their value is copied to a new variable
- pointers allow passing a reference instead

# PROBLEM 3: POINTER ARGUMENTS

```
void function(int *val) {
    int i = 1;
    val = &i;
}

int main() {
    int a=5, b=3;
    int *ptrs[] = {&a, &b};
    function(ptrs[0]);
    return a;
}
```

What is the return value of main?

**5**
(val is passed by value and a is never updated)

# POINTING TO POINTERS

```
void create_array(int **ptr, int len) {
    *ptr = malloc(sizeof(int)*len);
}

int main() {
    int *array;
    create_array(&array, 42);
    [...]
    free(array);
    return 0;
}
```

# FUNCTION POINTERS

```
void increment(int* val) {
    *val += 1;
}

void decrement(int* val) {
    *val -= 1;
}
```

Both Functions have the same **signature**

# FUNCTION POINTERS (CONT.)

```
void (*func)(int*) = increment;
int val = 1;

// Increment `val`
func(&val);

// Set to different function
func = decrement;

// Decrement `val`
func(&val);
```

**func** stores the address to increment

the value of **func** can be changed like other variables

# C STRINGS

**Stack-Allocated Strings**

```
char* mystring = “cs537”;
```

**Dynamically-Allocated Strings**

```
char* mystring = malloc(6);
strcpy(mystring, “cs537”);
```

# STRINGS ARE NULL-TERMINATED

```
char *mystring = “cs537”;
```

is the same as

```
char *mystring =
   {‘c’, ‘s’, ‘5’, ‘3’, ‘7’, ‘\0’};
```

NULL-termination allows **detecting the end** when traversing a string

# PROBLEM 4: STRINTG TERMINATION

```
#include “string.h”

int main() {
   char *str = {‘x’,‘\0’,‘y’,’z’};
   printf(“%s”, str);
   return 1;
}
```

What is the output of this program?

**“x”**
print will only insert the string up to the NULL-byte

# STRING MANIPULATION

```
size_t strlen(char *str)
```
Get the length of a string (including NULL)

```
int strcmp(const char *str1, const char *str2)
```
Compares the content of two strings and returns 0 if they are equal

```
char* strcpy(char *dest, const char *src)
```
Compares the content of two strings and returns 0 if they are equal

# PROBLEM 5: STRING COPY

```
#include “string.h”

int main() {
    char *str1 = “hello world”;
    char str2[6];

    strcpy(str2, str1+6);
    printf(“%s\n”, str2);

    return 0;
}
```

What is the console output of this program?

**“world”**
Only the second word is copied

# IMPLICIT BOOLEAN CONVERSION

```
int a = 1;
int b = 0;

if (a) {
   // this branch will be executed
}


if (!b) {
   // this branch will also be executed
}
```

integers != 0
evaluate as true

integers == 0
evaluate as false

# IMPLICIT BOOLEAN CONVERSION (POINTERS)

```
int a = 1;
int *ptr1 = &a;
int *ptr2 = NULL;

if (ptr1) {
    // this branch will be executed
}


if (!ptr2) {
    // this branch will also be executed
}
```

pointers != NULL
evaluate as true

pointers == NULL
evaluate as false

# PROBLEM 6: BOOLEAN CONVERSION

```
int main() {
    char var = 0;
    char *ptr = &var;

    if (var || ptr) {
        printf(“A\n”);
    } else {
        printf(“B\n”);
    }
    return 0;
}
```

What is the console output of `main()`?

**“A”**

`ptr` is not `NULL` and evaluates to `true`

# STRUCTURES

```c
struct student {
   int age;
   float gpa;
};

void func() {
   struct student s;
   s.age = 21;
   s.gpa = 4.0f;
}
```

C is not an object-oriented language

- Struct do not have methods
- No inheritance or interfaces

But, object-like functionality can be implemented combining structs and function pointers.

# UNIONS

```
union my_union {
    int val1;
    char val2;
    bool val3;
};

void func() {
    union myunion u;
    u.val1 = 5;
}
```

Union can be any *one* of its fields

**Be careful:**
Initializing one field and then accessing another on the same union is undefined behavior!

# The Preprocessor

- Runs before the compiler
- Not a Turing-complete language
- Only supports text replacement and basic if statements

```
#define WINDOWS

#if defined WINDOWS
   [win-specific code]
#elif defined UNIX
   [unix-specific code]
#else
   #error “Unknown OS”
#endif
```

# PREPROCESSOR CONSTANTS

We can use the preprocessor to define constants

```
#define NUMBER 5
int my_value = NUMBER;
```

But in modern C it is better to use the const keyword

```
const int NUMBER = 5;
int my_value = NUMBER;
```

# THATS ALL, FOR NOW

There are many things we did not cover, including

- type definitions
- switch statements
- inline assembly
- static and extern keywords
- volatile variables
- enumerations
- various legacy features
  (e.g., K&R function declarations)
- threading and synchronization primitives

# THATS ALL, FOR NOW

All problems are on github
https://github.com/kaimast/c-crashcourse

For more in-depth coverage of C, take a look at these textbooks.