A Recap of the C Programming Language

Computational Science II (CAAM 520)

Christopher Thiele

Rice University, Spring 2021

Overview

Before we start using C for our purposes, we will review

- variable initialization,
- pointers,
- segmentation faults,
- pointers and structures,
- pointers to pointers, etc.,
- void pointers and casts,
- function pointers,
- arrays, and
- dynamic memory allocation.

Variable initialization

Variables must be initialized ***explicitly***!

```
int i = 123;
int k;

printf("%d\n", i);
printf("%d\n", k); // Undefined result!
```

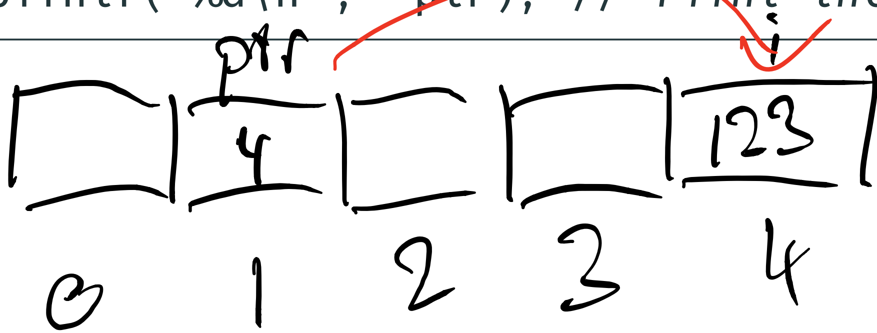
Pointers

Pointers are variables that store the address of another variable.

```
int i;
int *ptr = &i;

i = 123;

printf("%p\n", ptr);  // Print the address of i.
printf("%d\n", *ptr); // Print the value of i.
```



Pointers

Variables can be modified through pointers.

```
int i;
int *ptr = &i;

*ptr = 123;

printf("%p\n", ptr);  // Print the address of i.
printf("%d\n", *ptr); // Print the value of i.
```

Pointers

Typical use case: output arguments

```c
int foo()
{
  return 123;
}
```

vs.

```c
void foo(int *result)
{
  *result = 123;
}
```

Pointers

Typical use case: output arguments

Particularly useful for multiple output arguments and when using error codes!

```
int divide(int x, int y,
           int *quotient, int *remainder)
{
  if (y == 0) return -1;

  *quotient = x/y;
  *remainder = x%y;
  return 0;
}
```

Pointers

Like other variables, pointers must be initialized!

```
int *ptr;

// Undefined behavior, likely a segmentation fault!
*ptr = 123;
```

Pointers

We use `NULL` to indicate invalid pointers.

```
int *ptr = NULL;

// ...

// Check if pointer is valid.
if (ptr) { // Equivalent to ptr != NULL
  // ...
}

// Check if pointer is invalid.
if (!ptr) { // Equivalent to ptr == NULL
  // ...
}
```

Pointers

Pointers to structures allow more convenient notation.

```
typedef struct
{
  int i;
} my_struct_t;

void init(my_struct_t *s)
{
  (*s).i = 123;
  // Equivalent, but more convenient:
  s->i = 123;
}
```

Pointers

Pointers can point to variables of any type, including other pointers.

```
int i = 123, *ptr, **ptrptr;

ptrptr = &ptr;
*ptrptr = &i;

// Print value of ptrptr/address of ptr.
printf("%p\n", ptrptr);
// Print value of ptr/address of i.
printf("%p\n", *ptrptr);
// Print value of i.
printf("%d\n", **ptrptr);
```

Pointers

Why would we need pointers to pointers?

Pointers

int i, j *max

Why would we need pointers to pointers?

E.g., for functions that need have pointers as output arguments.

```
void ptr_max(const int *i, const int *k, int **max)
{
  if (*i > *k) {
    *max = i;
  }
  else {
    *max = k;
  }
}
```

Pointers

Constant pointers and pointers to constant things:

```
int i;

// What does each declaration do?
int *ptr1 = &i;
const int *ptr2 = &i;
int *const ptr3 = &i;
const int *const ptr4 = &i;
```

Pointers

Void pointers represent generic memory addresses. They can point to variables whose type is unknown.

```
int i;

void *ptr = &i;

// Error: Compiler does not know that ptr
// points to an integer!
*ptr = 123;

// We must cast void pointers before
// dereferencing them.
*((int*) ptr) = 123;
```

Pointers

Why would we need void pointers?

Pointers

Why would we need void pointers?

E.g., for functions that operate on data of any type:

```
// Copy any type of data.
void* memcpy(void *dst, const void *src, size_t n)

// Allocate and deallocate memory.
void* malloc(size_t size)
void free(void *ptr)
```

Pointers

Caution: C and C++ handle void pointers slightly differently!

```
// The following works *only* in C:
int *ptr = malloc(sizeof(int));

// In C++ we must cast explicitly.
int *ptr = (int*) malloc(sizeof(int));
```

→ It might be a good idea to cast, as someone else could use our C code in their C++ project.

Function pointers

We can create pointers to functions as well:

```
int add(int i, int k) { return i + k; }

// ...

// Create a pointer to the add function.
int (*add_fptr)(int, int) = add;

// Call add through the pointer.
add_fptr(3, 7);
```

→ Notice the parentheses in the function pointer declaration!

Arrays

C supports arrays of fixed size and any type:

```
int array[16];

// Indices start at zero!
for (int i = 0; i < 16; i++) {
  array[i] = i;
}

// What does this do?
array[16] = 123;
// How about this?
array[12345] = 123;
```

→ Be very careful with indices!

Arrays

Arrays of characters (strings) are particularly common and useful.

```
const char string[] = "hello, world!"; \0

printf("%d\n", strlen(string)); // 13
printf("%d\n", sizeof(string)); // 14 – why?
```

Dynamic memory allocation

We can allocate "arrays" ***dynamically***.

→ Technically, arrays and pointers to allocated memory are ***not*** the same, but the differences are negligible for our purposes.

```
int *array = (int*) malloc(n*sizeof(int));

if (!array) { // Equivalent to array == NULL
  fprintf(stderr, "Error: Allocation failed!\n");
  return -1;
}

// We can access the array as usual.
array[n - 1] = 123;
```

Dynamic memory allocation

Other ways to (re)allocate memory dynamically:

```
// Allocates *uninitialized* memory:
void* malloc(size_t size)

// Allocates memory and sets it to zero:
void* calloc(size_t num, size_t size)

// Reallocates memory, i.e., if we need more:
void* realloc(void *ptr, size_t new_size)
```

Dynamic memory allocation

If memory is allocated, it must be deallocated with `free()`.

```
int *array = (int*) malloc(n*sizeof(int));

// Deallocate memory.
free(array);
```

If memory is not released when it is no longer used, we have a ***memory leak***!

→ Why are leaks problematic?

Dynamic memory allocation

Example 1: Memory is allocated repeatedly, but never deallocated.

```
for (int i = 0; i < 16; i++) {
  int *array = (int*) malloc(n*sizeof(int));

  // Work with array in the loop.

  // free() is missing.
}
```

Dynamic memory allocation

Example 2: Memory is allocated, but the programmer is not aware of it.

```
char* get_message()
{
  char *msg = (char*) malloc(64);
  strcpy(msg, "hello, world!");
  return msg;
}
```

Dynamic memory allocation

Rule of thumb: For each call to `malloc()`, `calloc()`, or `realloc()`, there must be a matching call to `free()`.

Note to C++ programmers:

- If memory was allocated with `new`, it ***must*** be deallocated with `delete`.
- If memory was allocated with `malloc()`, `calloc()`, or `realloc()`, it ***must*** be deallocated with `free()`.

Pointer arithmetic

C allows arithmetic with pointers:

```
int *array = (int*) malloc(16*sizeof(int));

// Access 7th element.
array[6] = 123;
// Equivalently:
*(array + 6) = 123;
```

→ For `int*`, pointer arithmetic works in increments of `sizeof(int)` etc.

Pointer arithmetic

C allows arithmetic with pointers:

```
int *array = (int*) malloc(16*sizeof(int));

int *ptr = &array[3];
ptr += 3;
--ptr;          array[5]

// Which element does this set?
*ptr = 123;
```