JTSK-320111

Programming in C I

C-Lab I

Lecture 5 & 6

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This Week's Agenda

- Pointers and arrays
- Dynamic memory allocation
- Multi-dimensional arrays
- Recursive functions
- Dealing with larger projects
- Handling files
- Revision

Passing Arrays to Functions

- An array does not store its size
- This has to be provided as a parameter, or by making assumptions on the contents of the array (like for strings)
- When an array is passed to a function, a copy of the address of the first element is given
- Modifications to the elements are seen outside
- Modifications to the array are not seen outside
- Can you explain why?

Passing Arrays to Functions: Example

domain of the array or name of array is always a pointer

```
#include <stdio.h>
#include <stdlib.h>
void strange_function(int v[], int dim) {
  int i;
  for (i = 0; i < dim; i++)
    v[i] = 287;
  // v = (int *) malloc(sizeof(int) * 1000);
}
int main() {
  int array[] = {1, 2, 9, 16};
  int *p = &array[0];
  strange_function(array, 4);
  printf("%d %x %x\n", array[0], p, array);
}
```

int ** v

(&array,4)

destroying previous array and assign new values to old array
you are not returning any array so the array modification is not destroyed

**v
double pointer is used to change adress of an adress (or the adress of array)in the function replace v[] with **v

you can use %p instead of %x as both print hexadecimal

Dynamic Memory Allocation

for example int a[50] or char[50] is static i.e can't be changed during computation it is called static memory allocation. Dynamic on the other hand is flexible e.g not only depending on user input only but also depending on data type change , increase or decrease, from double to int and vice versa, also size of array can be changed later in code i.e from 50 to 10 and vice versa

- What if we do not know the dimension of the array while coding?
- Dynamic memory allocation allows you to solve this problem
  - And many others
  - But can also cause a lot of troubles if you misuse it

Pointers and Arrays

There is a strong relation between pointers and arrays

- Indeed an array is nothing but a pointer to the first element in the sequence
- We are looking at this in detail

Specifying the Dimension on the Fly

To specify the dimension on the fly you can use the `malloc()` function defined in the header file `stdlib.h`

always use free (ptr) allocation needs to be deallocated at one point memory is runout

```
#include <stdio.h>
#include <stdlib.h>
int main() {
  int *dyn_array, how_many, i;
  printf("How many elements? ");
  scanf("%d", &how_many);
  dyn_array =
    (int*) malloc(sizeof(int) * how_many);
  if (dyn_array == NULL)
    exit(1);
  for (i = 0 ; i < how_many; i++) {
    printf("\nInput number %d:", i);
    scanf("%d", &dyn_array[i]);
  } return 0;
}
```

exit , malloc and free are inside stdlib.h

if the allocation is not successful then null is returned duento allocationg more than physically finite memory

malloc it is amount of bytes , not amount of elements

for char you can remove size of (char) as it is= 1

NULL is a special value or macro

The `malloc()` Function (1)

malloc for allocating the memory
..see man alloc in linux
it is an unsigned int i.e memory cant be negative i.e always +ve
void pointer is a special type of pointer and can be converted
generic or any type pointer. void * malloc . malloc always
returns a pointer

- `void * malloc(unsigned int);`
- `malloc` reserves a chunk of memory
- The parameter specifies how many bytes are requested
- `malloc` returns a pointer to the first byte of such a sequence
- The returned pointer must be forced (cast) to the required type

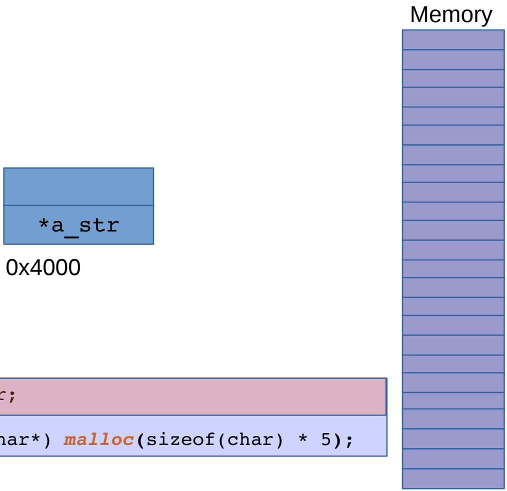
The malloc() Function (2)

```c
pointer    = (cast) malloc(number of bytes);


char* a_str;
a_str = (char*) malloc(sizeof(char) * how_many);
```

- `malloc` returns a `void *` pointer (i.e., a generic pointer) and this is assigned to a non `void *` pointer
- If you omit the casting you will get a warning concerning a possible incorrect assignment

Dynamically Allocating Space for an Array of `char`

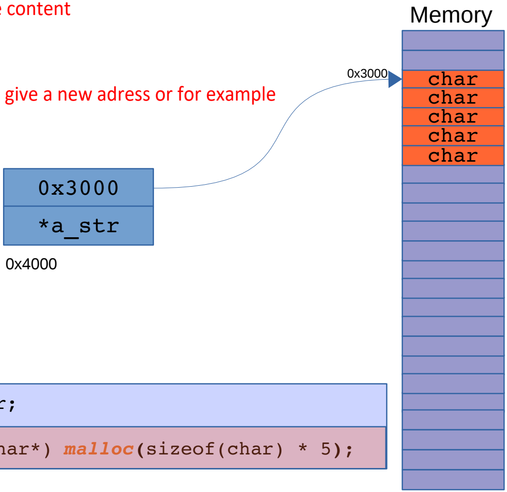



```c
char *a_str;
a_str = (char*) malloc(sizeof(char) * 5);
```

Dynamically Allocating Space for an Array of `char`

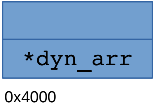
how to change the adress of the content
a_str = &some;
char some = 3;

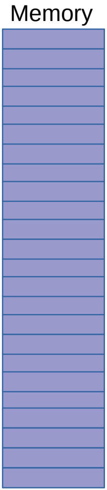
or you can do another malloc to give a new adress or for example
you can do this: a_str = 0x573
*(p +4) is equivalent to p[4]
*p is equivalent to p[0]




```
char *a_str;
a_str = (char*) malloc(sizeof(char) * 5);
```

Dynamically Allocating Space for an Array of `int`

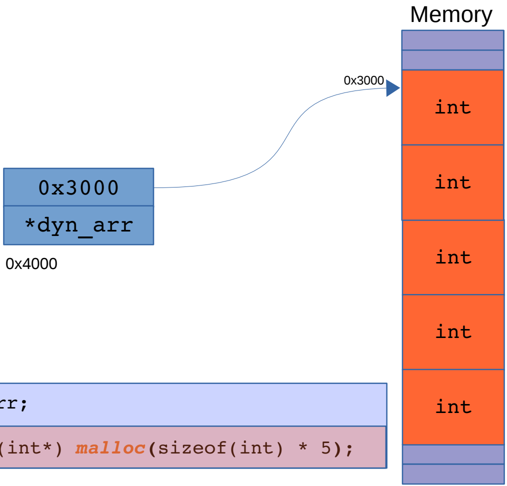





```
int *dyn_arr;

dyn_arr = (int*) malloc(sizeof(int) * 5);
```

Dynamically Allocating Space for an Array of `int`




```
int *dyn_arr;
dyn_arr = (int*) malloc(sizeof(int) * 5);
```

malloc() and free()

- All the memory you reserve via `malloc`, must be released by using the `free` function
- If you keep reserving memory without freeing, you will run out of memory

```
float *ptr;
int number;
...
ptr = (float*) malloc(sizeof(float) *
 number);
...
free(ptr);
```

Rules for `malloc()` and `free()`

- The following points are up to you (the compiler does not perform any control)
  1. Always check if `malloc` returned a valid pointer (i.e., not `NULL`)
  2. Free allocated memory just once
  3. Free only dynamically allocated memory
- Not following these rules will cause endless troubles
- `sizeof()` is compile time operator, it does not work on allocated memory

int * a = (int *) malloc (sizeof(int) * n);
sizeof (a) will not give number of elements but will give adress of first element

Review: Pointers, Arrays, Values

```c
#include <stdio.h>
#include <stdlib.h>
int length[2] = {7, 9};
int *ptr1, *ptr2; int n1, n2;
int main() {
  ptr1 = &length[0];
  // &length[0] is pointer to first elem
  ptr2 = length;
  // length is pointer to first elem therefore
  // same as above
  n1 = length[0];
  // length[0] is value
  n2 = *ptr2;
  // *ptr2 is value therefore same as above
  printf("ptr1: %p, ptr2: %p\n", ptr1, ptr2);
  printf("n1: %d, n2: %d\n", n1, n2);
  return 0;
}
```

Multi-dimensional Arrays

- It is possible to define multi-dimensional arrays
  - Mostly used are bidimensional arrays, i.e., tables or matrices
- As for arrays, to access an element it is necessary to provide an index for each dimension
  - Think of matrices in mathematics

Multi-dimensional Arrays in C

- It is necessary to specify the size of each dimension
  - Dimensions must be constants
  - In each dimension the first element is at position 0

```c
int matrix[10][20];    /* 10 rows, 20 cols */
float cube[5][5][5];   /* 125 elements */
```

- Every index goes between brackets

```c
matrix[0][0] = 5;
```

Multi-dimensional Arrays in C: Example

```
#include <stdio.h>
int main() {
  int table[50][50];
  int i, j, row, col;
  scanf("%d", &row);
  scanf("%d", &col);
  for (i = 0; i < row; i++)
    for (j = 0; j < col; j++)
      table[i][j] = i * j;
  for (i = 0; i < row; i++)
  {
    for (j = 0; j < col; j++)
      printf("%d ", table[i][j]);
    printf("\n");
  }
  return 0;
}
```

The `main` Function (1)

- Can return an `int` to the operating system
  - Program exit code (can be omitted)
  - print exit code in shell: `$> echo $?`
- Can accept two parameters:
  - An integer (usually called `argc`)
  - A vector of strings (usually called `argv`)
  - `argc` specifies how many strings contains `argv`

The main Function (2)

```
#include <stdio.h>
int main(int argc, char *argv[]) {
  int i;
  for (i = 1; i < argc; i++)
    printf("%d %s\n", i, argv[i]);
  return 0;
}
```

- Compile it and call the executable `paramscounter`
- Execute it as follows:

  `$> ./paramscounter first what this`
- It will print first, what and this, one word per line
- Note that argc is always greater or equal than one
- The first parameter is the program's name

The `const` Keyword

- The modifier `const` can be applied to variable declarations
- It states that the variable cannot be changed
  - i.e., it is not a variable but a constant
- When applied to arrays it means that the elements cannot be changed

const Examples

```
const double e = 2.71828182845905;
const char str[]= "Hello world";
e = 3;           /* error */
str[0] = 'h';    /* error */
```

- You can also use `#define` of the preprocessor
- But defines do not have type checking, while constants do

More `const` Examples

- `const char *text = "Hello";`
  - Does not mean that the variable `text` is constant
  - The data pointed to by `text` is a constant
  - While the data cannot be changed, the pointer can be changed
- `char *const name = "Test";`
  - `name` is a constant pointer
  - While the pointer is constant, the data the pointer points to may be changed
- `const char *const title = "Title";`
  - Neither the pointer nor the data may be changed

Recursive Functions (1)

- Can a function call other functions?
  - Yes, indeed function calls appear only inside other functions (and everything starts with the execution of `main`)
- Can a function call itself?
  - Yes, but in this case special care should be taken
- A function which calls itself is called a **recursive function**
- Function A calls function A
- At a certain point function B calls A
  - A calls A then A calls A then A calls A ...
- When coding recursive functions attention should be paid to avoid endless recursive calls

Recursive Functions (2)

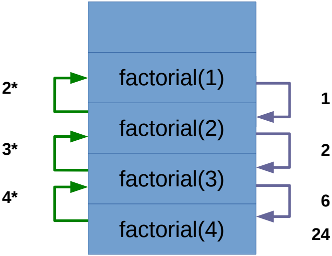
- Recursion theory can be studied for a longer time: here we will just scratch its surface from a basic coding standpoint
- Every recursive function must contain some code which allows it to terminate without entering the recursive step
  - Usually called **inductive base** or **base case**
- When recursion is executed, the new call should be driven "towards the inductive case"

Stack of Calls: Example (1)

```c
int factorial(int n) {
  if ((n == 0) || (n == 1))
    return 1;
  else
    return n * factorial(n - 1);
}
```

LIFO last in first out
stack is introduced in cs computer architecture
there is an associated stack with a program
in internal stack it will memporise all steps of factorial

disadvantages: takes a lot of memory to form stack and in the code it is easy to make a mistake as it is hard to come up and implement the formula



Stack of Calls: Example (2)

From the `main`: call `factorial(4)`

factorial(1): n = 1, printf("base"), return 1

factorial(2): n = 2, printf(2), val = 2 * factorial(1), printf(val), return val

factorial(3): n = 3, printf(3), val = 3 * factorial(2), printf(val), return val

factorial(4): n = 4, printf(4), val = 4 * factorial(3), printf(val), return val

~~factorial(1): n = 1~~, printf("base"), return 1

~~factorial(2): n = 2, printf(2), val~~ = 2 * 1, printf(2), return 2

~~factorial(3): n = 3, printf(3), val~~ = 3 * 2, printf(6), return 6

~~factorial(4): n = 4, printf(4), val~~ = 4 * 6, printf(24), return 24

Tracing the Stack of Calls

```
int factorial(int n) {
  int val;
  if ((n == 0) || (n == 1)) {
    printf("base\n");
    return 1;
  } else  {
    printf("called with par = %d\n", n);
    val = n * factorial(n - 1);
    printf("returning %d\n", val);
    return val;
  }
}
int main() {
  printf("%d\n", factorial(4));
  return 0;
}
```

One More Example: Fibonacci Numbers

$$F(N) = \begin{cases} 1, & N \leq 1 \\ F(N-1) + F(N-2), & N > 1 \end{cases}$$

```
int fibonacci(int n) {
  if ((n == 0) || (n == 1))
    return 1;
  else
    return fibonacci(n-1) + fibonacci(n-2);
}
```

Dealing with Big Projects

- Functions are a first step to break big programs in small logical units
- A further step consists in breaking the source into many files
  - Smaller files are easy to handle
  - Objects sharing a context can be put together and easily reused
- C allows to put together separately compiled files to have one executable

Declarations and Definitions

- **Declaration**: introduces an object. After declaration the object can be used
  - Example: functions' prototypes
- **Definition**: specifies the structure of an object
  - Example: function definition
- Declarations can appear many times, definitions just once

Building from Multiple Sources

- C compilers can compile multiple sources files into one executable
- For every declaration there must be one definition in one of the compiled files
  - Indeed also libraries play a role
  - This control is performed by the linker
- `gcc -o name file1.c file2.c file3.c`

Libraries

- Libraries are collection of compiled definitions
- You include header files to get the declarations of objects in libraries
- At linking time libraries are searched for unresolved declarations
- Some libraries are included by `gcc` even if you do not specifically ask for them

Linking Math Functions: Example

```
#include <math.h>
#include <stdio.h>

int main() {
  double n;
  double  sn;

  scanf("%lf\n", &n); /* double needs %lf */
  sn = sqrt(n);
  /* conversion from double to float ok */
  printf("Square root of %f is %f\n", n, sn);
}

    gcc -lm -o compute compute.c
```

Compilers, Linkers and More

- Different compilers differ in many details
  - Libraries names, ways to link against them, types of linking
- Check your documentation
- But preprocessing, compilation and linking are common steps

File Handling in C

- Input and output can come from/go into files
- C treats files as streams of data
- A stream is a sequence of bytes (either incoming or outgoing)
- The language does not provide basic constructs for file handling, but rather the standard library does

Files, C and UNIX

- The file view of C is influenced by UNIX
- UNIX sees everything as a file
- You have already used two files/streams
  - `stdin` (standard input): associated with the keyboard
  - `stdout` (standard output): associated with the screen
  - These files are always tied to your program by the operating system

Working with Files

- The paradigm is the following:
  - open the file
  - read/write from/into file
  - close the file
- In C the information concerning a file are stored in a `FILE` structure (i.e., `struct`) defined in `stdio.h`

File Modes

Streams can be handled in two modes: (only important for MS Windows)

- Text streams: sequence of characters logically organized in lines. Lines are terminated by a newline ('\n')
  - Sometimes pre/post processed
  - Example: text files
- Binary streams: sequence of raw bytes
  - Examples: images, mp3, user defined file formats, etc.

Opening a File

- To open a file the `fopen` function is used
  ```
  FILE *fopen(const char * name, const char * mode)
  ```
- `name`: name of the file (OS level)
- `mode`: indicates the type of the file and the operations that will be performed
  ```
  FILE *fptr;
  fptr = fopen("myfile.txt", "r");
  ```

Mode Strings

String	Meaning
`"r"`	Open for reading, positions at the beginning
`"r+"`	Open for reading and writing, positions at the beginning
`"w"`	Open for writing, truncate if exists, positions at the beginning
`"w+"`	Open for reading and writing, truncate if exists, positions at the beginning
`"a"`	Open for appending, does not truncate if exists, positions at the end
`"a+"`	Open for appending and writing, does not truncate if exists, positions at the end

A `b` or a `t` can be added to indicate it is a binary/text file

Closing a File

- `int fclose(FILE *fp);`
- Forgetting to close a file might result in a loss of data
- After a file is closed it is not possible anymore to read/write

```
FILE *fptr;
fptr = fopen("myfile.txt", "r");
if (fptr == NULL) {
  printf("Some error occurred!\n");
  exit(1);
}
...
/* do some operations */
fclose(fptr);
...
```

Reading/Writing

Prototype	Use
`int getc(FILE *fp)`	Returns next `char` from `fp`
`int putc(int c, FILE *fp)`	Writes a `char` to `fp`
`int fscanf(FILE* fp, char * format, ...)`	Gets data from `fp` according to the format string
`int fprintf(FILE* fp, char * format, ...)`	Outputs data to `fp` according to the format string

Line Input and Line Output

```
char *fgets(char *line, int max, FILE *fp);
```

- Already seen with `stdin`
- Used for files as well

```
int fputs(char *line, FILE *fp);
```

- Outputs/writes a string to a file

Files: Example 1

```c
#include <stdio.h>
#include <stdlib.h>
int main() {
  char ch;
  FILE *fp;
  fp = fopen("file.txt", "r");
  if (fp == NULL) {
    printf("Cannot open file!\n");
    exit(1);
  }
  ch = getc(fp);
  while (ch != EOF) {
    putchar(ch);
    ch = getc(fp);
  }
  fclose(fp);
  return 0;
}
```

Files: Example 2

```c
# include <stdio.h>
# include <stdlib.h>
int main () {
  char ch;
  FILE * fp;
  fp = fopen("file.txt", "r") ;
  if (fp == NULL) {
    printf("Cannot open file!\n");
    exit(1);
  }
  while((ch=getc(fp))!=EOF) {
    putchar(ch);
  }
  fclose(fp);
  return 0;
}
```

Files: Example 3

```c
# include <stdio.h>
# include <stdlib.h>
int main () {
  char ch;
  FILE * fp;
  fp = fopen("file.txt", "r") ;
  if (fp == NULL) {
    printf("Cannot open file!\n");
    exit(1);
  }
  while(!feof(fp)) {
    ch=getc(fp);
    if (ch!=EOF)
      putchar(ch);
  }
  fclose(fp);
  return 0;
}
```

Revisiting: Casting

- It is possible to overcome standard conversions (casting)
- To force to a different data type, put the desired data type before the expression to be converted
  `(type name) expression`
- Casting is a unary operator with high precedence

Revisiting: Casting – Example

```
int a;
float f1 = 3.456, f2 = 1.22;
/* these operations imply demotions */
a = (int) f1 * f2;     /* a is now 3 */
a = (int) (f1 * f2);  /* a is now 4 */
```

- You have already used casting when using `malloc`. `malloc` returns a `void *` pointer (i.e., a generic pointer) and this is assigned to a non `void *` pointer
- If you omit the casting you might get a warning concerning a possible incorrect assignment

Revisiting: String Functions

- Defined in `string.h`
- `strlen` determines the length of a string
- `strcat` concatenates two strings
- `strcpy` copies one string into another
- `strcmp` compares two strings
- `strchr` searches a char in a string
- `strdup` duplicates a string
- See man pages (`man 3 string`) or section B3 in the Kernighan & Ritchie book

Revisiting: `void *`

- `void *` is a generic pointer holding a memory address
  - `malloc` returns a `void *`, thus the need for a cast
- Every pointer can be assigned to a `void *` pointer and vice versa, without explicit casts
  - This can create big problems

Revisiting: Misusing void*

```
int main(void) {
  void * vp;    /* a generic pointer */
  int * ip;
  float f = 1.234,
  float * fp = &f;
  vp = fp;
  ip = vp;
  /*  float * assigned to int *
      via a generic pointer
      this will not work correctly ...
  */
  printf("%d\n", *ip);
  /* outputs some strange number */
  return 0;
}
```

Examples Revisited (1)

```
char a_string[] = "This is a string\0";
char *p;
int count = 0;
int main() {
  printf("%s\n", a_string);
  for (p = &a_string[0]; *p != '\0'; p++)
    count++;
  printf("The string has %d chars\n", count);
  p--;
  printf("Printing the reverse string:\n");
  while (count > 0) {
    printf("%c", *p);
    p--;
    count--;
  }
  return 0;
}
```

Examples Revisited (2)

To specify the dimension on the fly you can use the `malloc` function defined in the header file `stdlib.h`

```
...
int *dyn_array, how_many, i;
printf("How many elements? ");
scanf("%d", &how_many);
dyn_array = (int*) malloc(sizeof(int) *
  how_many);
if (dyn_array == NULL)
  exit(1);
for (i = 0 ; i < how_many; i++) {
  printf("\nInput number %d:", i);
  scanf("%d", &dyn_array[i]);
}
...
```

Examples Revisited (3) – Reading from the Keyboard

```
#include <stdio.h>
int main() {
  int v;
  char str[30];
  char line[80];
  printf("Enter a string: ");
  fgets(line, sizeof(line), stdin);
  sscanf(line, "%s", str);  // not really needed
  // just read str directly

  printf("Enter a number: ");
  fgets(line, sizeof(line), stdin);
  sscanf(line, "%d", &v);
  printf("String: %s\n", str);
  printf("Number: %d\n", v);
  return 0;
}
```

Conversion Specification for `printf()`

Conversion	**Meaning**
`%c`	single character
`%d`	signed decimal integer
`%f`	double (also float)
`%e`	floating point (exponential notation)
`%s`	string (pointer needs to be passed)

Conversion Specification for `scanf()`

Conversion	**Meaning**
as above	
`%f`	float (decimal notation)
`%lf`	double (decimal notation)

Final Exam: Details

- Information about exact time and location of the final exam will follow
- Programming exercises to be solved on paper
  - You have two hours to solve exercises
  - Similar to the programming assignments
  - Practice to write your programs on paper
- You do not need paper, it will be provided
- You may not use books or other documentation while taking the exam
- You may not use mobile phones, calculators or any other electronic devices