CH-230-A

Programming in C and C++

C/C++

Tutorial 4

Dr. Kinga Lipskoch

Fall 2020

Dynamic Memory Allocation

- 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`

```
#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;
}
```

The `malloc()` Function (1)

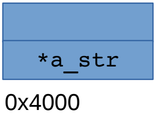
- `void * malloc(unsigned int);`
- `malloc` reserves a chunk of memory
- The parameter specifies how many bytes are requested
- `malloc` returns a pointer to the first byte of such a sequence
- The returned pointer must be forced (cast) to the required type

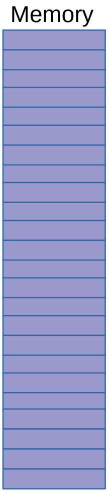
The malloc() Function (2)

```
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

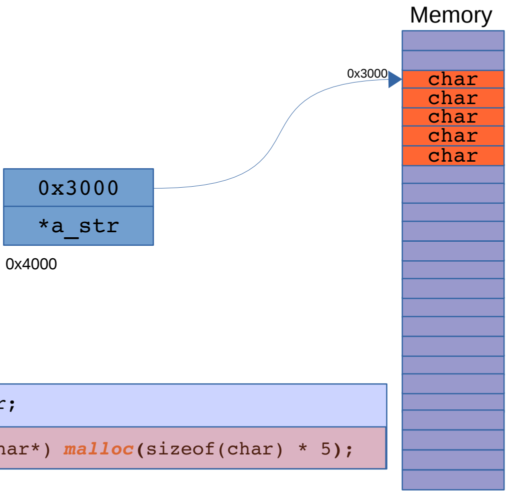
Dynamically Allocating Space for an Array of `char`





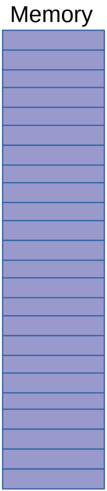

```
char *a_str;

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

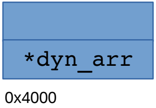
Dynamically Allocating Space for an Array of `char`




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

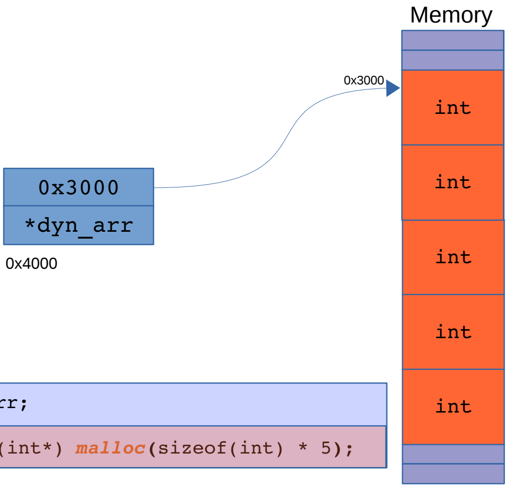
Dynamically Allocating Space for an Array of `int`






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

Dynamically Allocating Space for an Array of `int`




```c
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

Review: Pointers, Arrays, Values

```c
#include <stdio.h>
#include <stdlib.h>
int main() {
  int length[2] = {7, 9};
  int *ptr1, *ptr2; int n1, n2;
  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

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

- Every index goes between brackets

```
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)

```c
#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

Pointers and Arrays

- Ex:
```c
char array[5];
char *array_ptr1 = &array[0];
char *array_ptr2 = array;
// the same as above
```
- C allows pointer arithmetic:
  - Addition
  - Subtraction
- `*array_ptr` equivalent to `array[0]`
- `*(array_ptr+1)` equivalent to `array[1]`
- `*(array_ptr+2)` equivalent to `array[2]`
- What is `(*array_ptr)+1`?

Locating a Matrix Element in the Memory

- Consider the following
  `int table[ROW][COL];`
  where `ROW` and `COL` are constants
- `table` holds the address of the pointer to the first element
- `*table` holds the address of the first element
- What is the address of `table[i][j]`?
  `*(table + (i * COL + j))`
- One can determine the formula for an arbitrary multidimensional array with a similar pattern to the one above

Pointer Arithmetic with Arrays

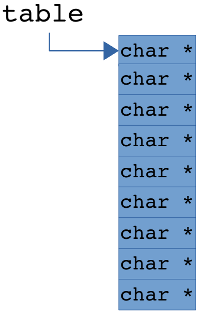
```c
#include <stdio.h>
#define ROW 2
#define COL 3
int main() {
  int arr[ROW][COL] = { {1, 2, 3}, {11, 12, 13} };
  int i = 1;
  int j = 2;
  int* p = (int*) arr;          // needs explicit cast
  printf("Address of [1][2]: %p\n", &arr[1][2]);
  printf("Address of [1][2]: %p\n", p + (i * COL + j));
  printf("Value of [1][2]: %d\n", arr[1][2]);
  printf("Value of [1][2]: %d\n", *(p + (i * COL + j)));
  printf("\n");
  printf("Address of [0][0]: %p\n", p + (0 * COL + 0));
  printf("Address of [0][1]: %p\n", p + (0 * COL + 1));
  printf("Address of [0][2]: %p\n", p + (0 * COL + 2));
  printf("Address of [1][0]: %p\n", p + (1 * COL + 0));
  printf("Address of [1][1]: %p\n", p + (1 * COL + 1));
  printf("Address of [1][2]: %p\n", p + (1 * COL + 2));
  return 0;
}
```

Variably Sized Multidimensional Arrays

- Unidimensional arrays can be allocated "on the fly" using the `malloc()` function
- Possible also for multidimensional arrays, but more tricky
- Underlying idea: a pointer can point to the first element of a sequence
- A pointer to a pointer can then point to the first element of a sequence of pointers
  - And each of those pointers can point to first element of a sequence

Pointers to Pointers for Multidimensional Arrays (1)

- Consider the following
  `char **table;`
- We can make table to point to an array of pointers to `char`
  `table = (char **) malloc(sizeof(char *) * N);`
- Every element in the array of `N` rows is a `char*`

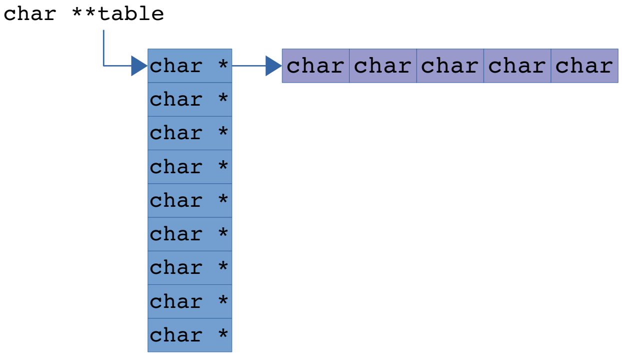


Pointers to Pointers for Multidimensional Arrays (2)

- Every pointer in the array can in turn point to an array
- In this way a two-dimensional array with `N` rows and `M` columns has been allocated

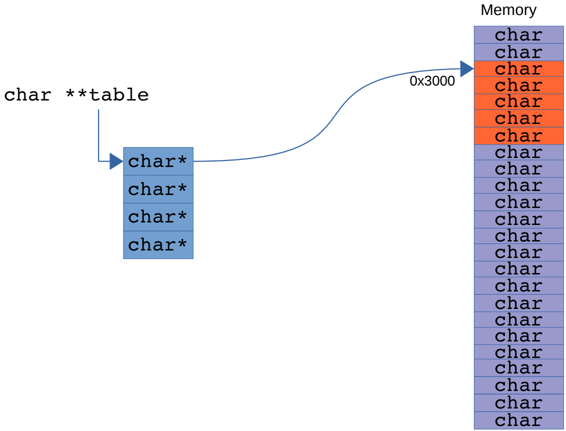
```
for (i = 0; i < N; i++)
  table[i] = (char *) malloc(sizeof(char) * M);
```

Pointers to Pointers for Multidimensional Arrays (3)



To access a generic element in the dynamically allocated matrix a matrix-like syntax can be used. Let us see why ...

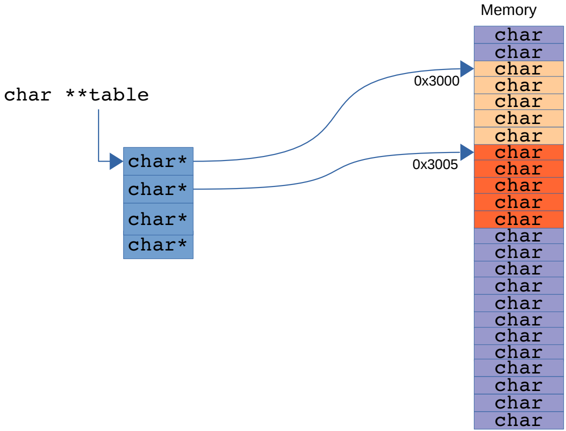
Allocating Space for a Multidimensional Array (1)



Case i=0

```c
for (i = 0; i < 4; i++)
  table[i] = (char *) malloc(sizeof(char) * 5);
```

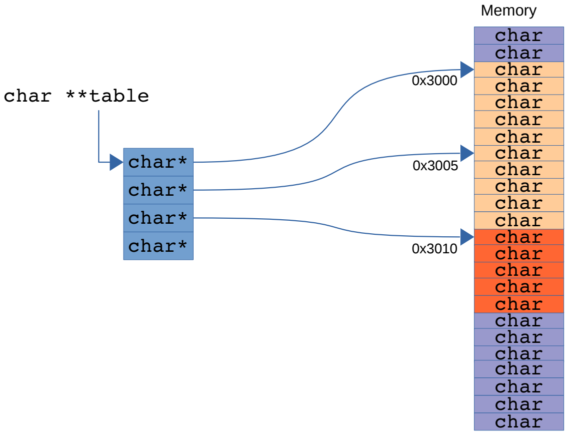
Allocating Space for a Multidimensional Array (2)



Case i=1

```
for (i = 0; i < 4; i++)
  table[i] = (char *) malloc(sizeof(char) * 5);
```

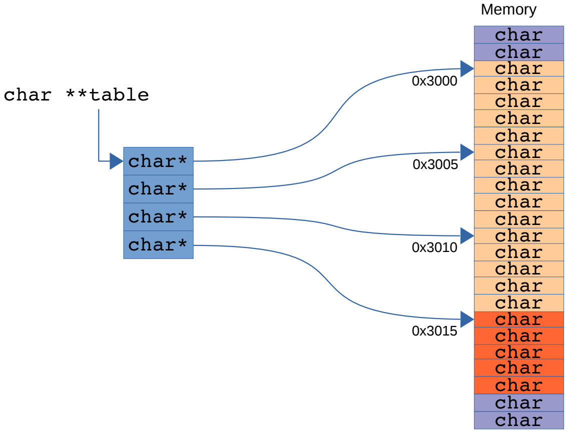
Allocating Space for a Multidimensional Array (3)



Case i=2

```
for (i = 0; i < 4; i++)
  table[i] = (char *) malloc(sizeof(char) * 5);
```

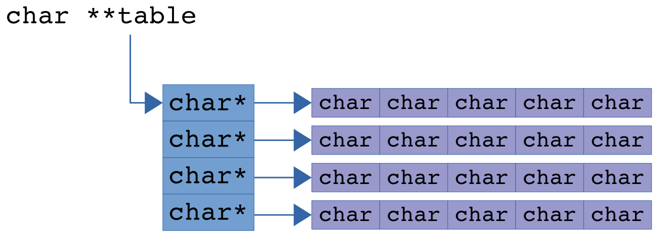
Allocating Space for a Multidimensional Array (4)



Case i=3

```
for (i = 0; i < 4; i++)
  table[i] = (char *) malloc(sizeof(char) * 5);
```

Drawing Memory in a Different Way: The Result is a Table




```
for (i = 0; i < 4; i++)
  table[i] = (char *) malloc(sizeof(char) * 5);
```

De-allocating a Pointer to Pointer Structure

- Everything you have allocated via `malloc()` must be de-allocated via `free()`
- Ex: De-allocation of a 2D array with `N` elements

```
int i;
for (i = 0; i < N; i++)
  free(table[i]);
free(table);
```

Working with 2D Dynamic Arrays

```
#include <stdio.h>
#include <stdlib.h>
void set_all_elements(int **arr, int numrow, int numcol) {
  int r, c;
  for (r = 0; r < numrow; r++)
    for (c = 0; c < numcol; c++)
      arr[r][c] = r * c;  // some value ...
}
int main() {
  int **table, row;
  table = (int **) malloc(sizeof(int *) * 3);
  if (table == NULL)
    exit(1);
  for (row = 0; row < 3; row++) {
    table[row] = (int *) malloc(sizeof(int) * 4);
    if (table[row] == NULL)
      exit(1);
    }
    set_all_elements(table, 3, 4);
}
```

Static vs. Dynamic Array Allocation (1)

- `int a[n][m]` leads to an index offset calculation using the known array dimensions
- `int **a` treats `a` as an array `int *[]` and once indexed the result as an array of `int []`
- Statically allocated arrays occupy less memory
- Pointers to pointers allow tables where every row can have its own dimension
- One can have pointers to pointers to pointers (e.g., `int ***`) to have 3D data structures

Static vs. Dynamic Array Allocation (2)

- Static allocation
  - `int a[100][50]; int b[n][m];`
  - Syntax for allocation is easy
  - Release/reallocation not possible at runtime
  - Allocated memory is contiguous
- Dynamic allocation
  - `int **a; int *b[100], int ***c; ...`
  - Call(s) of `malloc` is needed
  - Syntax for allocation is more difficult
  - Release/reallocation possible at runtime using `free`, `realloc`
  - Allocated memory can be, but in general is not contiguous
- Passing arrays to functions: `static_dyn_allocation.c`
- Further reading/study:
  https://www.cse.msu.edu/~cse251/lecture11.pdf