4. Functions, Recursion, Call by Value

4. Functions, Recursion, Call by Value

4.1. Functions and their parameters

- Blocks of code can sometimes re-use the same variables and need to be used throughout a program
- For example calculating the maximum of two integers:

```
int maximum = 0, a = 12, b = 10;
{
  if (a > b) {
    maximum = a;
  } else {
    maximum = b;
  }
}
// maximum now holds the value of a or b, whichever is largest
```

4.1. Functions and their parameters: Declaring Functions

- Before you can use (call) a function, you have to declare it (similar to how we have to declare variables before use).
- A function declaration contains a return type, function name, and parameters, example:

```
int maximum( int a, int b );
```

- You typically declare *and* implement the function before **`main()`**, example:

```
int maximum( int a, int b ) {
  if (a > b) {
    return a;
  } else {
    return b;
  }
}
```

4.1. Functions and their parameters: Declaring Functions

- With each function call, formal parameters need actual parameters, *unless* the function prototype has default values:

```cpp
#include <iostream>  // output to the console
#include <cstdint>  // we're using the uint16_t type
void drawLine(char symbol = '-', uint16_t len = 25) {
  for (auto line = 0; line < len; line++) std::cout << symbol;
  std::cout << std::endl;
}
int main() {
  drawLine();  // writes 25 times the '-' symbol to console
  drawLine(50);  // writes 50 times the '-' symbol to console
  drawLine('=', 9);  // writes 9 times the '=' symbol to console
  return 0;
}
```

4. Functions, Recursion, Call by Value

4.1. Functions and their parameters: Declaring Functions

- Functions can call other functions, allowing cycles:
  function **a()** calls **b()**, **b()** calls **a()**
  → In this case, declarations need to come first, example:

```
int a();  // declaration of function a()
int b();  // declaration of function b()
int a() {  // implementation of function a():
  std::cout << "Yes" << std::endl;
  return b();
}
int b() {  // implementation of function b():
  std::cout << "No"<< std::endl;
  return a();
}
```

4. Functions, Recursion, Call by Value

4.1. Functions and their parameters: Declaring Functions

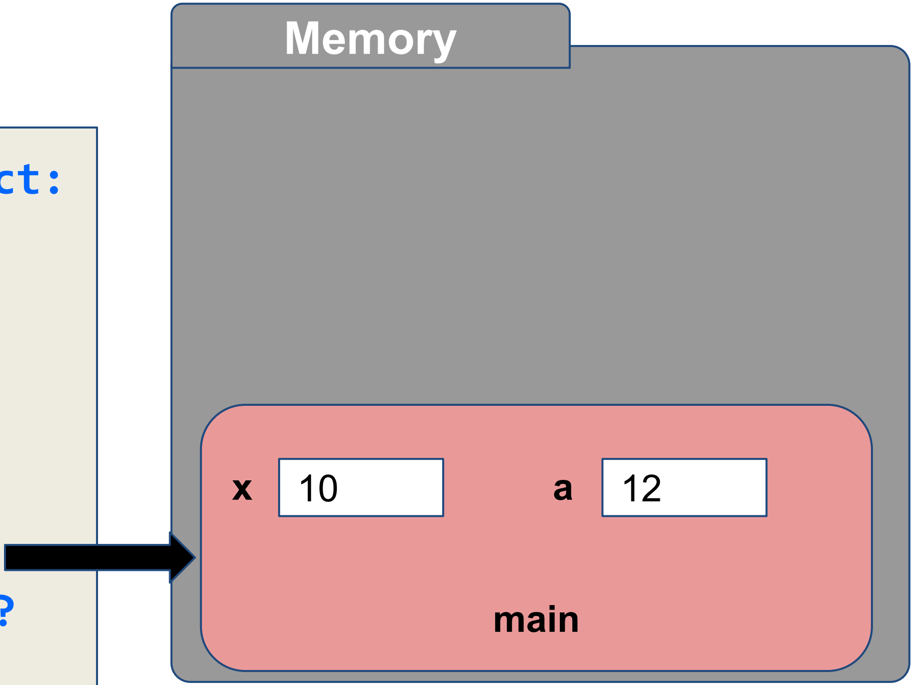
- A function declaration can have *parameters*: variables that obtain a value when the function is called and that are treated as local variables in the implementation of the function
- A function can have a return type. If not, we use `void` → Is this a type?

```
void printMaximum( int a, int b ) {  // a and b are parameters
  if (a > b) {              // a and b can be used as variables of
    std::cout << a;         // type integer in the implementation of
  } else {                  // the function
    std::cout << b;
  }
  std::cout << std::endl;    // note that we don't return anything
}
```

4.1. Functions and their parameters: Using Functions

- A function is *called*:

```
// declare & implement myFunct:
int myFunct(int b, int a) {
  a = 2 * b + a * a;
  return a + 1;
}
// now we can call myFunct:
int main() {
  int x = 10; int a = 12;
  a = myFunct(a, x+1);  // a?
  return 0;
}
```



A stack is created in memory, in which the function's local variables are stored

4. Functions, Recursion, Call by Value

4.1. Functions and their parameters: Using Functions

- A function is *called*:

```
// declare & implement myFunct:
int myFunct(int b, int a) {
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}
// now we can call myFunct:
int main() {
  int x = 10; int a = 12;
  a = myFunct(a, x+1);  // a?
  return 0;
}
```

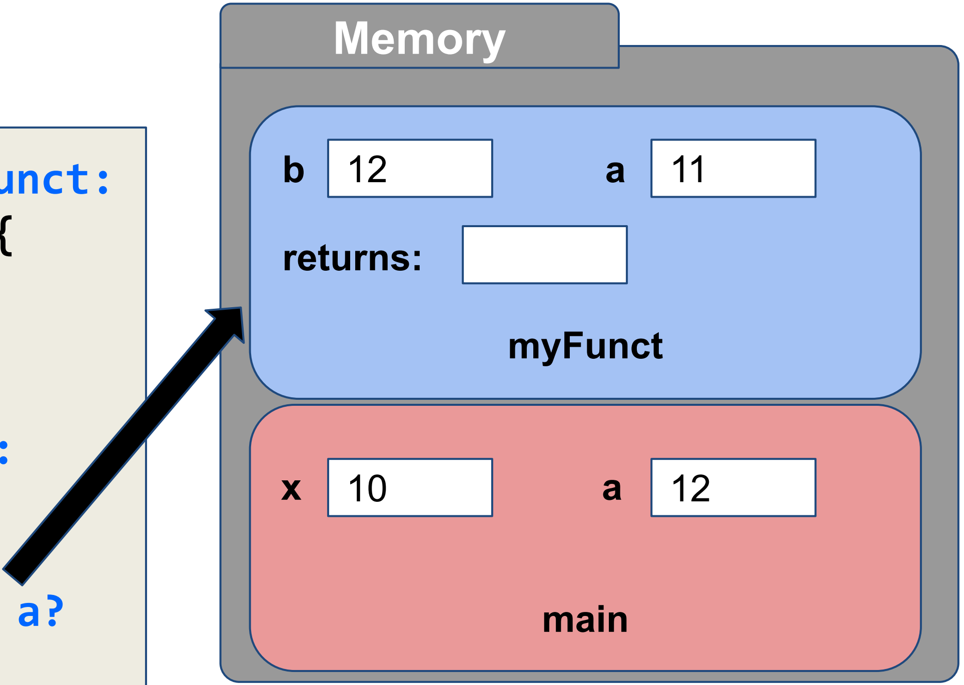

A stack is created in memory, in which the function's local variables are stored

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4. Functions, Recursion, Call by Value

Ubiquitous Computing

4.1. Functions and their parameters: Using Functions

- A function is *called*:

```
// declare & implement myFunct:
int myFunct(int b, int a) {
  a = 2 * b + a * a;
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}
// now we can call myFunct:
int main() {
  int x = 10; int a = 12;
  a = myFunct(a, x+1);  // a?
  return 0;
}
```
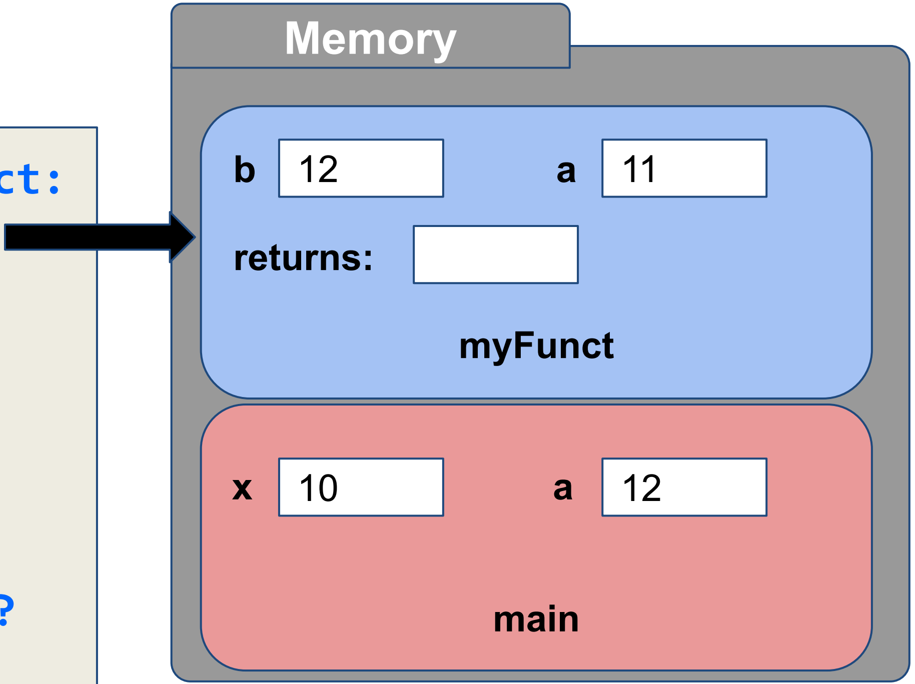



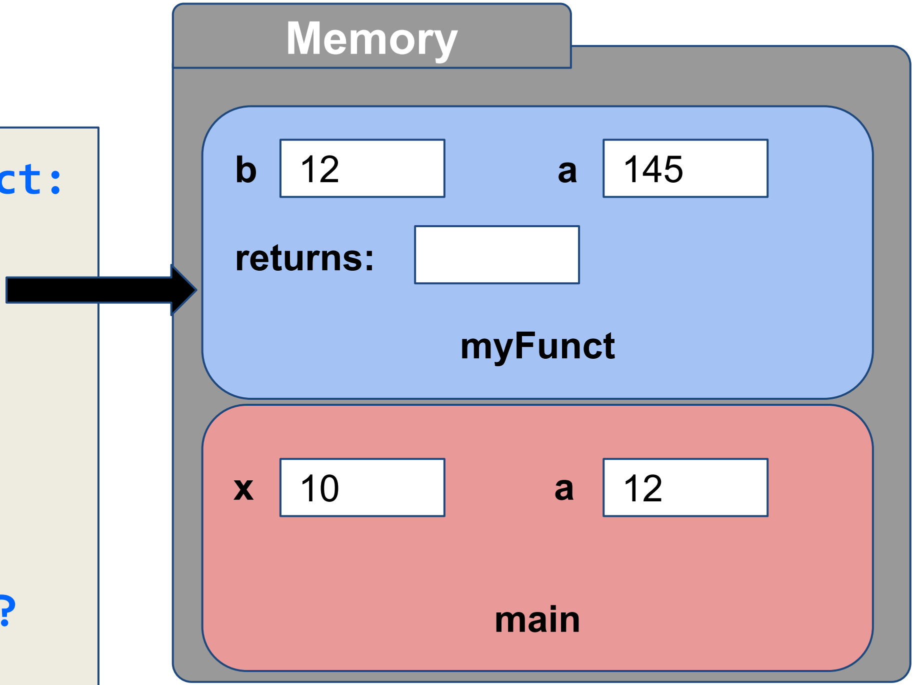
A stack is created in memory, in which the function's local variables are stored

4. Functions, Recursion, Call by Value

4.1. Functions and their parameters: Using Functions

- A function is *called*:

```
// declare & implement myFunct:
int myFunct(int b, int a) {
  a = 2 * b + a * a;
  return a + 1;
}
// now we can call myFunct:
int main() {
  int x = 10; int a = 12;
  a = myFunct(a, x+1);  // a?
  return 0;
}
```

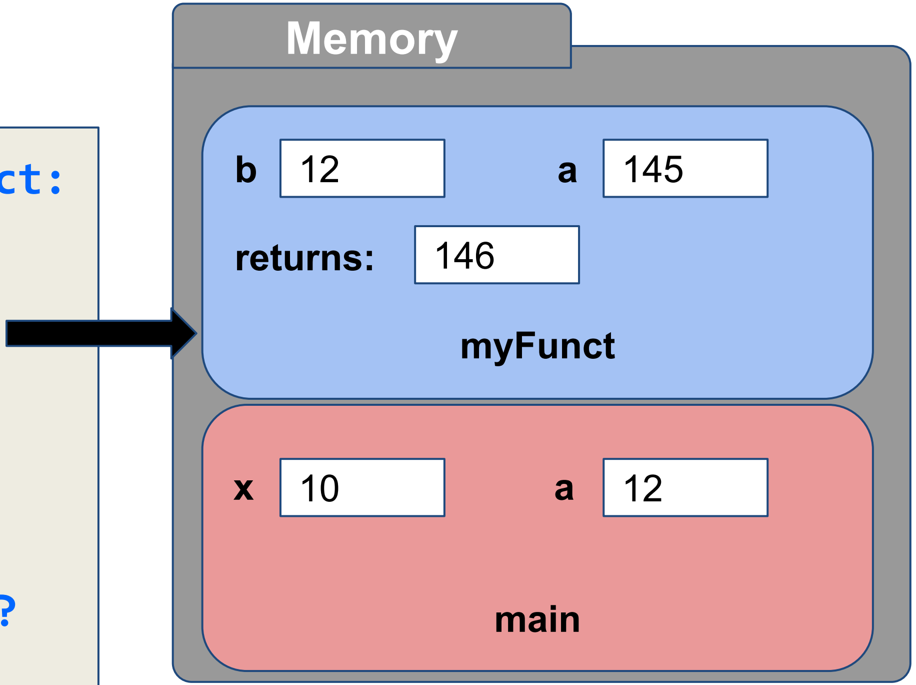


A stack is created in memory, in which the function's local variables are stored

4.1. Functions and their parameters: Using Functions

- A function is *called*:

```
// declare & implement myFunct:
int myFunct(int b, int a) {
  a = 2 * b + a * a;
  return a + 1;
}
// now we can call myFunct:
int main() {
  int x = 10; int a = 12;
  a = myFunct(a, x+1);  // a?
  return 0;
}
```



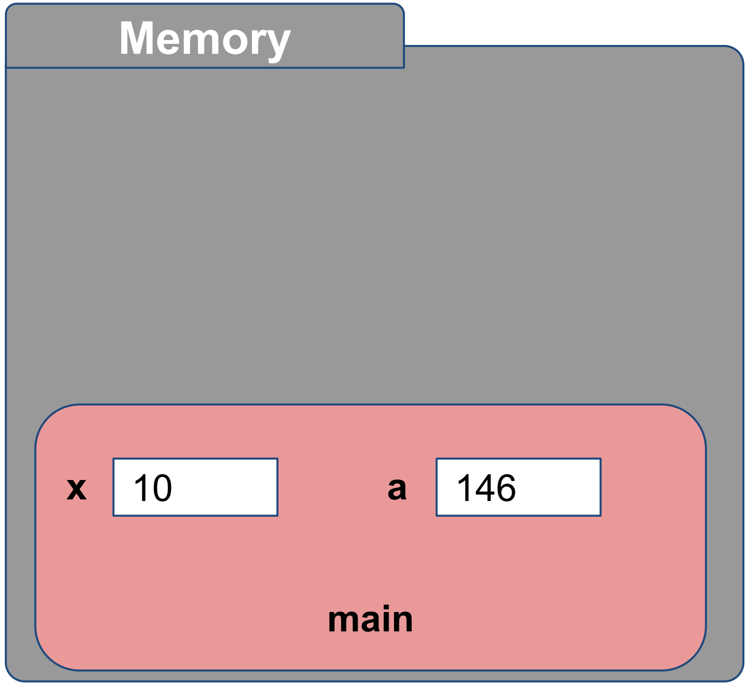
A stack is created in memory, in which the function's local variables are stored

4. Functions, Recursion, Call by Value

4.1. Functions and their parameters: Using Functions

- A function is *called*:

```
// declare & implement myFunct:
int myFunct(int b, int a) {
  a = 2 * b + a * a;
  return a + 1;
}
// now we can call myFunct:
int main() {
  int x = 10; int a = 12;
  a = myFunct(a, x+1);  // a?
  return 0;
}
```



A stack is created in memory, in which the function's local variables are stored

4.1. Functions and their parameters: Using Functions

- Maze Game v.1.0: expand this code to move the player and add color

```
/* First draft of Maze Game: draw the player, respond to key presses */
#include <ncurses.h>  // functions to draw colored text in terminal
int main() {
  char c = ' ';           // used for user key input
  auto x = 10, y = 5;     // (x,y) position of player: start at (10,10)
  initscr(); curs_set(0);   // ncurses: initialize window, then hide cursor
  while ( c != 'q' ) {     // as long as the user doesn't press q ..
    mvaddch(y, x, '@');    // ncurses function: draw a @ at position (x,y)
    c = getch();           // capture the user's pressed key
    // handle here the moving
  }
  endwin();               // ncurses function: close the ncurses window
  return 0;
}
```

4.1. Functions and their parameters: Using Functions

```
/* First draft of Maze Game: draw the player, respond to key presses
   Result of the in-class programming code (see YouTube video of the lecture)
*/

#include <ncurses.h>  // functions to draw colored text in terminal

// initialize all the functions to start drawing in ncurses
void initNCurses() {
  initscr(); curs_set(0);  // ncurses: initialize window, then hide cursor
  noecho();  // don't show keys pressed in terminal
  start_color();  // use color
  init_pair(1, COLOR_BLUE, COLOR_GREEN);
  init_pair(2, COLOR_RED, COLOR_YELLOW);
}
```

4. Functions, Recursion, Call by Value

4.1. Functions and their parameters: Using Functions

```
void clearScreen() {
  attron(COLOR_PAIR(1));  // set color pair to 1
  for ( auto line = 0; line < LINES; line++) {
    for ( auto col = 0; col < COLS; col++) {
      mvaddch(line, col, '.');  // ncurses function: draw '.' at (x,y)
    }
  }
  attroff(COLOR_PAIR(1));
}

// draw a symbol at (x,y) with color colorpair
void draw(int x, int y, char symbol, int colorpair) {
  attron(COLOR_PAIR(colorpair));  // set color pair to 1
  mvaddch(y, x, symbol);  // ncurses function: draw '.' at (x,y)
  attroff(COLOR_PAIR(colorpair));
}
```

4. Functions, Recursion, Call by Value

4.1. Functions and their parameters: Using Functions

```
int main() {
  auto c = ' ';           // used for user key input
  auto x = 10, y = 10;   // (x,y) position of player: start at (10,10)
  initNCurses();          // initialize ncurses functionality
  while ( c != 'q' ) {    // as long as the user doesn't press q ..
    clearScreen();
    draw(x, y, '@', 2);   // draw our player
    c = getch();          // capture the user's pressed key
    switch (c) {
      case 'w': y--; break;  // go up
      case 's': y++; break;  // go down
      case 'a': x--; break;  // go left
      case 'd': x++; break;  // go right
    }
  }
  endwin();             // ncurses function: close the ncurses window
  return 0;
}
```

4.2. Recursive Functions

- A function can call itself. For example in a function to calculate the factorial of a number (notation: n!)

```
// factorial of n (n!):
double factr(double n) {
  if (n == 0.0)
    return 1.0;
  else if (n > 0.0)
    return n * factr(n-1);
}
```

```
double f = factr(3.0);
```

Mathematical definition:

$$\boxed{n!} = \begin{cases} 1 & \text{for } n = 0 \\ n \,.\, \boxed{(n-1)!} & \text{for } n > 0 \end{cases}$$

so:
2! = 2 . 1 = 2
3! = 3 . 2 . 1 = 6
4! = 4 . 3 . 2 . 1 = 24
5! = 5 . 4 . 3 . 2 . 1 = 120
and so on …

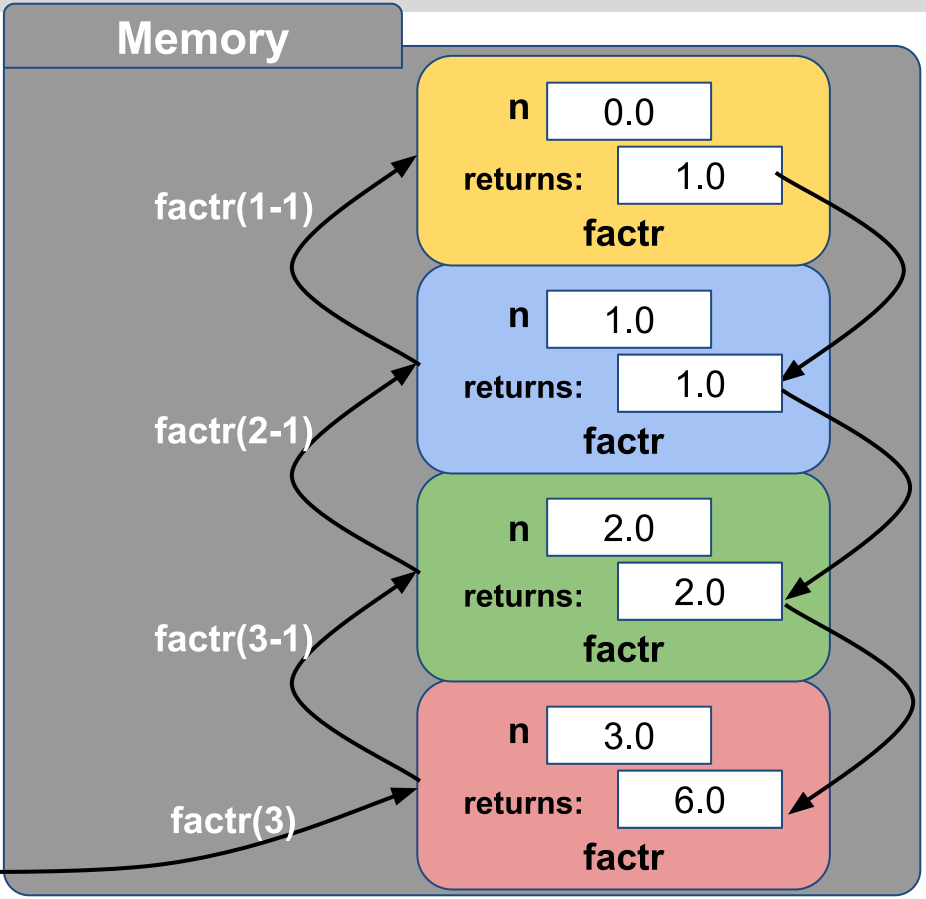
4. Functions, Recursion, Call by Value

4.2. Recursive Functions

- Whenever a function is called, a new space is reserved in memory for parameters and local variables. Example:

```
double factr(double n) {
  if (n == 0.0)
    return 1.0;
  else if (n > 0.0)
    return n * factr(n-1);
}
```

```
double f = factr(3.0);
```



4. Functions, Recursion, Call by Value

4.3. Call by Value

In C++, most parameters are passed **by value**

- This means, a function always receives **copies** of the actual parameters
- When the function is called, the values of the actual parameters are assigned to the formal parameters in the function declaration:

```
double factr(double n);   // n is a formal parameter of factrr
```

```
double y = factr(6.0);    // 6.0 is the actual parameter of factr
```

- With call-by-value, variables given as actual parameters are never changed
- The same variable can be simultaneously passed to multiple parameters:

```
int a = 10;
y = maximum(a, a);     // the value 10 is copied to both parameters
```

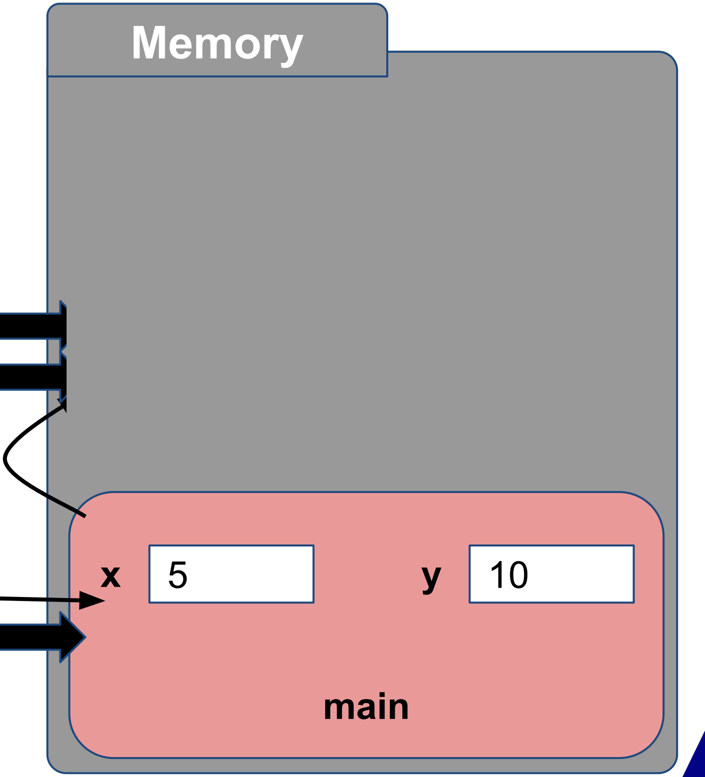
4. Functions, Recursion, Call by Value

4.3. Call by Value

In C++, parameters are passed **by value**

So the variable does not get passed, *just its value*

```cpp
#include <iostream>  // output to terminal
void swap(int x, int y){
   int temp = 0;
   temp = x; x = y; y = temp;
}
int main()  {
   int x = 5, y = 10;
   swap(x, y);
   std::cout << x << ", " << y << std::endl;
   return 0;
}
```



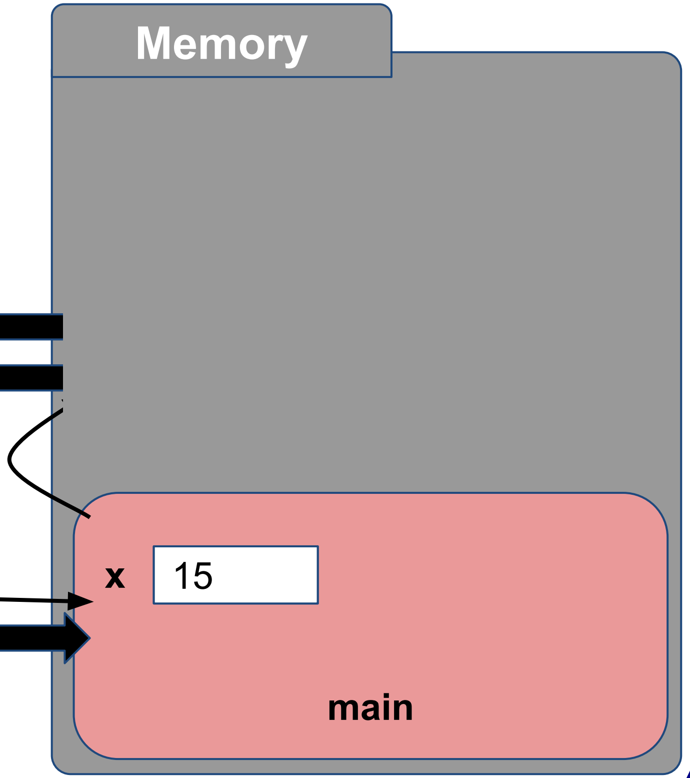
4. Functions, Recursion, Call by Value

4.3. Call by Value

In C++, parameters are passed **by value**

You can use the function's return value:

```cpp
#include <iostream>  // output to terminal
int addFive(int x) {
   x += 5;
   return x;
}
int main()  {
   int x = 10;
   x = addFive(x);
   std::cout << x << std::endl;
   return 0;
}
```



4.4. **`inline`** Functions, Overloading, **`=delete`**

- **`inline`** tells the compiler that inline substitution of a function is preferred over function call: instead of calling the function and transferring control to the function body, a copy of the function body is executed
- This avoids overhead from the function call (passing the arguments and retrieving the result)
- This may result in a larger executable (due to repeating multiple times)

```
inline int maximum( int a, int b ) {
  return (a > b)? a : b;
}
```

4.4. **`inline`** Functions, Overloading, **`=delete`**

- Sometimes, the same functionality is needed on different types:

```
auto maximum( int a, int b );
auto maximum( double a, double b );
auto maximum( char a, char b );
```

(note that `auto` is not allowed for the function's parameters, deduced return types are a C++14 extension)

- Multiple functions with the same name are allowed, if
  - the number of parameters are different, or
  - at least one parameter has a different type
- This is ***overloading*** the function name, and should be used for multiple functions of the same functionality. Note that with subtle differences, like signed/unsigned, float/double, it is hard to predict what will be called

4.4. **`inline`** Functions, Overloading, **`=delete`**

- There are four Overloading Resolution Rules
  - An exact match between parameter types
  - A promotion (e.g., char to int)
  - A standard type conversion (e.g. float and int)
  - A constructor or user-defined type conversion (see later)

- **`= delete`** can be used to prevent calling the wrong overload:

```
void myFunction(int) { ; }
void myFunction(double) = delete;
int main() {
  myFunction(7);     // this is fine
  myFunction(7.0);   // this results in a compilation error
  return 0;
}
```

4.5. Default Parameters and Function Attributes

- Parameters can be given a default value (If the call does not supply a value for this parameter, this default value will be used):
  - All default parameters must be the *rightmost* parameters
  - Default parameters must be declared only once
  - Default parameters can improve compile time and avoid redundant code because they avoid defining other overloaded functions

```
void myFunction(int a, int b = 7);   // declaration of myFunction

void myFunction(int a, int b) { ; }  // definition of myFunction
int main() {
  myFunction(8);    // this is fine, a = 8, b = 7
  return 0;
}
```

4.5. Default Parameters and Function Attributes

- Functions can be marked with standard properties, to express their intent:
  - `[[noreturn]]` indicates that a function does not return, for optimization purposes or compiler warnings (from C++11)
  - `[[deprecated]]`, `[[deprecated("reason")]]` indicates that the use of a function is discouraged through a compiler warning (from C++14)
  - `[[nodiscard]]`, `[[nodiscard("reason")]]` (C++17, resp. C++20) throws a warning if the function's return value is not handled

```
[[noreturn]] void myFunction() { std::exit(0); }

[[deprecated("old function, use newFunction instead")]]
void oldFunction(int p) { … }

[[nodiscard("please handle return value")]] int getMaximum() { … }
```

4. Functions, Recursion, Call by Value

4.6. Header files and Modules

- It is likely that any code you will write will have to be split into several functions that call each other, instead of implementing everything in the `main()` function
- We define and implement these functions in separate files, if they form a collection that belong to each other (see for example the functions we used from ncurses)
- This is a **module**: a part of a program that can be compiled separately
- In C++, a module always should consist of two files:
  - a **header** file (`*.h`), which contains the function declarations
  - an **implementation** file (`*.cpp`), in which the functions are implemented

4. Functions, Recursion, Call by Value

4.6. Header files and Modules

Maze.cpp

```
/* Second draft of Maze Game: drawing functions are our module "drawMaze" */
#include "drawMaze.h"  // functions related to drawing
int main() {
  auto c = ' ';             // used for user key input
  auto x = 10, y = 10;  // (x,y) position of player: start at (10,10)
  initNCurses();            // initialize ncurses functionality
  while ( c != 'q' ) {  // as long as the user doesn't press q ..
    clearScreen();
    draw(x, y, '@', 2);    // draw our player
    c = getch();              // capture the user's pressed key
    switch (c) {
      case 'w': y--; break;  // go up
      case 's': y++; break;  // go down
      case 'a': x--; break;  // go left
      case 'd': x++; break;  // go right
    }
  }
  endwin();                 // ncurses function: close the ncurses window
  return 0;
}
```

4.6. Header files and Modules

drawMaze.h

```
/* Drawing functions declared */
#include <ncurses.h>  // functions to draw colored text in terminal

// initialize all the functions to start drawing in ncurses and use color
void initNCurses();

// clear the screen
void clearScreen();

// draw a symbol at (x,y) with color colorpair
void draw(int x, int y, char symbol, int colorpair);
```

4.6. Header files and Modules

drawMaze.cpp

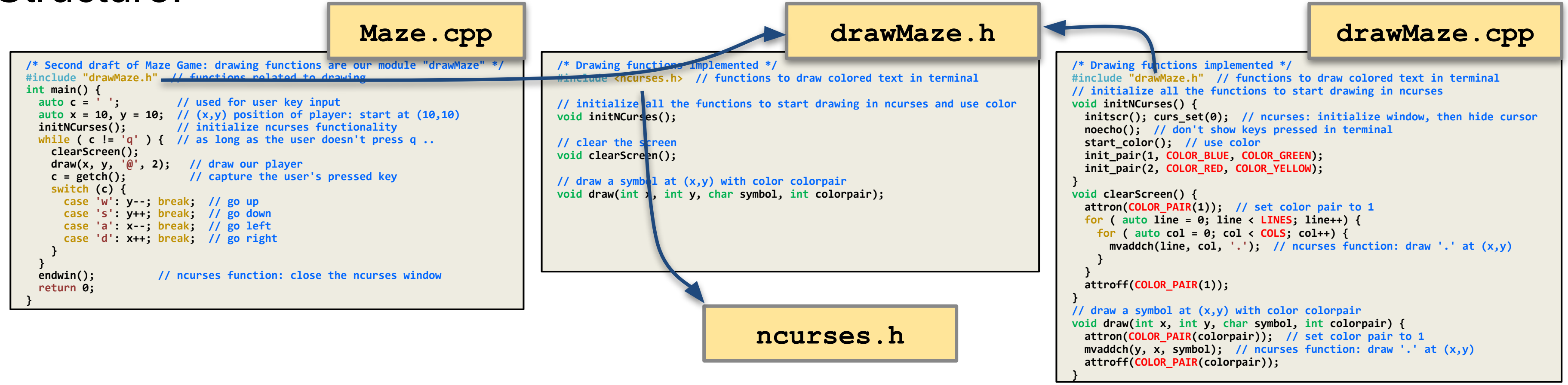
```
/* Drawing functions implemented */
#include "drawMaze.h"  // functions to draw colored text in terminal

// initialize all the functions to start drawing in ncurses
void initNCurses() {
  initscr(); curs_set(0);  // ncurses: initialize window, then hide cursor
  noecho();  // don't show keys pressed in terminal
  start_color();  // use color
  init_pair(1, COLOR_BLUE, COLOR_GREEN);
  init_pair(2, COLOR_RED, COLOR_YELLOW);
}
void clearScreen() {
  attron(COLOR_PAIR(1));  // set color pair to 1
  for ( auto line = 0; line < LINES; line++) {
    for ( auto col = 0; col < COLS; col++) {
      mvaddch(line, col, '.');  // ncurses function: draw '.' at (x,y)
    }
  }
  attroff(COLOR_PAIR(1));
}
```

4.6. Header files and Modules

drawMaze.cpp

```
// draw a symbol at (x,y) with color colorpair
void draw(int x, int y, char symbol, int colorpair) {
  attron(COLOR_PAIR(colorpair));  // set color pair to 1
  mvaddch(y, x, symbol);  // ncurses function: draw '.' at (x,y)
  attroff(COLOR_PAIR(colorpair));
}
```

Structure:



Maze.cpp

```
/* Second draft of Maze Game: drawing functions are our module "drawMaze" */
#include "drawMaze.h"  // functions related to drawing
int main() {
  auto c = ' ';           // used for user key input
  auto x = 10, y = 10;  // (x,y) position of player: start at (10,10)
  initNCurses();          // initialize ncurses functionality
  while ( c != 'q' ) {  // as long as the user doesn't press q ..
    clearScreen();
    draw(x, y, '@', 2);   // draw our player
    c = getch();          // capture the user's pressed key
    switch (c) {
      case 'w': y--; break;  // go up
      case 's': y++; break;  // go down
      case 'a': x--; break;  // go left
      case 'd': x++; break;  // go right
    }
  }
  endwin();             // ncurses function: close the ncurses window
  return 0;
}
```

drawMaze.h

```
/* Drawing functions implemented */
#include <ncurses.h>  // functions to draw colored text in terminal

// initialize all the functions to start drawing in ncurses and use color
void initNCurses();

// clear the screen
void clearScreen();

// draw a symbol at (x,y) with color colorpair
void draw(int x, int y, char symbol, int colorpair);
```

drawMaze.cpp

```
/* Drawing functions implemented */
#include "drawMaze.h"  // functions to draw colored text in terminal
// initialize all the functions to start drawing in ncurses
void initNCurses() {
  initscr(); curs_set(0);  // ncurses: initialize window, then hide cursor
  noecho();  // don't show keys pressed in terminal
  start_color();  // use color
  init_pair(1, COLOR_BLUE, COLOR_GREEN);
  init_pair(2, COLOR_RED, COLOR_YELLOW);
}
void clearScreen() {
  attron(COLOR_PAIR(1));  // set color pair to 1
  for ( auto line = 0; line < LINES; line++) {
    for ( auto col = 0; col < COLS; col++) {
      mvaddch(line, col, '.');  // ncurses function: draw '.' at (x,y)
    }
  }
  attroff(COLOR_PAIR(1));
}
// draw a symbol at (x,y) with color colorpair
void draw(int x, int y, char symbol, int colorpair) {
  attron(COLOR_PAIR(colorpair));  // set color pair to 1
  mvaddch(y, x, symbol);  // ncurses function: draw '.' at (x,y)
  attroff(COLOR_PAIR(colorpair));
}
```

4. Functions, Recursion, Call by Value

4.6. Header files and Modules

Maze Game v.2.0: How to compile the program?

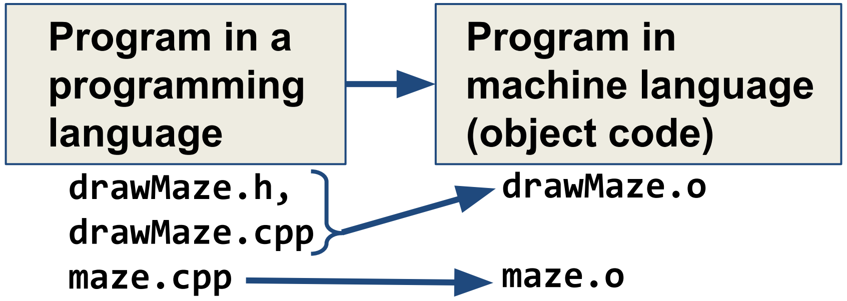
- First compile the module and the program into object files:

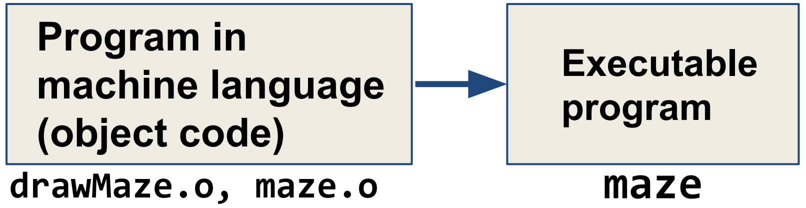
  `g++ -c drawMaze.cpp -std=c++11` → object file `drawMaze.o`

  `g++ -c maze.cpp -std=c++11` → object file `maze.o` is created

- Then link the object files:

  `g++ maze.o drawMaze.o -o maze -l ncurses`


Program in a programming language
Program in machine language (object code)
drawMaze.h,
drawMaze.cpp
drawMaze.o
maze.cpp
maze.o

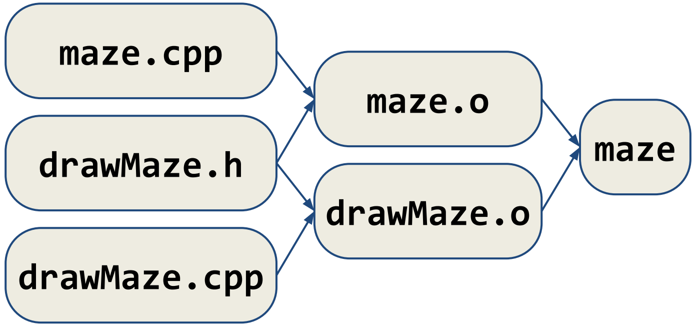


4.6. Header files and Modules

- Why use modules?
  - To **better structure** the program code: Separate modules make it easier to divide your code and find where you need to change or continue your source code
  - Make modules **re-usable** by others: Anyone can read the header (`*.h`) file and will know what functions they can use if the module is included, reading the implementation (`*.cpp`) is not needed
  - **Save compilation time**: Object files are already compiled, they just need to be linked to other modules and the program code

4.6. Header files and Modules: The **make** utility

- Revisiting the Maze Game v.2.0, we have these *dependencies*:



compile **drawMaze.cpp:**

```
g++ -c drawMaze.cpp -std=c++11s
```

compile **maze.cpp:**

```
g++ -c maze.cpp -std=c++11
```

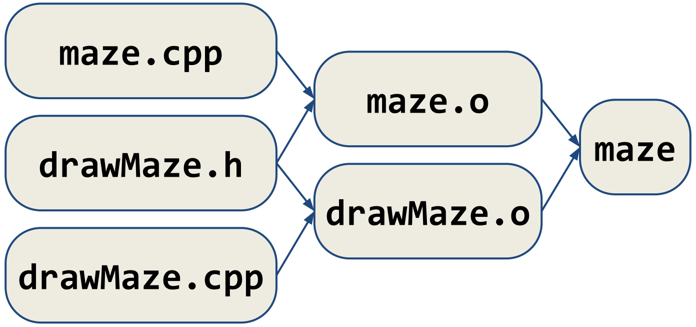
link the objects files into the executable program **maze:**

```
g++ maze.o drawMaze.o -o maze -l ncurses
```

- After a change, we want to recompile only the affected files
- The **make** program automates this process for us:
  just type `make` in the terminal, in the code's directory

4.6. Header files and Modules: The **make** utility

- We need to tell **make** about these dependencies in a specific file that we need to create in the code's directory: **Makefile**



- After each rule, we need to type a **tab** before each g++ command in **Makefile**

Makefile

```
# Rule to make our program when
# ’drawMaze.o’ and ’maze.o’ are compiled:
maze: drawMaze.o maze.o
	g++ drawMaze.o maze.o -o maze -l ncurses
# Rule for dependency 'maze.o':
maze.o: maze.cpp drawMaze.h
	g++ -c maze.cpp -std=c++11
# Rule for dependency 'drawMaze.o':
drawMaze.o: drawMaze.cpp drawMaze.h
	g++ -c drawMaze.cpp -std=c++11
```

4. Functions, Recursion, Call by Value

Summary

```
int maximum( int a, int b );
```

- A function returns at most one value and thus must have a return type (either `int`, `float`, `double`, `bool`, `char`, etc., or `void`: no return value)
- A function has a name and a list of parameters between braces
- The parameters are variables of the types `int`, `float`, `double`, `bool`, `char`
- The function is implemented as a block following the function definition, between curly braces:
- Each time this function is called, these statements are executed with any parameters as local variables

```
int maximum( int a, int b ) {
  if (a > b) {
    return a;
  } else {
    return b;
  }
}
```

5. Arrays, Multidimensional Arrays

5. Arrays, Multidimensional Arrays

5.1. Arrays: Reminders

Types (`int`, `float`, `double`, `bool`, `char`, etc.) tell the compiler:

- the size of the variables (e.g., 4, 8, 1 bytes) in memory
- how these bits in memory should be interpreted
- and know the possible operations on them

For example:

if **`height`** and **`width`** are variables of type `int`, then the compiler knows

- that 4 bytes need to be reserved for each of them,
- which are organized so they span the whole numbers from -2147483648 to 2147483647
- and that **`height`** * **`width`** is a legal operation

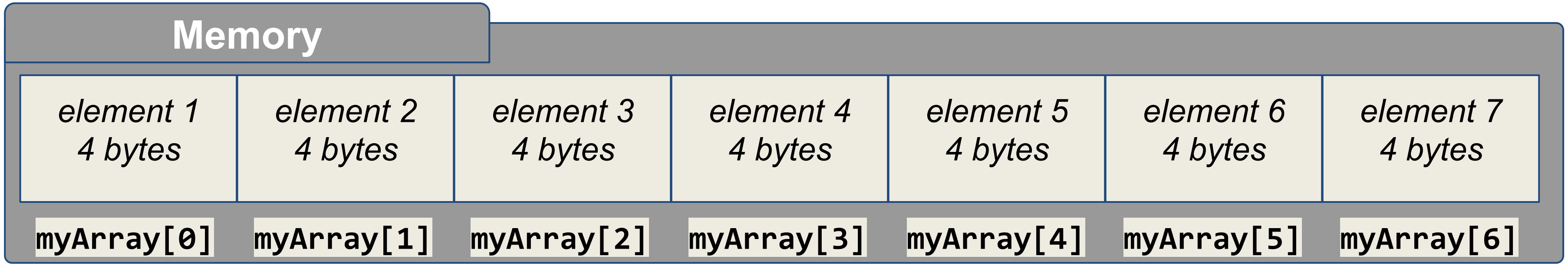
5. Arrays, Multidimensional Arrays

5.1. Arrays

- An array is a serially numbered collection of variables that are all of the same *type*
- The number of elements is the *size* of the array
- Array elements are accessible via their *index*, from 0 to size-1

For example:

`float myArray[7];` is an array of 7 `float` variables, indexed from 0 to 6:



5. Arrays, Multidimensional Arrays

5.1. Arrays: Initialization, sizeof

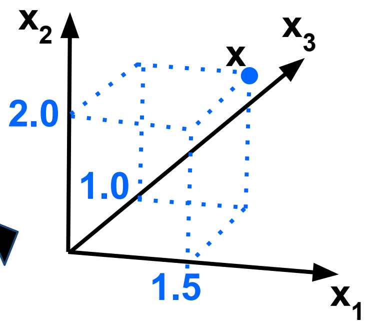
- An array can be initialized by listing the elements between curly braces, **{** and **}**, and separated by commas:
  ```
  double myArray[] = {1.09, 2.18, 4.36, 8.72};
  ```
  In this case, the array will automatically get the size 4
- `sizeof` is built-in operator that returns the number of *bytes* for the given variable or type:
  ```
  int myArraySize = sizeof(myArray) / sizeof(myArray[0]);  // 16/4
  ```
- Loops are typically used for larger arrays:
  ```
  bool myArray[400];
  ```
  ```
  for (int i = 0; i < 400; i++) myArray[i] = false;
  ```

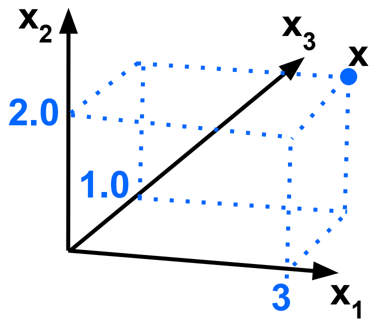
5. Arrays, Multidimensional Arrays

5.1. Arrays

- Example: a three-dimensional vector

```
double y[3]; // y is a 3d vector
y[0] = 1.5;
y[1] = 2.0;
y[2] = 1.0;
// or shorter:
double x[] = { 1.5, 2.0, 1.0 };

x[0] = 3.0;
```



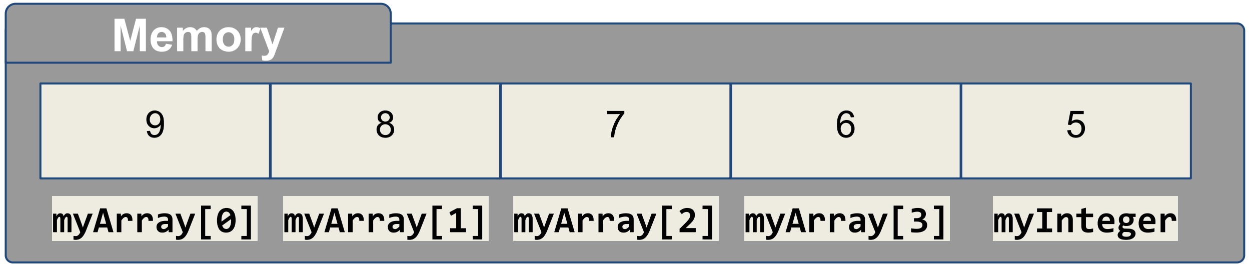


5.1. Arrays: Writing beyond the array boundary

- Most C++ compilers allow using *any* array indices to access array elements, even incorrect ones
- Non-existing array elements are usually other parts of memory, such as other variables or program code:

```
int myArray[4] = {9, 8, 7, 6};
int myInteger = 5;
std::cout << myArray[4] << std::endl;  // returns only a warning
```

- What could happen: `myArray[4]` returns the value of myInteger:



5. Arrays, Multidimensional Arrays

5.1. Arrays

Example 01 (difficulty level: 🌶️)

```
/**
  Write a program that initializes an array of 50 booleans, repeatedly having two
  elements with a true value, followed by one element with false.
  So the array starts with: true, true, false, true, true, false, true, true, …
  Do not use any variables other than myArray.
*/

int main() {
  bool myArray[50];




  return 0;
}
```

5. Arrays, Multidimensional Arrays

5.1. Arrays

Example 02 (difficulty level: 🌶️🌶️)

```
/**
  Write a program that lets a user fill an array of 10 integers, using a loop,
  and then calculate and output the average of all given numbers to the terminal.
  Assume that the user enters a valid number each time.
  */
#include <iostream>  // to allow use of std::cout, std::cin, and std::endl
int main() {
  int myArray[10];




  return 0;
}
```

5. Arrays, Multidimensional Arrays

5.1. Arrays

Example 03 (difficulty level: 🌶️🌶️🌶️)

```cpp
/**
  Write a program that draws a histogram or bar chart through
  an array of 17 integers. To 'draw' the bars, use the string
  "\u2589" or an empty space.
  */
#include <iostream>  // std::cout, std::cin, and std::endl
#include <random>    // rand(), returns a pseudo-random int
int main() {
  int myArray[17];
  for (int i = 0; i < 17; i++) {  // fill array with random
    myArray[i] = ( rand() % 25 ); // numbers between 0 and 24
    // draw here with std::cout and std::endl
    std::cout << myArray[i] << std::endl;
  }
  return 0;
}
```

example output:

```
7 ▉▉▉▉▉▉▉
24▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉
23▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉
8 ▉▉▉▉▉▉▉▉
5 ▉▉▉▉▉
22▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉
19▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉
3 ▉▉▉
23▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉
9 ▉▉▉▉▉▉▉▉▉
15▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉
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17▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉
17▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉▉
12▉▉▉▉▉▉▉▉▉▉▉▉
3 ▉▉▉
2 ▉▉
```

5. Arrays, Multidimensional Arrays

5.2. Multidimensional Arrays

- An array can be multidimensional, for example 2-dimensional:

```
int myTable[2][4] = { {1, 2, 3, 4}, {5, 6, 7, 8} };
```

- This array is essentially an array of 2 arrays: `myTable[0]`, `myTable[1]`
- Initialization of larger arrays typically needs nested loops:

```
double map[100][20];
for (int x = 0; x < 100; x++) {
  for (int y = 0; y < 20; y++) {
    map[x][y] = 0.0;
  }
}
```

- `sizeof(myTable)` will return the total size, so 2x4x4=32 bytes
- `sizeof(myTable[0])` will return 4x4 = 16 bytes

5. Arrays, Multidimensional Arrays

5.2. Multidimensional Arrays: Maze Game v.3.00

- Expand on version 2.00 by drawing an actual maze in the screen background, in a tiled way (since the screen can be any size)
- Add this as a two-dimensional array that you initialize yourself in the **`redraw`** function to build up a maze, for example:

```
auto maze[][15] = { {1, 0, 1, 1, 1, 0, 1, 1, 1, 0, 0, 0, 0, 0, 1},
                   {0, 0, 0, 0, 1, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0},
                   {1, 1, 1, 0, 1, 1, 1, 0, 0, 1, 0, 1, 1, 1, 0},
                   {1, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 1, 0, 0},
                   {1, 0, 1, 1, 1, 0, 1, 1, 1, 1, 0, 1, 1, 0, 1},
                   {1, 0, 1, 0, 0, 0, 1, 0, 1, 0, 0, 1, 0, 0, 1},
                   {0, 0, 1, 0, 1, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1},
                   {1, 0, 1, 0, 1, 0, 1, 1, 1, 0, 0, 0, 0, 1, 0},
                   {1, 0, 1, 0, 1, 0, 1, 0, 0, 0, 1, 1, 0, 1, 0},
                   {1, 1, 1, 0, 1, 0, 1, 0, 1, 0, 1, 0, 0, 1, 0}
                 };  // array for drawing a maze as a background
```

5.2. Multidimensional Arrays: Maze Game v.3.00

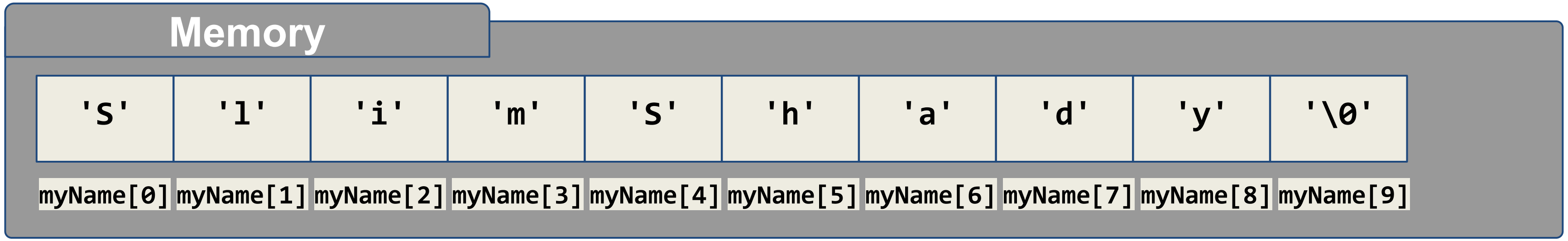
```
/* Third draft of Maze Game: We add an actual maze to our module "drawMaze" */
#include "drawMaze.h"  // functions related to drawing the maze and player
int main() {
  auto c = ' ';            // used for user key input
  auto x = 10, y = 10;     // (x,y) position of player: start at (10,10)
  initNCurses();           // initialize ncurses window and draw the maze
  while ( c != 'q' ) {     // as long as the user doesn't press q ..
    clearScreen();
    draw(x, y, '@', 2);     // draw our player and maze, check for collisions
    c = getch();            // capture the user's pressed key
    switch (c) {
      case 'w': y--; break;   // go up
      case 's': y++; break;   // go down
      case 'a': x--; break;   // go left
      case 'd': x++; break;   // go right
    }
  }
  endwin();               // ncurses function: close the ncurses window
  return 0;
}
```

5. Arrays, Multidimensional Arrays

5.3. Arrays: Strings (Arrays of char)

- Strings are sequences of symbols, for example to store textual data
- In C++, there is no built-in (primitive) string type. Sequences of characters can easily be implemented as an **array** of **`char`** variables, which *always* end with a zero (a character that has the value **`0`**, or also: `'\0'`, but NOT `'0'`):

```
char myName[10] = {'S', 'l', 'i', 'm', 'S', 'h', 'a', 'd', 'y', 0};
std::cout << yourName << std::endl;  // returns contents of yourName
```



5. Arrays, Multidimensional Arrays

5.3. Arrays: Strings (Arrays of char)

- Later, we will see that :
```
char yourName[] = "Marshall Bruce Mathers III";  // works, too, and
                                                 //   ends with a 0
```
- We have already used constant strings when writing output for the terminal:
```
#include <iostream>
std::cout << "This is a string!" << std::endl;
```
- The ending zero (which also is present in the constant strings such as these two above) makes sure that we never go beyond the end of the string
- As such, the empty string `""` contains still one character (with value `0`, or also: `'\0'`, but NOT `'0'`)

5. Arrays, Multidimensional Arrays

5.3. Arrays: Strings (Arrays of char)

- With arrays of characters, you can manage any string already, but you will see that strings are not as easy to deal with as the basic types (`int`, `float`, `double`, `bool`, `char`). For example concatenating two strings is lots of work:

```
/** Write a program that concatenates two strings, s1 and s2, no matter
    what size they have */
#include <iostream>  // use std::cout, std::cin, and std::endl
int main() {
  char s1[] = "Apples and ", s2[] = "oranges";
  // create a new string s, which contains s1 and s2 below:

  std::cout << "Concatenated string: " << s << std::endl;
  return 0;
}
```

5. Arrays, Multidimensional Arrays

5.4. Arrays as function parameters

- In C++, array parameters are passed ***by reference***

```
void swap( int a[10], int i, int j) {  // this swap function works!
  int temp = a[i];  // after this function ends, the original array a
  a[i] = a[j];      // will have swapped the values in its elements i
  a[j] = temp;      // and j. Variables i, j, and temp were created
}                   // at function start and are removed from memory
```

- The function above thus uses the actual array parameter, not a copy
- With ***call-by-reference***, variables given as actual parameters may be changed by the function
- In a function declaration, arrays can be of unspecified length:

```
void swap( int a[], int i, int j);  // Note we'll have to check for a's size
```

5.5. Reading char arrays from the terminal

- When trying our this approach:

```
char buffer[80];
std::cin >> buffer;
```

  you will see this has a few flaws: **`cin`** stops reading beyond the first whitespace character (so we cannot input sentences), and we might have a buffer overrun when we enter more than 80 characters

- The correct approach is to use:

```
char buffer[80];
std::cin.get( buffer, 80 );  // Reads at most 79 characters, 0 is last element
```

- In the above, **`get()`** seems to be a function, but: What exactly is **`cin`**?

5. Arrays, Multidimensional Arrays

5.6. Lambda Expressions and Range-based Loops (since C++11)

- Lambda expressions construct a **closure**: an unnamed function object that is capable of capturing variables in scope
- These are typically used for short code snippets that are not reused and therefore do not specifically require a name:

```
auto x = [](char symbol) { std::cout << symbol << ' '; };
```

```
auto x = [](double d, int t) -> double { return (d<t)?0:d; };
```

capture clause (see later)   parameters   return type   function body

5. Arrays, Multidimensional Arrays

5.6. Lambda Expressions and Range-based Loops (since C++11)

- Lambdas are the simplest way of passing functions as arguments, two other methods are (1) passing functions as pointers and (2) using the std::function<> template class → see [more in-depth information] or later in this course

5. Arrays, Multidimensional Arrays

5.6. Lambda Expressions and Range-based Loops (since C++11)

- The foreach loop or range-based for loop eases iterating over data
- It leaves out the iterator, initialization and stopping conditions:

```
#include <iostream>  // output to the console
int main() {
  int array[]= { 8, 2, 7, 2, 8, 7, 9, 1};
  for( auto value : array ) {  // foreach loop over array
    std::cout << value << ' ';
  }
  std::cout << std::endl;
  return 0;
}
```

5. Arrays, Multidimensional Arrays

5.6. Lambda Expressions and Range-based Loops (since C++11)

- **`std::for_each`** loops are similar to range-based for loops, and provided in **`<iostream>`**
- They apply a *function* to each of the elements in the range [first,last):

```cpp
#include <iostream>  // output to the console, for_each
int main() {
  char array[] = {'H', 'e', 'l', 'l', 'o', '?'};
  std::for_each(std::begin(array), std::end(array),
                [](char sym) { std::cout << sym << ' '; });
  std::cout << std::endl;
  return 0;
}
```