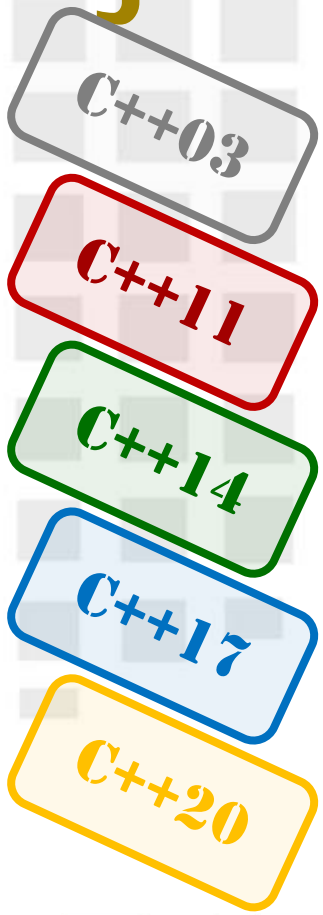
Institut Mines-Télécom
Didier GUERIOT (Dpt. ITI)
Johanne VINCENT (Dpt. INFO)
Reda BELLAFQIRA (Dpt. ITI)
Didier.Gueriot@imt-atlantique.fr
Johanne.Vincent@imt-atlantique.fr
Reda.Bellafqira@imt-atlantique.fr

Advanced C++ programming

- **Introduction to C++**
  - → C++: from C and beyond
  - Slot 2 → Classes, objects and lifetime (vs. JAVA)
  - → Oriented-Object Programming (inheritance, polymorphism)
- **Memory management & object manipulation**
  - → References, « copy » / « move » object construction
  - → Overloading operators
- **Template vs OO programming**
  - → Template functions and classes
- **The Standard Template Library**
  - → Containers, iterators and algorithms
  - → Using sequence & associative containers …
- **Smart pointers (STL & Boost)**



Object vs. class (1/3)

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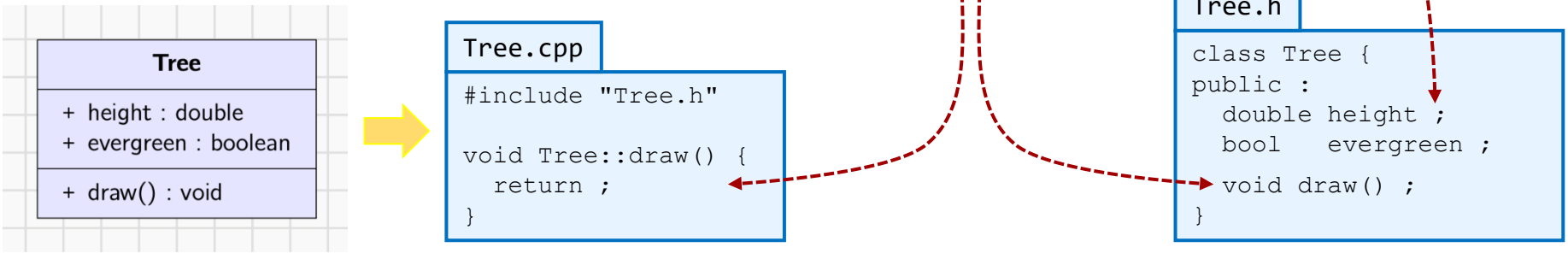
- **What's a class ?**
  - *"A **user-defined type** or data structure having data (attributes) and functions (methods)"*
  - Basically, it's just a "**map**" or instructions giving:
    - how to build and destroy entities (**objects**) complying with this map,
    - what's inside such objects (types of data): **attributes**
    - how to interact with such objects: **methods**



Object vs. class (2/3)

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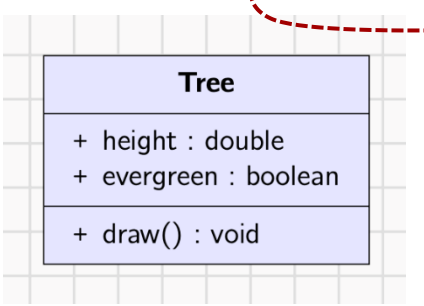
TP 2

- What's a class ?
  - C++ standard code organization (≠ JAVA)
    - Two separate files
      - declaration (**.h**) : attributes (type, size) & methods signatures specification
      - definition (**.cpp**) : methods implementation (their C++ code)



Tree.h

```
class Tree {
public :
  double height ;
  bool   evergreen ;
  void draw() ;
}
```

Tree.cpp

```
#include "Tree.h"

void Tree::draw() {
  return ;
}
```

    - Desired objectives
      - when building the binary executable, prevent from useless class recompiling
      - split up the class interface (public) from its implementation (often more private)

Object vs. class (3/3)

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- **What's an object ?**
  - A class is like a **mold** allowing to create different **objects** (called **instances** of the class) ▶ each instance represents a specific entity thus filling a specific area in memory.
  - Example :

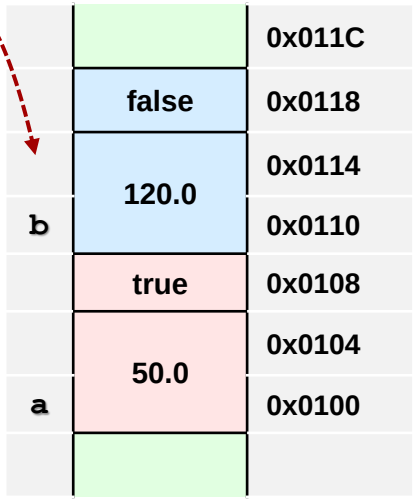
```
// A 50 meters high evergreen tree
Tree a ;

// Another 120 meters high deciduous tree
Tree b ;
```

Tree.h

```
class Tree {
public :
  double height ;
  bool   evergreen ;

  void draw() ;
}
```



  - The **`Tree`** class represents, in the computer :
    - what's a tree (tree height and if evergreen)
    - how the program may use it (here, it can only draw itself)
  - **`a`** and **`b`** are two instances of the **`Tree`** class
  - **`a`** and **`b`** are two variables (objects) of type **`Tree`**
  - **`a`** and **`b`** are two different trees

Using objects (1/2)

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- Access to attributes and methods calls
  - « . » from one object
  - « -> » from a pointer to one object

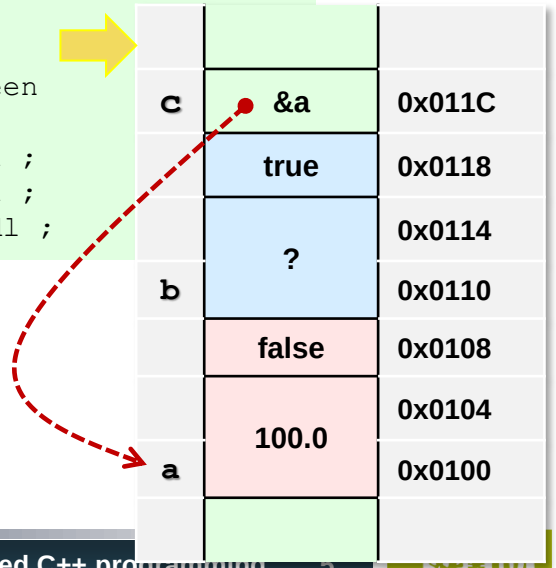
Tree.h

```
class Tree {
public :
  double height ;
  bool   evergreen ;
  void draw() ;
}
```

```
// A tree
Tree a ;

// Another tree
Tree b ;

// c is a pointer
//   to Tree a
// (*c) is Tree a
Tree* c = &a ;
```

```
// Modifying attributes values (write access)
//   => set the tree height and if it's evergreen
a.height     = 50.0 ;  // Height of tree a becomes 50.0 meters
b.evergreen  = true ;  // Tree b becomes evergreen
(*c).height  = 100.0 ; // Height of tree a becomes 100.0 meters
c->evergreen = false ; // Tree a becomes deciduous

// Getting attributes values (read access)
//   => get the tree height and if it's evergreen
cout << "Height of a = " << a.height << endl ;
cout << "b evergreen ? " << b.evergreen << endl ;
cout << "Height of a = " << (*c).height << endl ;
cout << "a evergreen ? " << c->evergreen << endl ;
```

```
// Calling the draw() method of one tree
//   => from the object or the object address
a.draw() ;      // Tree a draws itself
b.draw() ;      // Tree b draws itself
(*c).draw() ;   // Tree a draws itself
c->draw() ;     // Tree a draws itself
```



Using objects (2/2)

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- **Method call ~ function call**
  - An extra variable is added on the stack
    - **`this`** : Inside the method, **`this`** is the address of the object from which the method is called (thus, this specific object is known)

Tree.h

```
class Tree {
public :
  double height ;
  bool   evergreen ;
  void draw() ;
}
```

1

4

```
int main (int argc , char* argv[]) {
  Tree a ; a.evergreen = true ; a.height = 0.0 ;
  a.draw () ;
  return 0 ;
}
```

Tree.cpp

2

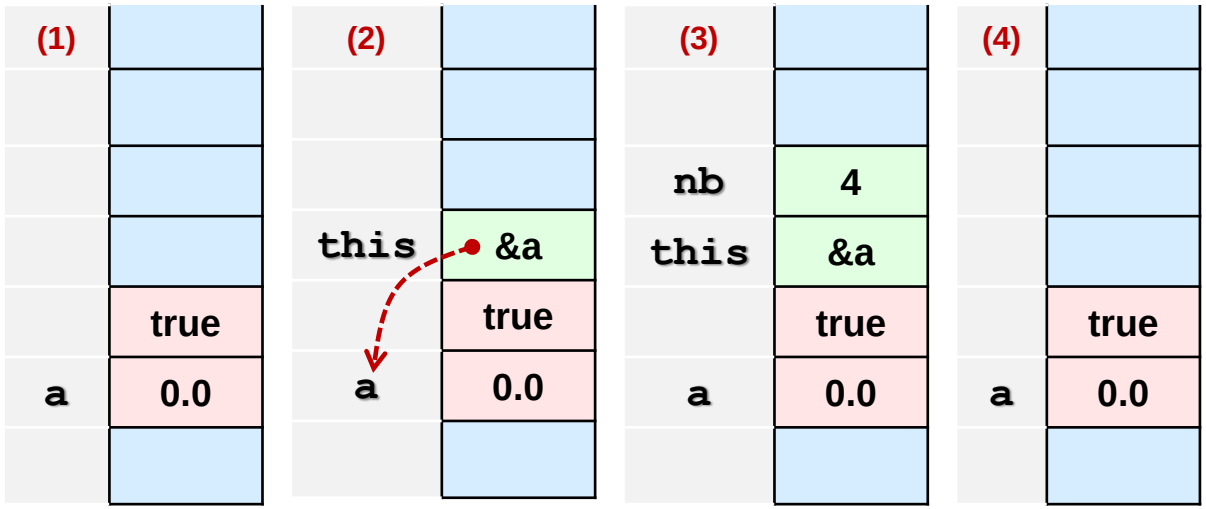
3

```
#include "Tree.h"

void Tree::draw () {
  int nb = 4 ;
  if (evergreen)
    cout << "Green tree" ;
  else
    cout << "Yellow tree" ;
}
```

```
void Tree::draw () {
  …
  if (this->evergreen)
    …
}
```

Green tree



Objects birth and death (1/2)

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- Two specific methods are always called at both ends of an object lifetime (provided by you or the compiler)
  - a **constructor** : called after the system reserves enough memory to store object attributes values

    `Tree()`
    - **initialization** of object attributes values, resources allocation
  - the **destructor** : called just before the system frees the memory reserved for the object

    `~Tree()`
    - **release** of resources the object still owns, …

Tree.h

```
class Tree {
public :
  double height ;
  bool   evergreen ;

  Tree () ;
  ~Tree() ;
}
```

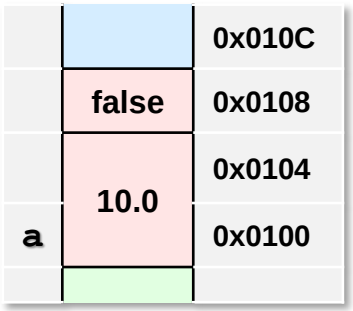
Tree.cpp

```
#include "Tree.h"

Tree::Tree():height(10.0), evergreen(false)
{}

Tree::~Tree() {}
```

```
int main (…)
{
  Tree a ;
}
```



Objects birth and death (2/2)

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- **Remarks**
  - A default constructor (no parameter) and the destructor are provided by the compiler **only** when you don't.

Tree.h

```
class Tree {
public :
  double height ;
  bool   evergreen ;

  void draw() ;
}
```

compilation

Tree.h

```
class Tree {
public :
  double height ;
  bool   evergreen ;

  Tree () ;
  ~Tree() ;
}
```

Tree.cpp

```
#include "Tree.h"

Tree::Tree()
{}

Tree::~Tree()
{}
```

  - You may also provide several constructors to make object initialization easier (no default compiler provided one in that case)

Tree.h

```
class Tree {
public :
  double height ;
  bool   evergreen ;

  Tree (double h) ;
}
```

Tree.cpp

```
#include "Tree.h"

Tree::Tree(double h):height(h), evergreen(false)
{}
```

Objects lifetime (1/2)

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- How are the objects you created, destroyed ?
  - Depends on the kind of memory allocation you asked
    - If on the **stack** (the compiler is in charge: destructor is called and memory released when exiting object **scope**)
    - If in the **heap** (you are responsible for requesting the destruction, **memory leaks** if you don't)

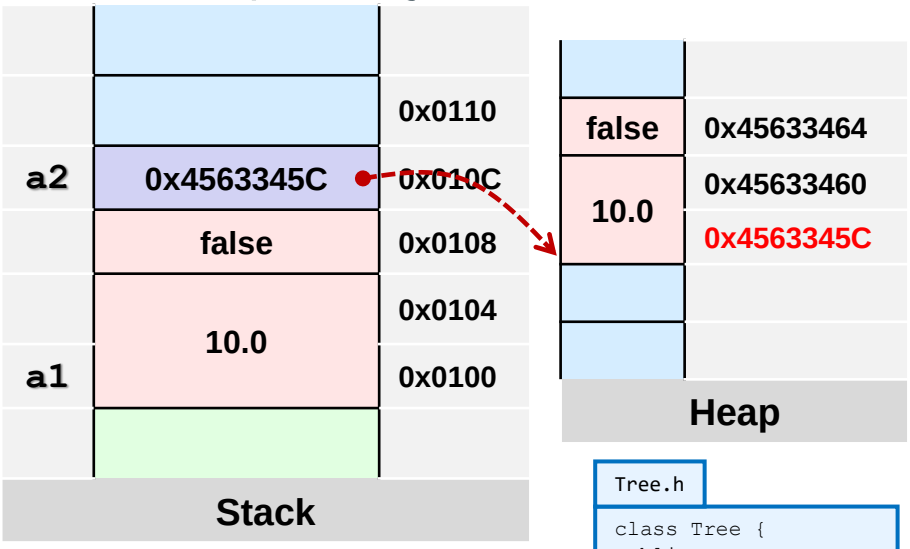
```
#include "Tree.h"

int main (int argc , char* argv[]) {

  // We want to create 2 trees
  Tree  a1 ;               // on the stack
  Tree* a2 = new Tree ;    // in the heap

  // Ask them to draw themselves
  a1.draw() ;
  a2->draw() ;

  // We need to explicitly request the destruction
  //   of the heap-allocated tree though the pointer a2
  delete a2 ;
}
```



Tree.h

```
class Tree {
public :
  double height ;
  bool   evergreen ;
}
```

The compiler is only responsible for the lifetime of the variables you declare i.e. `Tree a1` and pointer to `Tree a2` (not the tree itself), according to their scopes.

Objects lifetime (2/2)

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- What is really happening?

```
#include "Tree.h"
int main (int argc , char* argv[]) {

  // We want to create 2 trees
  Tree  a1 ;                  // on the stack
  Tree* a2 = new Tree ;       // in the heap

  // Ask them to draw themselves
  a1.draw() ;
  a2->draw() ;

  // We need to explicitly request
  //   the destruction of the heap-allocated
  //   tree through the pointer a2
  delete a2 ;
}
```

a1 lifetime

1) System allocates memory on the stack to store Tree **a1**
2) Constructor of class Tree is called to initialize **a1** contents

Program execution is leaving the variable **a1** scope:
1) **a1** is a Tree object: class Tree destructor is called on **a1**
2) System releases memory allocated for object **a1** in the stack

a2 lifetime

1) System allocates memory on the stack to store **a2**, a pointer to a Tree
2) System allocates memory in the heap to store a Tree
3) Constructor of class Tree is called to initialize this Tree contents
4) The address of this Tree object is returned and stored in variable **a2**

You request to destroy the tree **a2** points to:
1) Class Tree destructor is called on this object
2) System releases memory allocated for this Tree object in the heap

Program execution is leaving the variable **a2** scope:
1) **a2** is a pointer (a number): no destructor.
2) System releases memory allocated for the pointer **a2** in the stack

Building a binary executable (1/3)

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- **C++ files organization**
  - Header files (« .h ») :
    - **Declaration** : types, constants, functions, **classes (attributes and signature methods)**
    - Files to be included when the declared entities are needed.
  - Implementation files (« .cpp ») :
    - **Definition** : global variables, functions contents, **class methods code**
    - **Files to be compiled to produce intermediate binaries and finally the binary executable.**
- **Only one entry point for one program**
  - The « main » function

```
int main (int argc , char* argv[]) {
  ...  // Program …
  return 0 ;
}
```

Building a binary executable (2/3)

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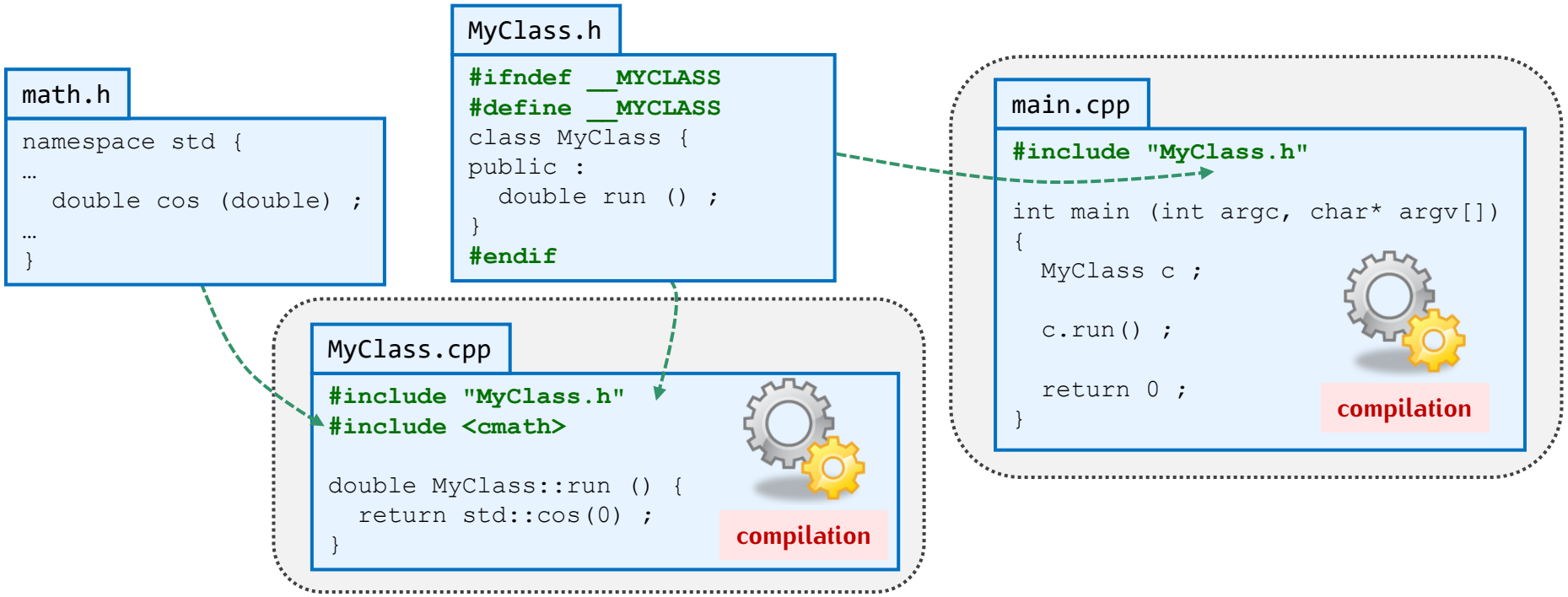
- Using C++ preprocessor
  - Including file class declaration (.h): **`#include`**
  - Preventing one class declaration from multiple inclusion: **`#define`**, **`#ifndef`**, **`#endif`**, ...



Building a binary executable (3/3)

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TP 1.3

MyClass.h

```
class MyClass {
public :
  double run () ;
}
```

MyClass.cpp

```
#include "MyClass.h"
#include <cmath>

double MyClass::run () {
  return std::cos(0) ;
}
```

main.cpp

```
#include "MyClass.h"

int main (int argc, char* argv[])
{
  MyClass c ;

  c.run() ;

  return 0 ;
}
```

math.h

```
namespace std {
…
  double cos (double) ;
…
}
```

libm.so

01010110111
10100010010
01010000101

1 **Compiling :**

```
g++ -c MyClass.cpp
```

MyClass.o

01010110111
10100010010
01010000101

2 **Compiling :**

```
g++ -c main.cpp
```

main.o

0101011
1010001
0101000

3 **Linking :**

```
g++ -o my_prog main.o MyClass.o -lm
```

my_prog

01010110111
10100010010
01010000101

```
-std=c++11 -Wall
```

Practice

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- **Building your first C++ program with class ☺**
  - Compiling, linking, running
  - "Make" the process automatic …
- **Managing objects lifetime**
  - Understanding constructor / destructor calling time
  - Static vs. dynamic allocation
- **Bonus : "Inside memory"!**
  - Displaying addresses
  - Analyzing object memory footprints