(Minimal)
(Practical)
Introduction to **C++** and **OOP**

For use in the Geant4 course

Largely incomplete

Not meant to replace good C++, UML, and OOP books!

Maria Grazia Pia

C++ basics

*C++ is **not** an object oriented language*

A “superset” of C

You can write procedural code in C++

Getting started

```
// my first program in C++
#include <iostream>
int main ()
{
  std::cout << "Hello World!";
  return 0;
}
```

// This is a **comment** line

#include <iostream>

- directive for the **preprocessor**

int main ()

- beginning of the definition of the **main function**
- the main function is the point by where all C++ programs start their execution
- all C++ programs must have a main function
- body enclosed in braces {}

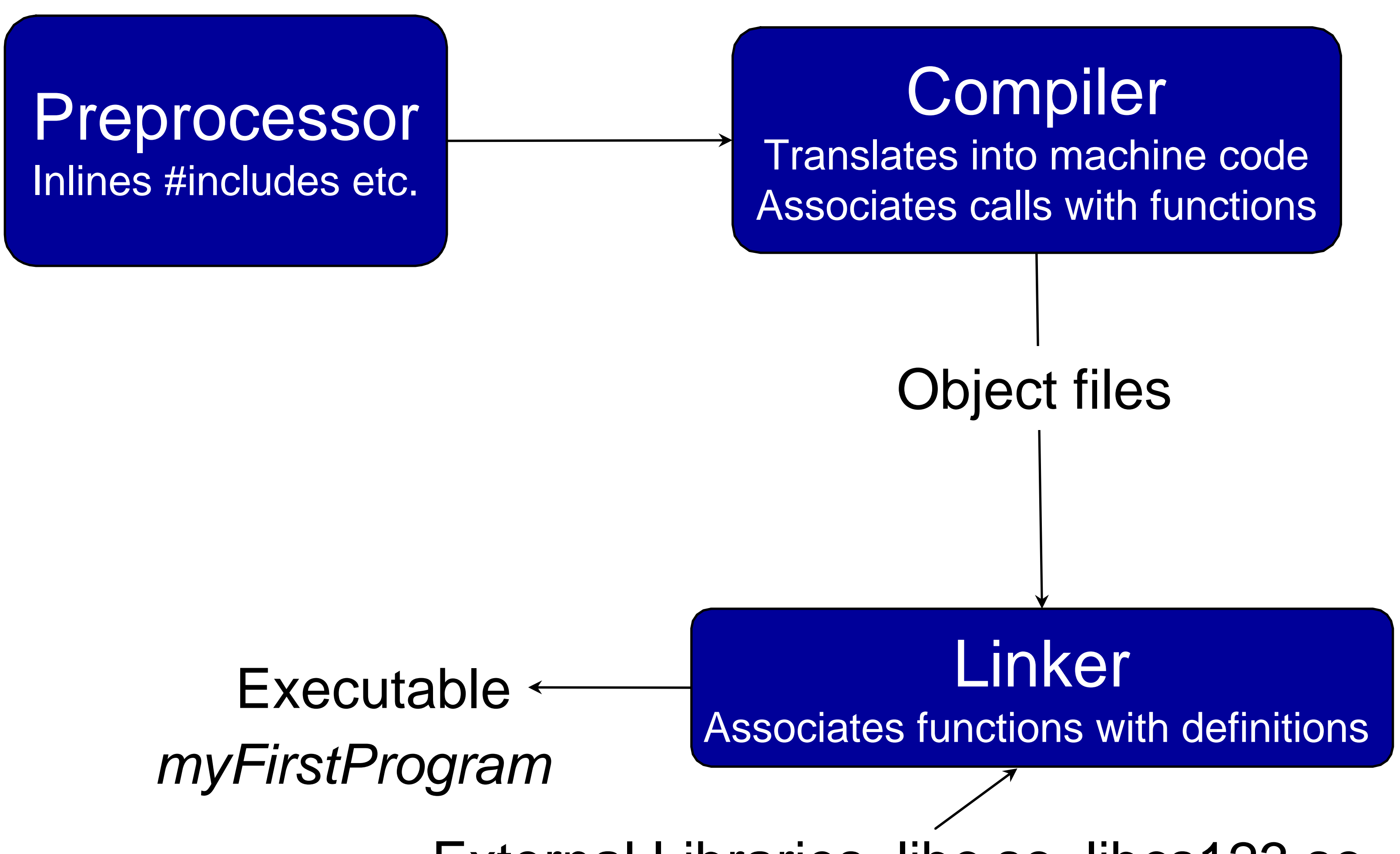
cout << "Hello World";

- C++ statement
- cout is declared in the iostream standard file within the std namespace
- cin
- semicolon (;) marks the end of the statement

return 0;

- the return statement causes the main function to finish
- return may be followed by a return code (here: 0)
  - return code 0 for the main function is generally interpreted as the program worked OK

Compilation



Using namespace

```
#include <iostream>
#include <string>
...
std::string question = “What do I learn this week?”;
std::cout << question << std::endl;

using namespace std;
…
string answer = “How to use Geant4”;
cout << answer << endl;
```

Variables

```
#include <iostream>
#include <string>
using namespace std;
int main ()
{
  // declaring variables:
  int a, b; // declaration
  int result;
  // process:
  a = 5;
  b = 2;
  a = a + 1;
  result = a - b;
  // print out the result:
  cout << result << endl;
  string myString = "This is a string";
  cout << myString << endl;
  const int neverChangeMe = 100;
  // terminate the program:
  return 0;
}
```

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Scope of variables

- global variables can be referred from anywhere in the code
- local variables: limited to the block enclosed in braces ({})

Initialization

```
int a = 0; // assignment operator
int a(0);  // constructor
```

const

the value cannot be modified after definition

References and Pointers

The address that locates a variable within memory is what we call a ***reference*** to that variable

```
x = &y;        // reference operator & "the address of"
```

Reference is an alias

```
int i = 10;
int& ir = i;        // reference (alias)
ir = ir + 1;        // increment i
```

A variable which stores a reference to another variable is called a **pointer**
Pointers are said to "point to" the variable whose reference they store

```
z = *x;        // z equal to "value pointed by" x
```

```
double* z;   // z is a pointer to a double
double x = 35.7;
z = &x;      // therefore *z is 35.7
```

```
z = 0;       // null pointer (not pointing to any valid reference or memory address)
```

Read pointer declarations right to left

```
// A const River
const River nile;

// A pointer to a const River
const River* nilePc;

// A const pointer to a River
River* const nileCp;

// A const pointer to a const River
const River* const nileCpc;
```

Dynamic memory

Operator new

pointer = new type

```
Student* paul = new Student;
```

If the allocation of this block of memory failed,
the failure could be detected by checking if paul took a null pointer value:

```
if (paul == 0) {
  // error assigning memory, take measures
};
```

Operator delete

```
delete paul;
```

Dynamic memory should be freed once it is no longer needed,
so that the memory becomes available again for other requests of dynamic memory
Rule of thumb: every **new** must be paired by a **delete**
Failure to free memory: **memory leak**

C++ Gotcha

Do not return pointers (or references) to local variables!

```
double* myFunction(void) {
  double d;
  return &d;
}
int main() {
  double* pd = myFunction();
  *pd = 3.14;
  return 0;
}
```

Boom! (maybe)

C++ “Gotcha”

Uninitialized pointers are bad!

```
int* i;

if ( someCondition ) {
    …
    i = new int;
} else if ( anotherCondition ) {
    …
    i = new int;
}

*i = someVariable;
```

“null pointer exception”

Memory allocation jargon

- **"on the stack"**
  - scope: block delimited by {}
  - object alive till it falls out of scope
  - calls constructor / destructor
- **"on the heap"**
  - **new** and **delete** operators
  - new calls constructor, delete calls destructor
  - object exists independently of scope in which it was created
  - also "on the free store" or "allocated in dynamic memory"
  - be careful: new → delete, new[] → delete[]
  - for safety, same object should both allocate and deallocate

Operators
(most common ones)

Assignment =

Arithmetic operators +, -, *, /, %

Compound assignment +=, -=, *=, /=, …

`a+=5; // a=a+5;`

Increase and decrease ++, --

`a++; // a=a+1;`

Relational and equality operators ==, !=, >, <, >=, <=

Logical operators ! (not), && (and), || (or)

Conditional operator (?)

```
a>b ? a : b
// returns whichever is greater, a or b
```

Explicit type casting operator

`int i; float f = 3.14; i = (int) f;`

Control structures

```
if (x == 100)
 {
   cout << "x is ";
   cout << x;
 }
```

```
if (x == 100)
  cout << "x is 100";
else
  cout << "x is not 100";
```

```
while (n>0) {
  cout << n << ", ";
  --n;
}
```

```
do {
  cout << "Enter number (0 to end): ";
  cin >> n;
  cout << "You entered: " << n << endl;
} while (n != 0);
```

for *(initialization; condition; increase) statement;*

```
for (int n=10; n>0; n--) {
  cout << n << ", ";
 }
```

```
for (n=10; n>0; n--)
 {
   cout << n << ", ";
   if (n==3)
    {
      cout << "countdown aborted!";
      break;
    }
 }
```

```
loop:
cout << n << ", ";
n--;
if (n>0) goto loop;
cout << “Procedural programming!“ ;
```

Functions

In C++ *all* function parameters are passed by **copy**

```
Type name(parameter1, parameter2, ...)
{
  statements…;
  return somethingOfType;
}
```

No type: void

```
void printMe(double x)
{
  std::cout << x << std::endl;
}
```

Arguments passed by value and by reference

```
int myFunction (int first, int second);
```

Pass a **copy** of parameters

```
int myFunction (int& first, int& second);
```

Pass a **reference** to parameters

They may be **modified** in the function!

```
int myFunction (const int& first, const int& second);
```

Pass a **const reference** to parameters

They may **not** be **modified** in the function!

More on Functions

Default values in parameters

```
double divide (double a, double b=2. )
{
  double r;
  r = a / b;
  return r;
}
```

```
int main ()
{
  cout << divide (12.) << endl;
  return 0;
}
```

Overloaded functions

Same name, different parameter type

A function cannot be overloaded only by its return type

```
int operate (int a, int b)
{
  return (a*b);
}
```

```
double operate (double a, double b)
{
  return (a/b);
}
```

OOP basics

OOP basic concepts

- **Object, Class**
  - A class defines the abstract characteristics of a thing (object), including the thing's attributes and the thing's behaviour
- **Inheritance**
  - "Subclasses" are more specialized versions of a class, which ***inherit*** attributes and behaviours from their parent classes (and can introduce their own)
- **Encapsulation**
  - Each object exposes to any class a certain ***interface*** (i.e. those members accessible to that class)
  - Members can be **public**, **protected** or **private**
- **Abstraction**
  - Simplifying complex reality by modelling classes appropriate to the problem
  - One works at the most appropriate level of inheritance for a given aspect of the problem
- **Polymorphism**
  - It allows one to treat derived class members just like their parent class' members

Class and Object

Object: is characterized by
attributes (which define its state) and operations

A **class** is the blueprint of objects of the same type

```
class Rectangle {
  public:
  Rectangle (double,double); // constructor
  ~Rectangle() { // empty; } // destructor
  double area () { return (width * height); } // member function
  private:
  double width, height; // data members
};
```

```
Rectangle  rectangleA (3.,4.); // instantiate an object of type "Rectangle"
Rectangle* rectangleB = new Rectangle(5.,6.);
cout << "A area: "  <<  rectangleA.area()   << endl;
cout << "B area: "  <<  rectangleB->area() << endl;
delete rectangleB;                    // invokes the destructor
```

The class interface in C++

Usually defined in a header (.h or .hh) file:

```
class Car {
  public:
  // Members can be accessed by any object

  protected:
  // Can only be accessed by Car and its derived objects

  private:
  // Can only be accessed by Car for its own use.
};
```

Constructor and assignment

```
class String {
public:
  String( const char* value ); // constructor
  String( const String& rhs ); // copy constructor
  ~String();
  String& operator=( const String& rhs); // assignment operator
private:
        char* data;
};
```

```
int main() {
        String s1 = “anton”;
        String s2( “luciano” );
        s2 = s1;
};
```

Classes: Basic Design Rules

- Hide all member variables
- Hide implementation functions and data
- Minimize the number of public member functions
- Avoid default constructors
- Use **const** whenever possible / needed

OK:

A invokes a function of a B object
A creates an object of type B
A has a data member of type B

Bad:

A uses data directly from B
(without using B's interface)

Even worse:

A directly manipulates data in B

Inheritance

- A key feature of C++
- Inheritance allows to create classes derived from other classes
- Public inheritance defines an **“is-a”** relationship
  - *In other words: what applies to a base class applies to its derived classes*

```
class Base {
  public:
    virtual ~Base() {}
    virtual void f() {…}
  protected:
    int a;
  private:
    int b; …
};
```

```
class Derived : public Base {
 public:
    virtual ~Derived() {}
    virtual void f() {…}
    …
};
```

Polymorphism

- Mechanism that allows a derived class to modify the behaviour of a member declared in a base class

```
Base* b = new Derived;
b->f();
delete b;
```

Which f() gets called?

Liskov Substitution Principle

- One way of expressing the notion of subtype (or “is-a”)

If Derived is a subtype of Base, then
Base can be replaced everywhere with Derived,
without impacting any of the desired properties of the program

- In other words, you can substitute Base with Derived, and nothing will “go wrong”

Inheritance and virtual functions

```
class Shape
{
 public:
    Shape();
    virtual void draw();
};
```

A virtual function defines the interface and provides an implementation; derived classes may provide alternative implementations

```
class Circle : public Shape
{
    public:
        Circle (double r);
        void draw();
    private:
        double radius;
};
```

```
class Rectangle : public Shape
{
    public:
        Rectangle(double h, double w);
     private:
        double height, width;
};
```

Abstract classes, Abstract interfaces

Abstract class,
cannot be instantiated

```
class Shape
{
    public:
        Shape();
        virtual area() = 0;
};
```

Abstract Interface
a class consisting of
pure virtual functions only

A pure virtual function
defines the interface
and delegates the implementation
to derived classes

```
class Circle : public Shape
{
    public:
        Circle (double r);
        double area();
    private:
        double radius;
};
```

```
class Rectangle : public Shape
{
    public:
        Rectangle(double h, double w);
        double area();
    private:
        double height, width;
};
```

Concrete class

Inheritance and Virtual Functions

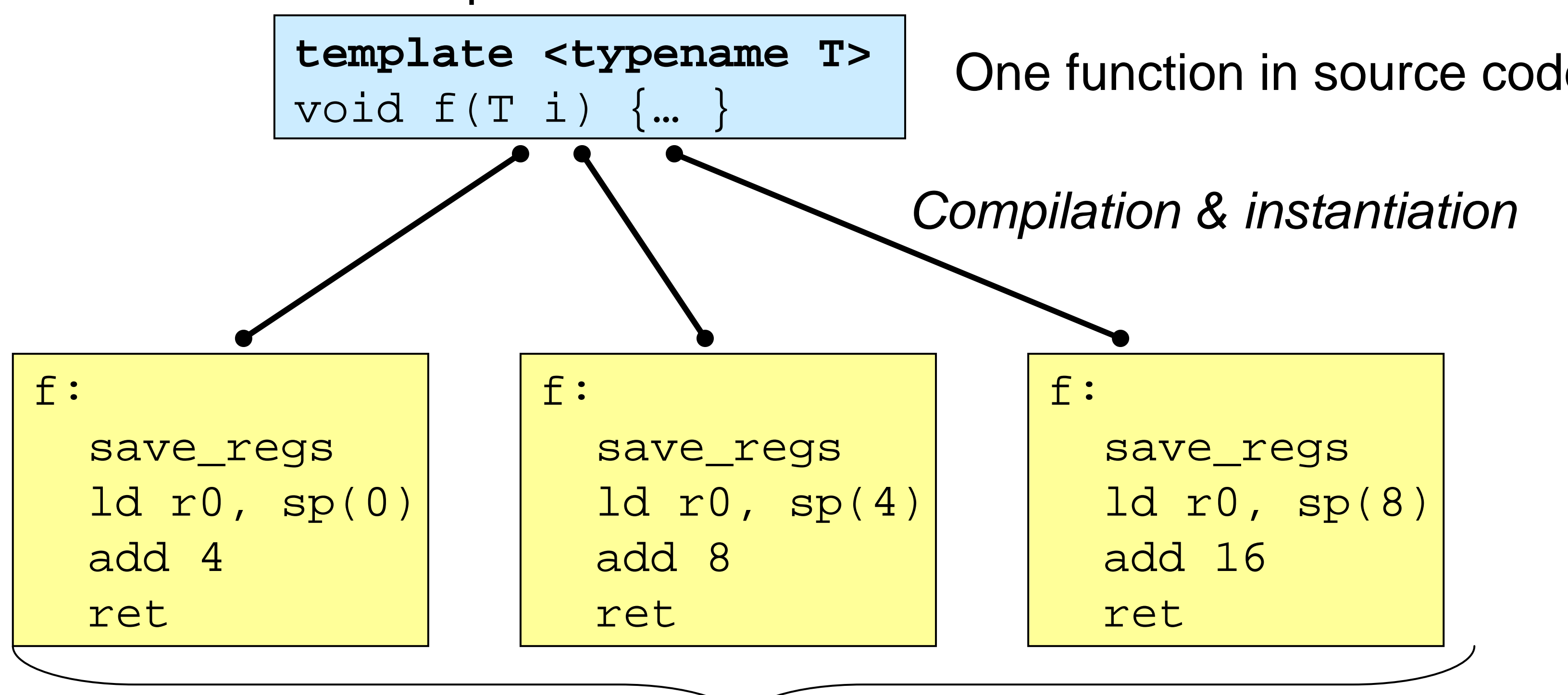
	Inheritance of the **interface**	Inheritance of the **implementation**
Non virtual function	Mandatory	Mandatory
Virtual function	Mandatory	By default Possible to reimplement
Pure virtual function	Mandatory	Implementation is mandatory

More C++

Templates

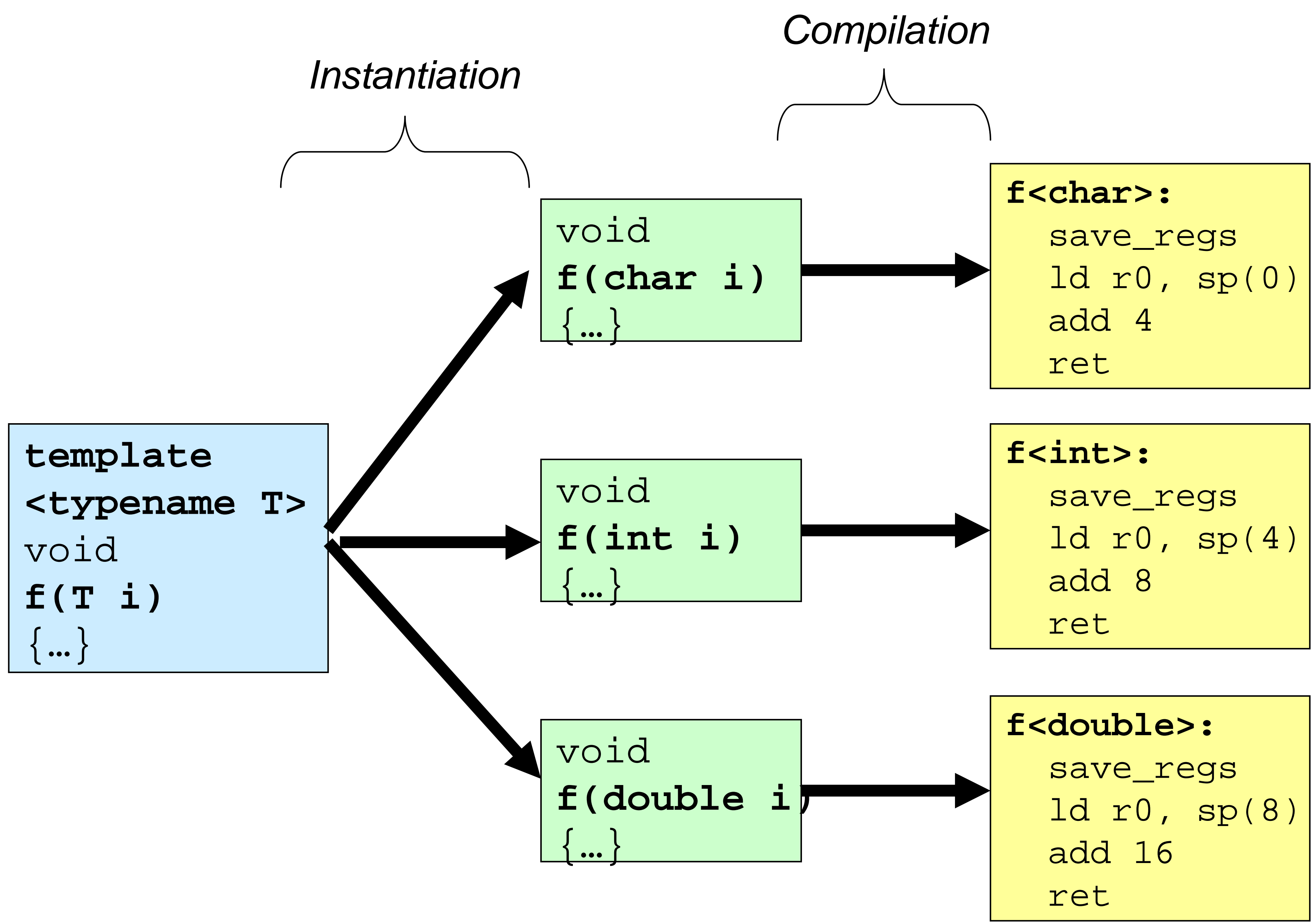
Minimal introduction, only to introduce STL

- A C++ template is just that, a template
- A single template serves as a pattern, so it can be used multiple times to create multiple instantiations



Multiple functions in assembly language

- **Function** templates
- **Class** templates
- **Member** templates


Instantiation
Compilation
template
<typename T>
void
f(T i)
{…}
void
f(char i)
{…}
void
f(int i)
{…}
void
f(double i)
{…}
f<char>:
save_regs
ld r0, sp(0)
add 4
ret
f<int>:
save_regs
ld r0, sp(4)
add 8
ret
f<double>:
save_regs
ld r0, sp(8)
add 16
ret

Standard Template Library (STL)

Containers

- **Sequence**
  - **vector**: array in contiguous memory
  - **list**: doubly-linked list (fast insert/delete)
  - **deque**: double-ended queue
  - stack, queue, priority queue
- **Associative**
  - **map**: collection of (key,value) pairs
  - **set**: map with values ignored
  - multimap, multiset (duplicate keys)
- **Other**
  - **string**, basic_string
  - **valarray:**for numeric computation
  - bitset: set of N bits

Algorithms

- **Non-modifying**
  - find, search, mismatch, count, for_each
- **Modifying**
  - copy, transform/apply, replace, remove
- **Others**
  - unique, reverse, random_shuffle
  - sort, merge, partition
  - set_union, set_intersection, set_difference
  - min, max, min_element, max_element
  - next_permutation, prev_permutation

std::string

Example:

```
#include <string>

void FunctionExample()
{
  std::string s, t;
  char c = 'a';
  s.push_back(c);  // s is now “a”;
  const char* cc = s.c_str();  // get ptr to “a”
  const char dd[] = ‘like’;
  t = dd;  // t is now “like”;
  t = s + t;  // append “like” to “a”
}
```

std::vector

use std::vector,
not built-in C-style array,
whenever possible

Example:

```
#include <vector>
void FunctionExample()
{
  std::vector<int> v(10);
  int a0 = v[3];         // unchecked access
  int a1 = v.at(3);      // checked access
  v.push_back(2);        // append element to end
  v.pop_back();          // remove last element
  size_t howbig = v.size();  // get # of elements
  v.insert(v.begin()+5, 2);  // insert 2 after 5th element
}
```

std::vector (more)

Example:

```
#include <vector>
#include <algorithm>

void FunctionExample()
{
  std::vector<int> v(10);
  v[5] = 3;  // set fifth element to 3
  std::vector<int>::const_iterator it
                = std::find(v.begin(), v.end(), 3);
  bool found = it != v.end();
  if (found) {
    int three = *it;
    }
}
```

Iterators

- *iterator* – kind of generalized pointer
- Each container has its own type of iterator

```
void FunctionExample() {
  stl::vector<int> v;
  stl::vector<int>::const_iterator it = v.begin();
  for (it = v.begin() ; it != v.end() ; it++) {
    int val = *it;
  }
}
```

A few practical issues

Organizational Strategy

image.hh

Header file: Class definition

```
void SetAllPixels(const Vec3& color);
```

image.cc

.cc file: Full implementation

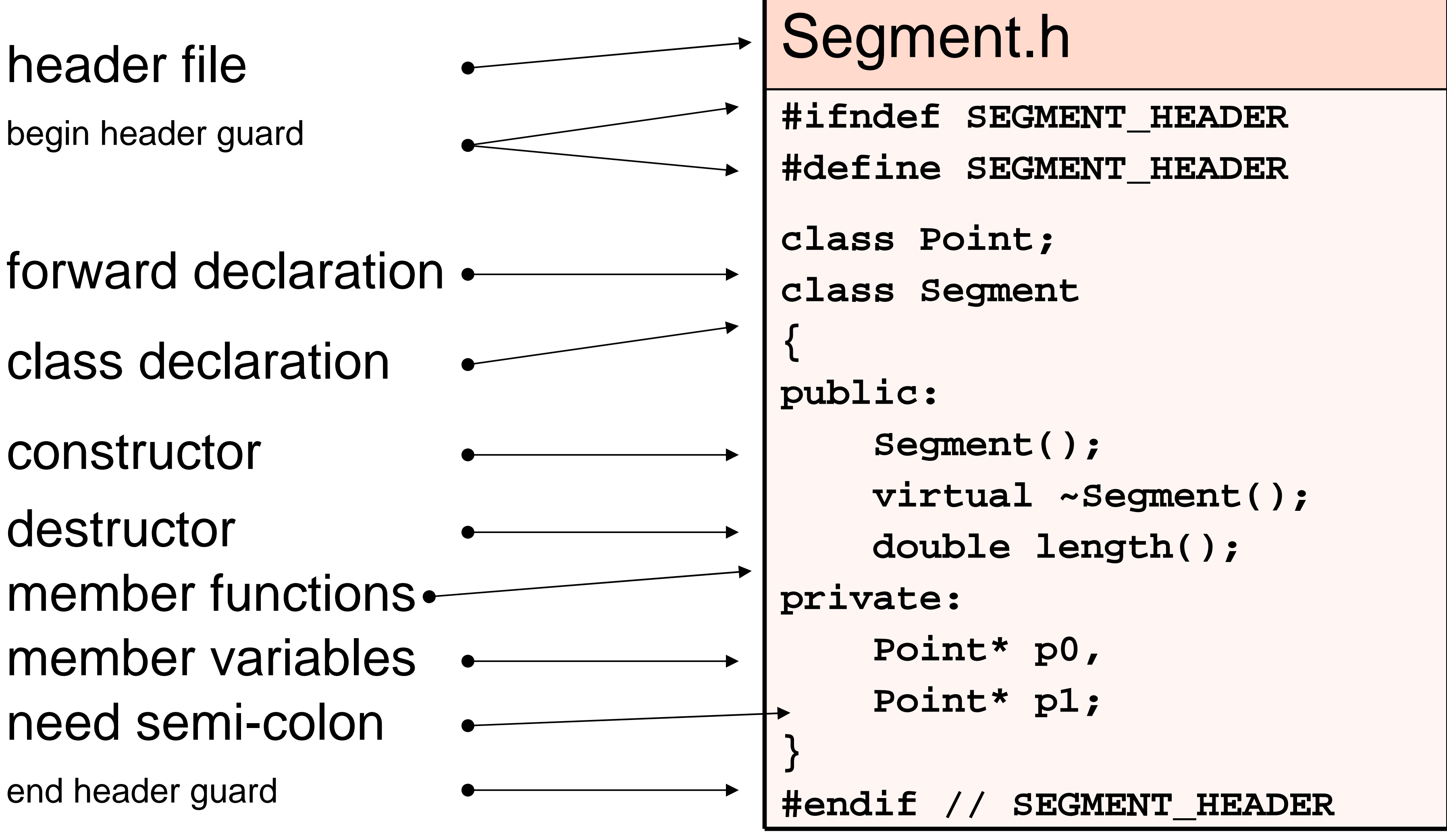
```
void Image::SetAllPixels(const Vec3& color) {
   for (int i = 0; i < width*height; i++)
     data[i] = color;
}
```

main.cc

Main function

```
myImage.SetAllPixels(clearColor);
```

How a Header File looks like



Forward Declaration

Gui.hh

```
Class Gui
{
//
};
```

Controller.hh

```
//Forward declaration
class Gui;

class Controller
{
//...
private:
    Gui* myGui;
//...
};
```

- In header files, only include what you must
- If only pointers to a class are used, use forward declarations

Header file and implementation

File Segment.hh

```
#ifndef SEGMENT_HEADER
#define SEGMENT_HEADER

class Point;
class Segment
{
public:
    Segment();
    virtual ~Segment();
    double length();
private:
    Point* p0,
    Point* p1;
};
#endif // SEGMENT_HEADER
```

File Segment.cc

```
#include “Segment.hh”
#include “Point.hh”
Segment::Segment() // constructor
{
    p0 = new Point(0.,0.);
    p1 = new Point(1.,1.);
}
Segment::~Segment() // destructor
{
    delete p0;
    delete p1;
}
double Segment::length()
{
    function implementation …
}
```

"Segmentation fault (core dumped)"

Typical causes:

```
int intArray[10];
intArray[10] = 6837;
```

Access outside of array bounds

```
Image* image;
image->SetAllPixels(colour);
```

Attempt to access a NULL or previously deleted pointer

These errors are often very difficult to catch and can cause erratic, unpredictable behaviour

UML

Unified Modelling Language

- The UML is a graphical language for
  - specifying
  - visualizing
  - constructing
  - documenting

  the artifacts of software systems
- Define an easy-to-learn, but semantically rich visual modeling language
- Added to the list of OMG adopted technologies in November 1997 as UML 1.1
- Version evolution

Building Blocks

- The basic building blocks of UML are:
  - model elements
    - classes, interfaces, components, use cases etc.
  - relationships
    - associations, generalization, dependencies etc.
  - diagrams
    - class diagrams, use case diagrams, interaction diagrams etc.
- Simple building blocks are used to create large, complex structures

Structural Modeling: Core Elements

Construct	Description	Syntax
class	a description of a set of objects that share the same attributes, operations, methods, relationships and semantics	
interface	a named set of operations that characterize the behavior of an element	«interface»
component	a physical, replaceable part of a system that packages implementation and provides the realization of a set of interfaces.	
node	a run-time physical object that represents a computational resource	
constraint	a semantic condition or restriction	{constraint}

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Structural Modeling: Core Relationships

Construct	Description	Syntax
association	a relationship between two or more classifiers that involves connections among their instances	
aggregation	A special form of association that specifies a whole-part relationship between the aggregate (whole) and the component part	
generalization	a taxonomic relationship between a more general and a more specific element	
dependency	a relationship between two modeling elements, in which a change to one modeling element (the independent element) will affect the other modeling element (the dependent element)	
realization	a relationship between a specification and its implementation	

Class

- Classes can have 4 parts
  - **Name**
  - **Attributes**
  - **Operations**
  - Responsibilities

- Classes can show **visibility** and **types**

- All parts but the Name are optional

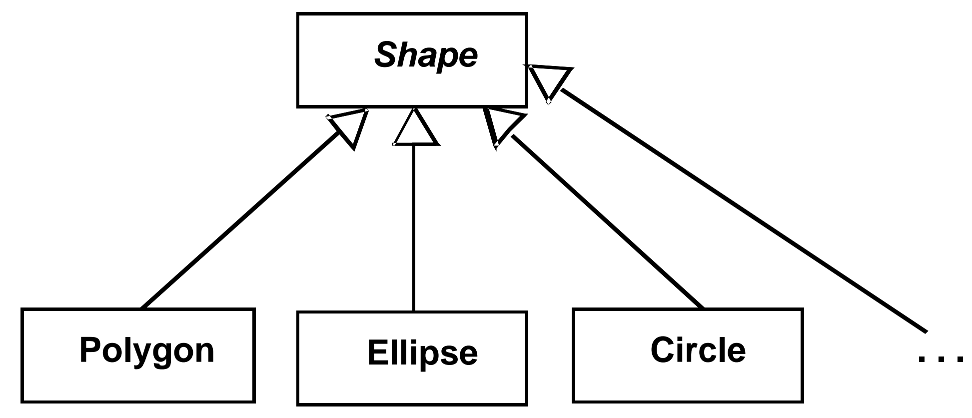
MyClassName

+Some**Public**Attribute : SomeType
-Some**Private**Attribute : SomeType
#Some**Protected**Attribute : SomeType

+ClassMethodOne()
+ClassMethodTwo()

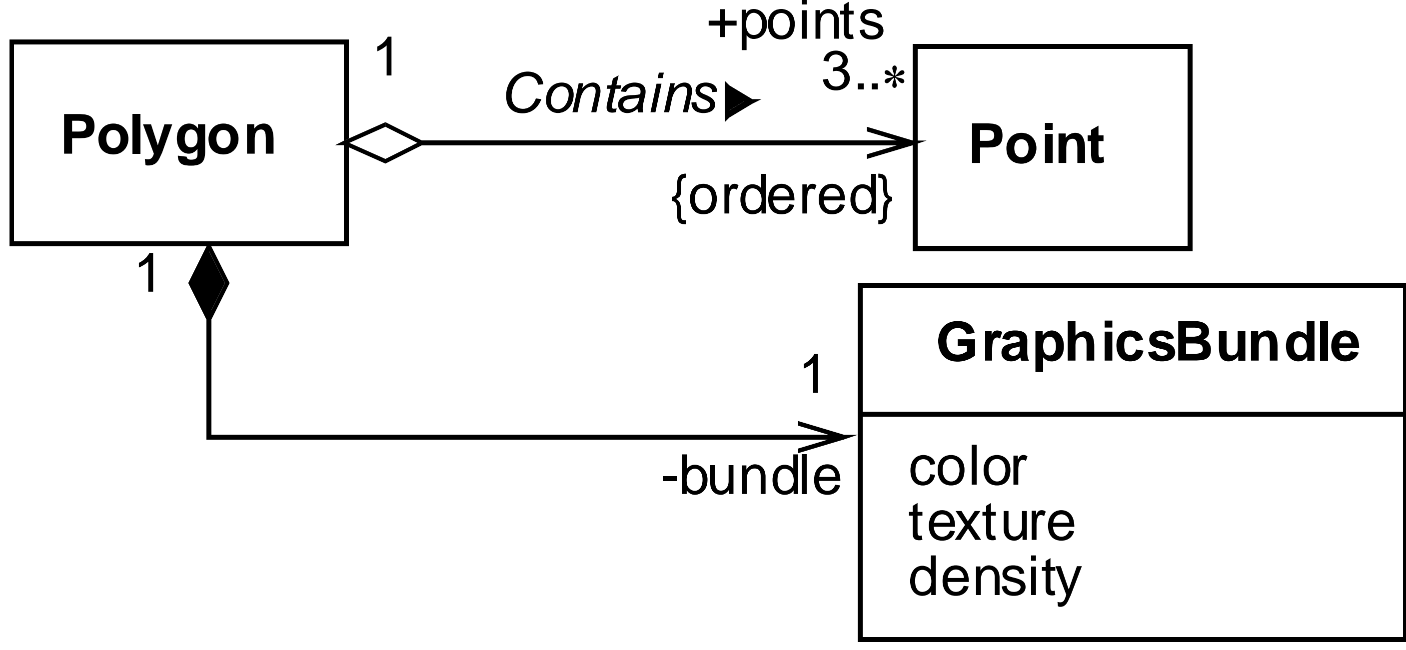
Responsibilities
-- can optionally be described here.

Generalization

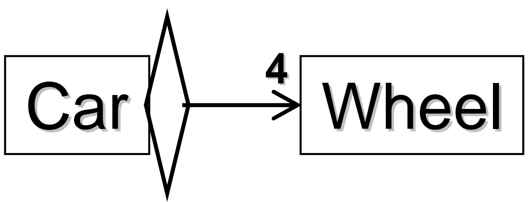


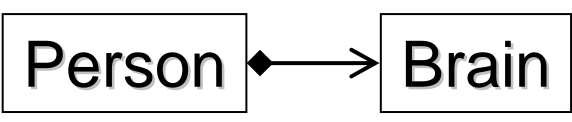
Models inheritance

Associations



Aggregation or Composition?





Aggregation is a relationship in which one object is a part of another

A aggregates B
=
B is part of A, but their lifetimes may be different

Composition is a relationship in which one object is an integral part of another

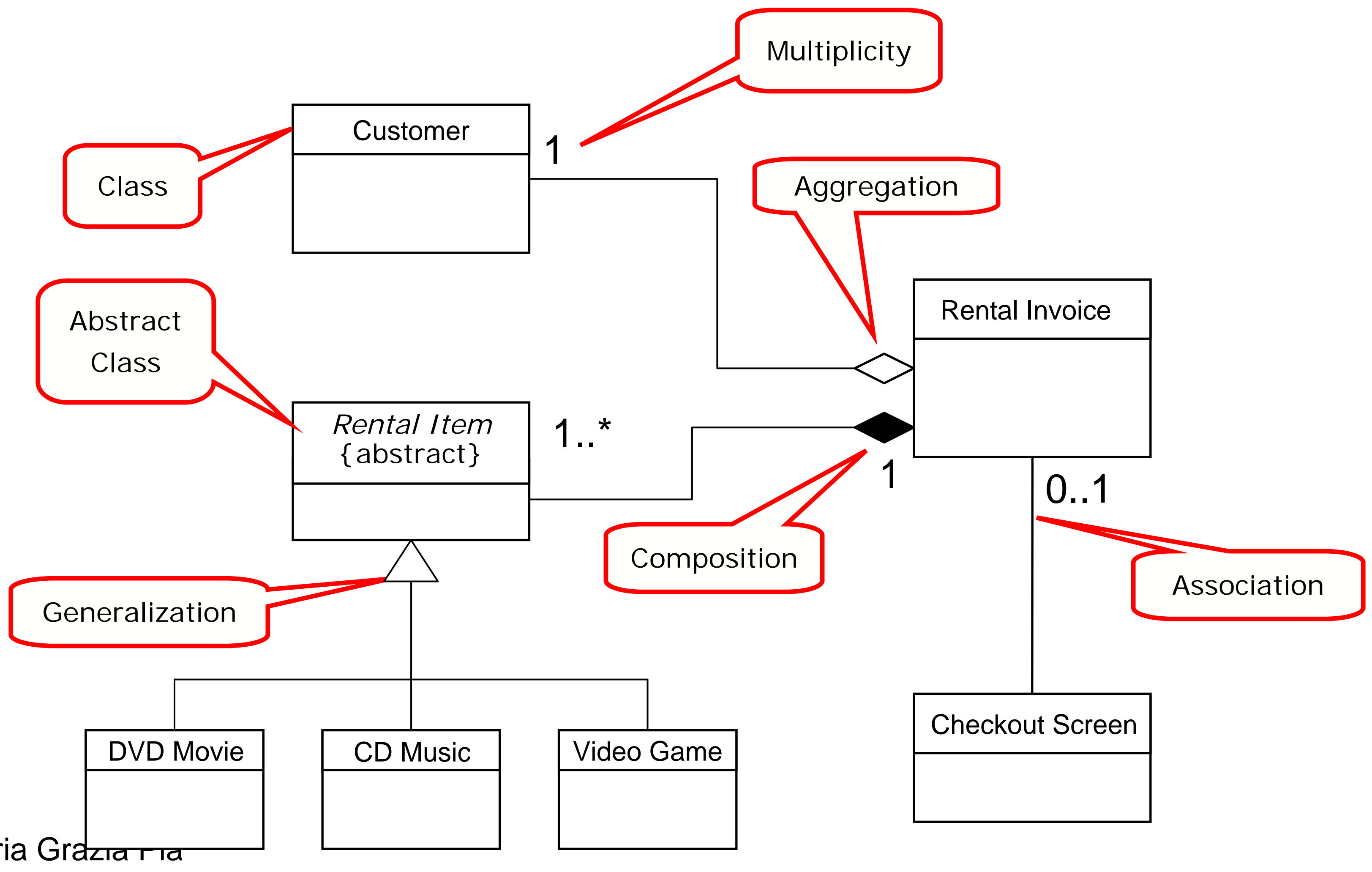
A contains B
=
B is part of A, and their lifetimes are the same

Main UML Diagrams

- **Class** Diagrams
- Use Case Diagrams
- **Collaboration** Diagrams
- **Sequence** Diagrams
- Package Diagrams
- Component Diagrams
- Deployment Diagrams
- Activity Diagrams
- State Diagrams

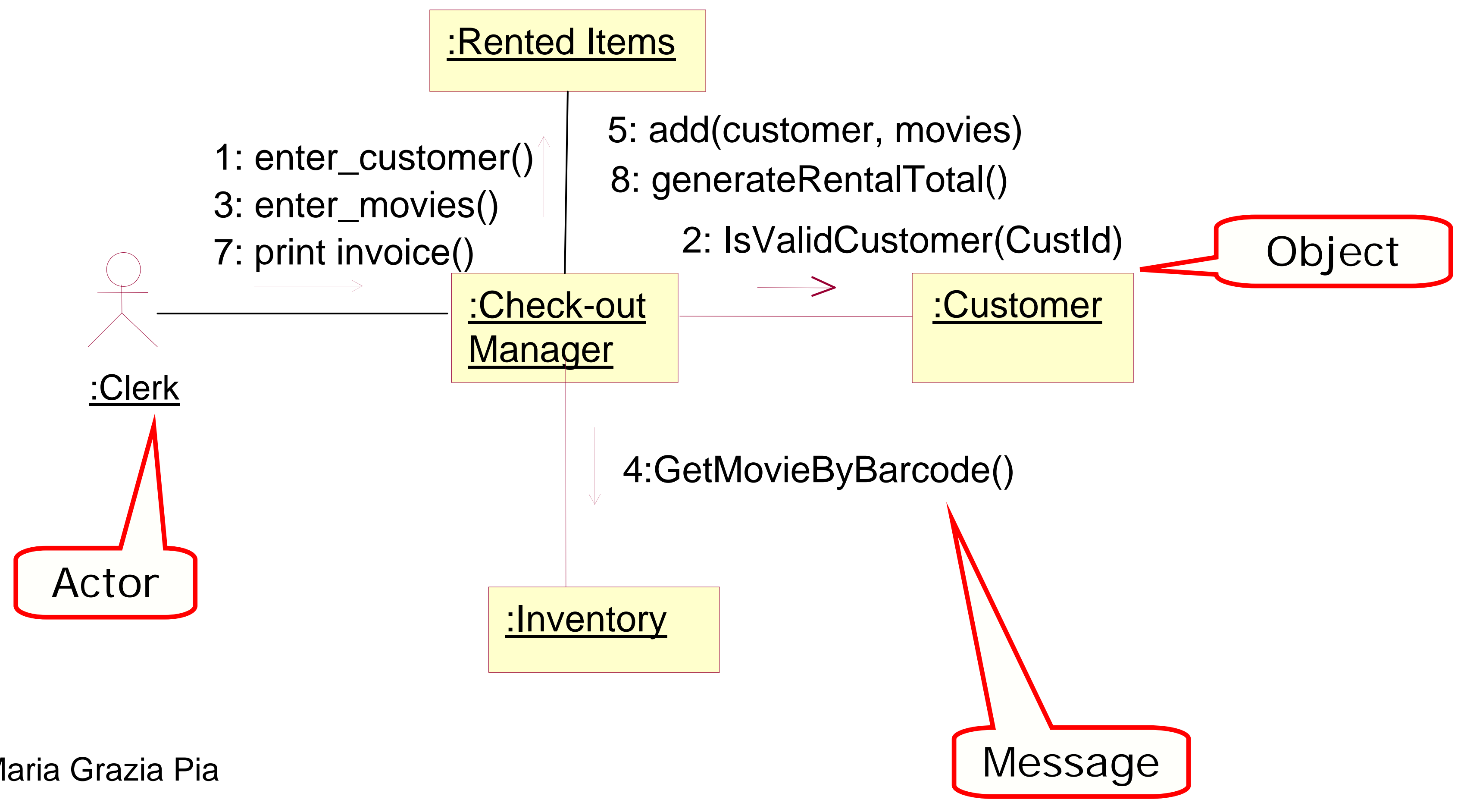
UML Class Diagram

Describe the **classes** in the system
and the **static** relationships between classes



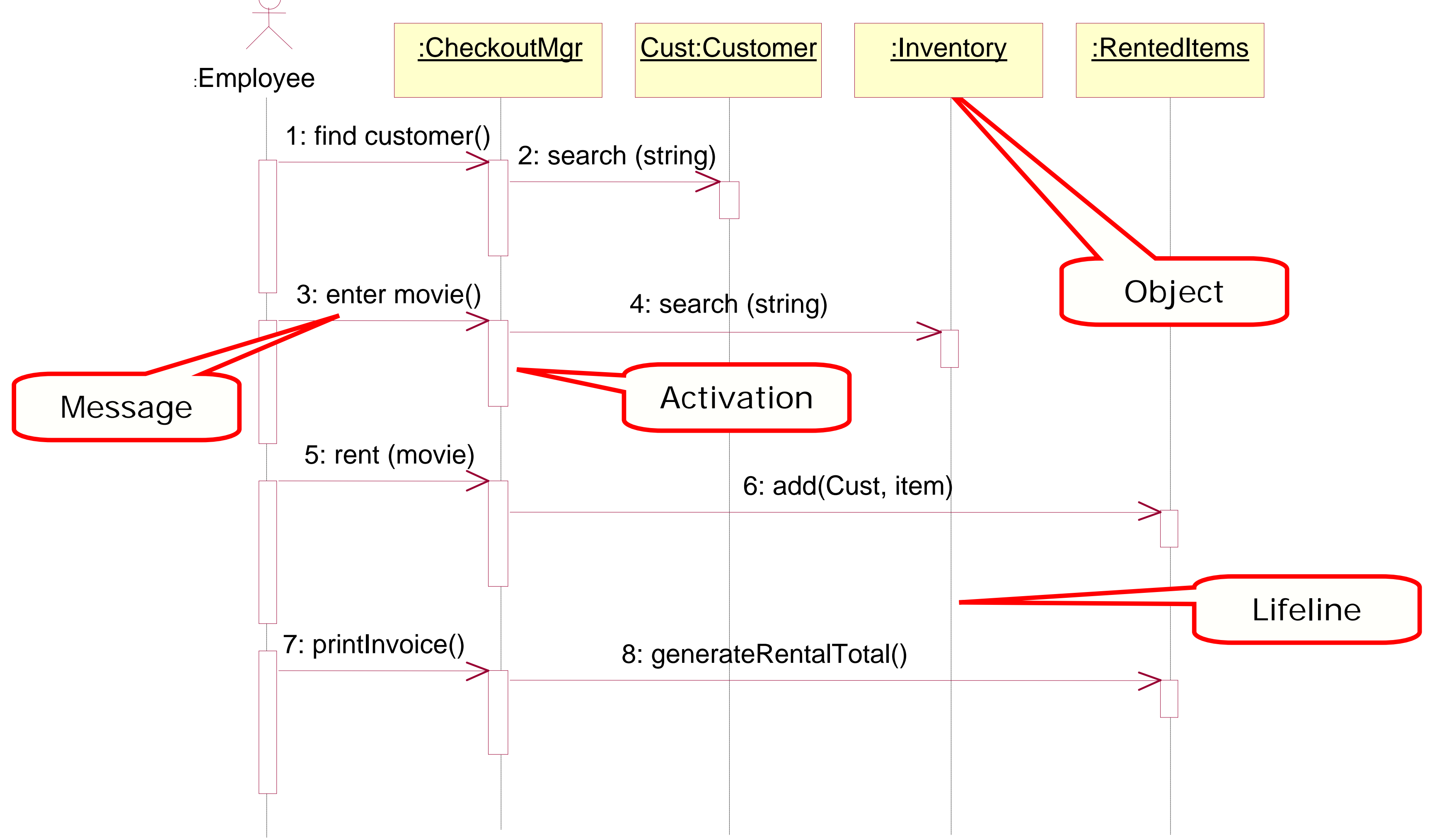
Collaboration Diagram - Rent Movie

Describe object **interactions** organized around the objects and their links to each other



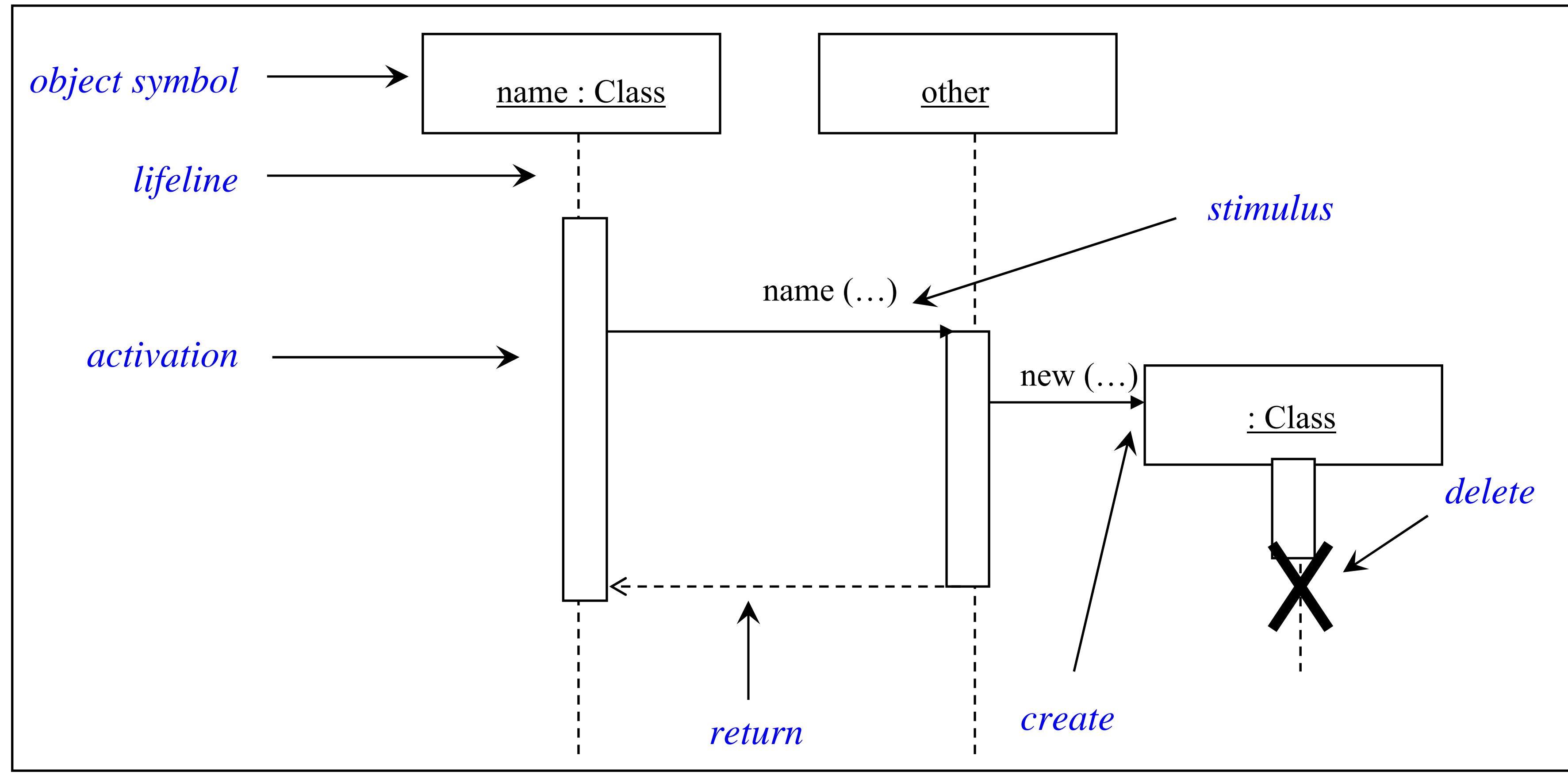
Sequence Diagram - Rent Movie

Describe interactions between objects arranged in time sequence



Sequence and collaboration diagrams can be cloned from each other

Sequence Diagram



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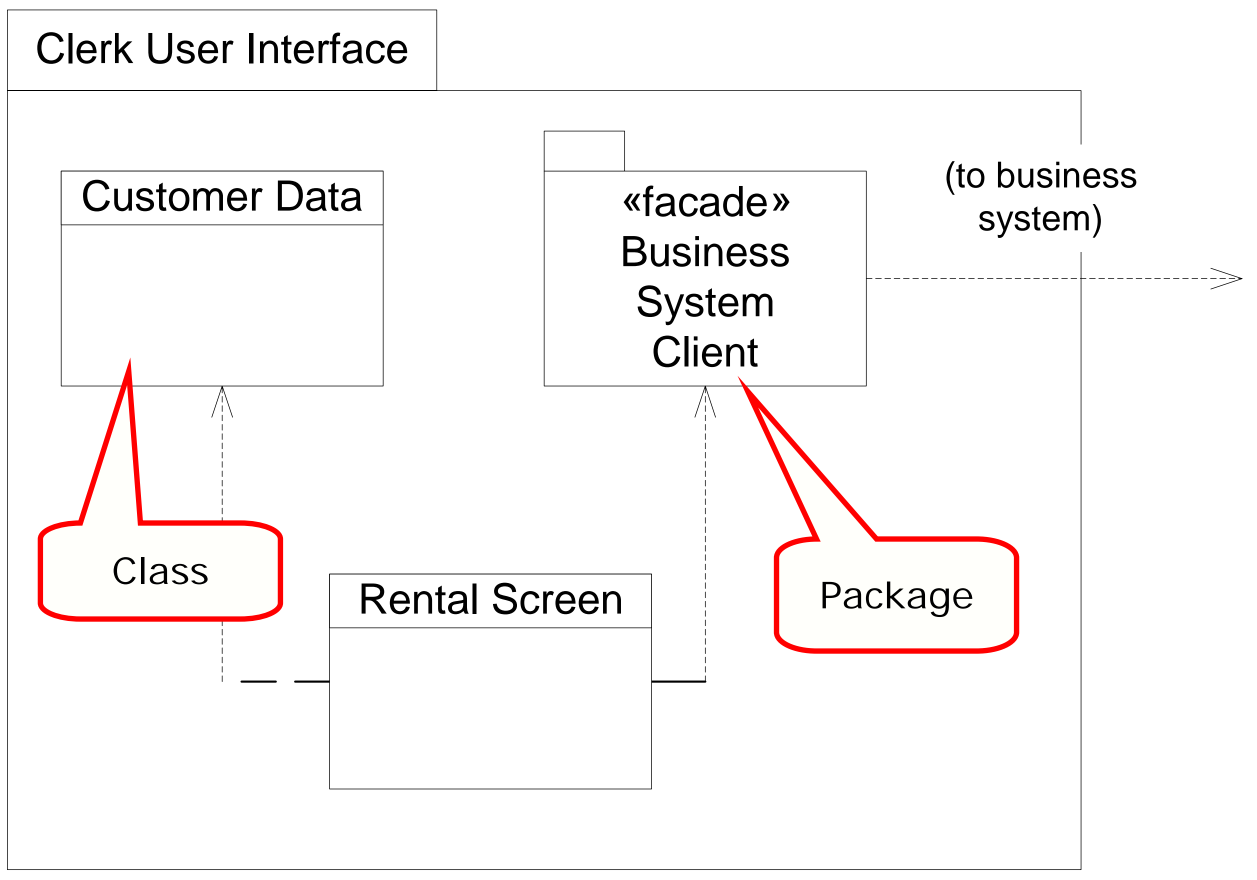
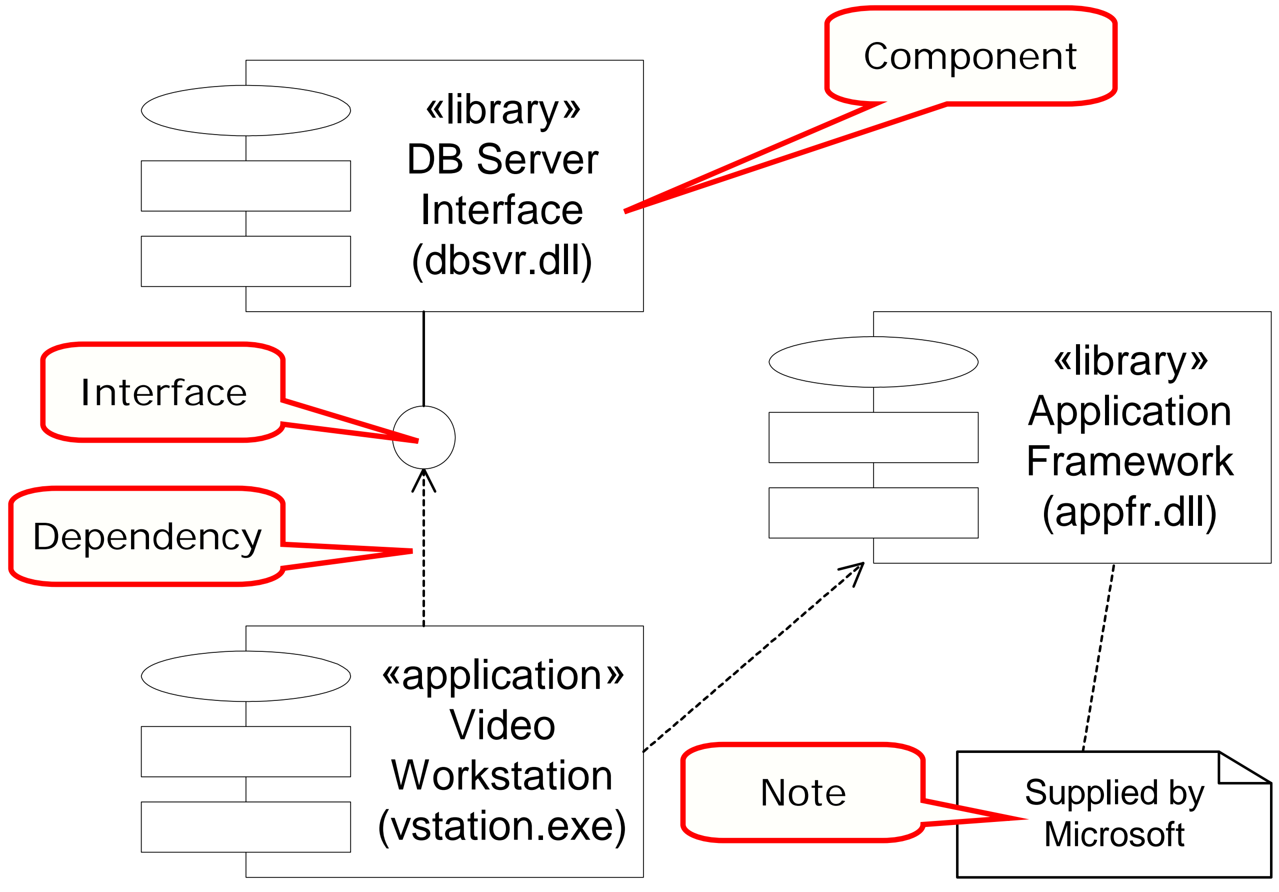
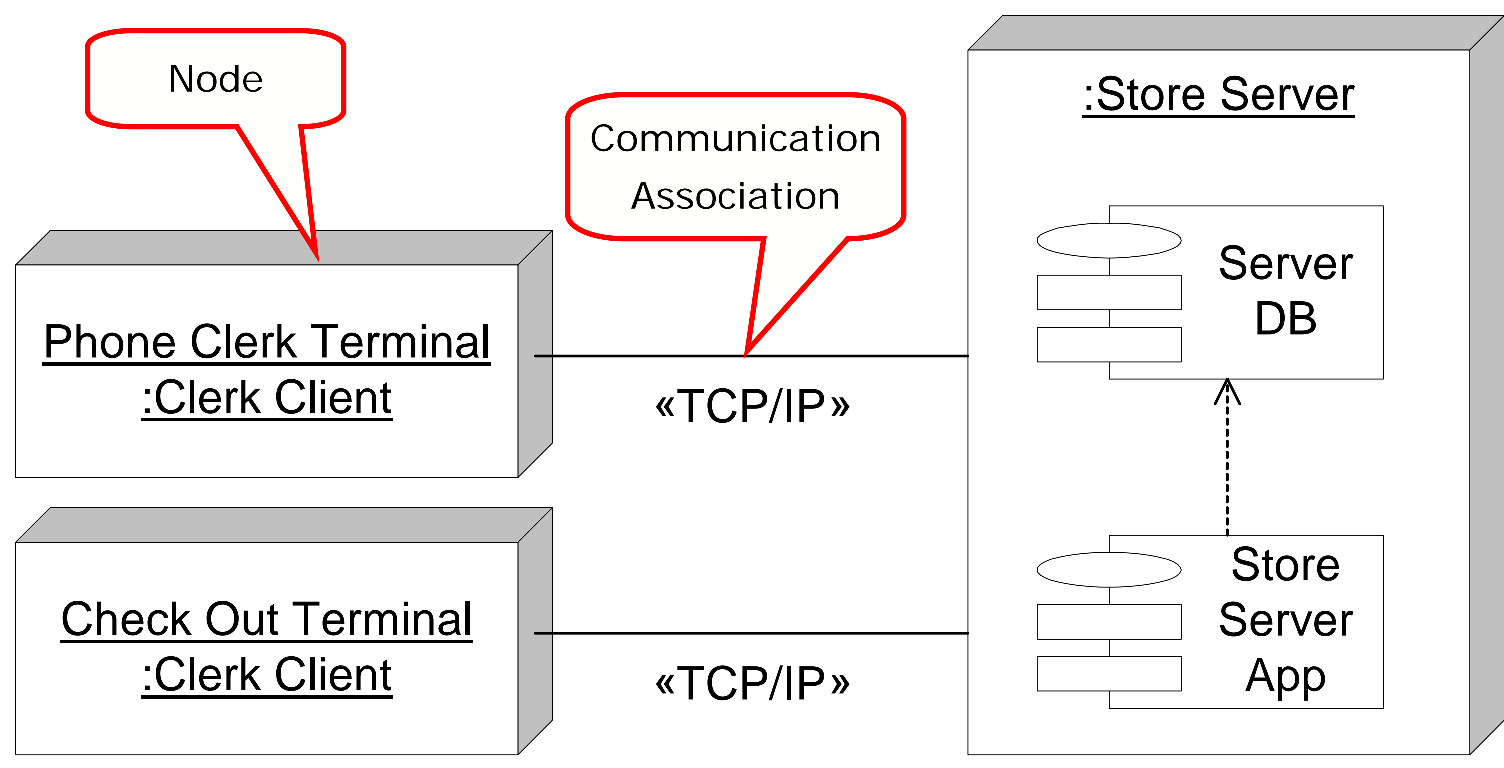
Package Diagram



Component Diagram



Deployment Diagram



Introduction to Design Patterns

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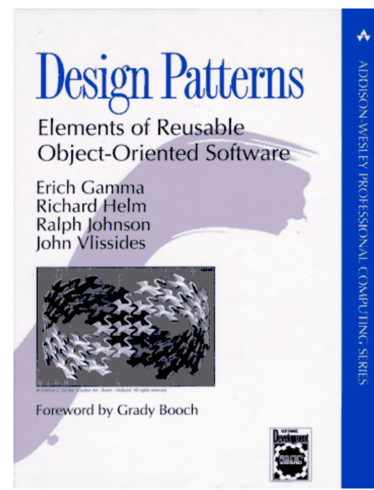
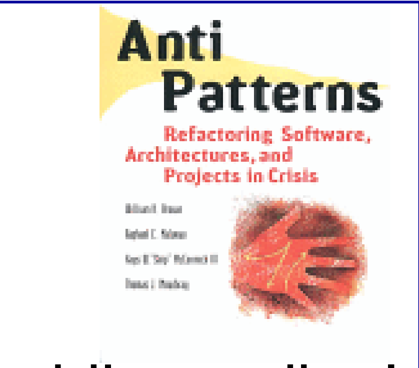
Design Patterns

Gamma, Helm, Johnson and Vlissides
Design Patterns,
Addison-Wesley 1995, ISBN 0-201-63361-2
(Gang-of-Four)



- Each design pattern names, explains and evaluates an important and recurring design in object-oriented systems
- A design pattern makes it easier to reuse successful designs and architectures
- Three categories of patterns
  - Creational
  - Structural
  - Behavioral



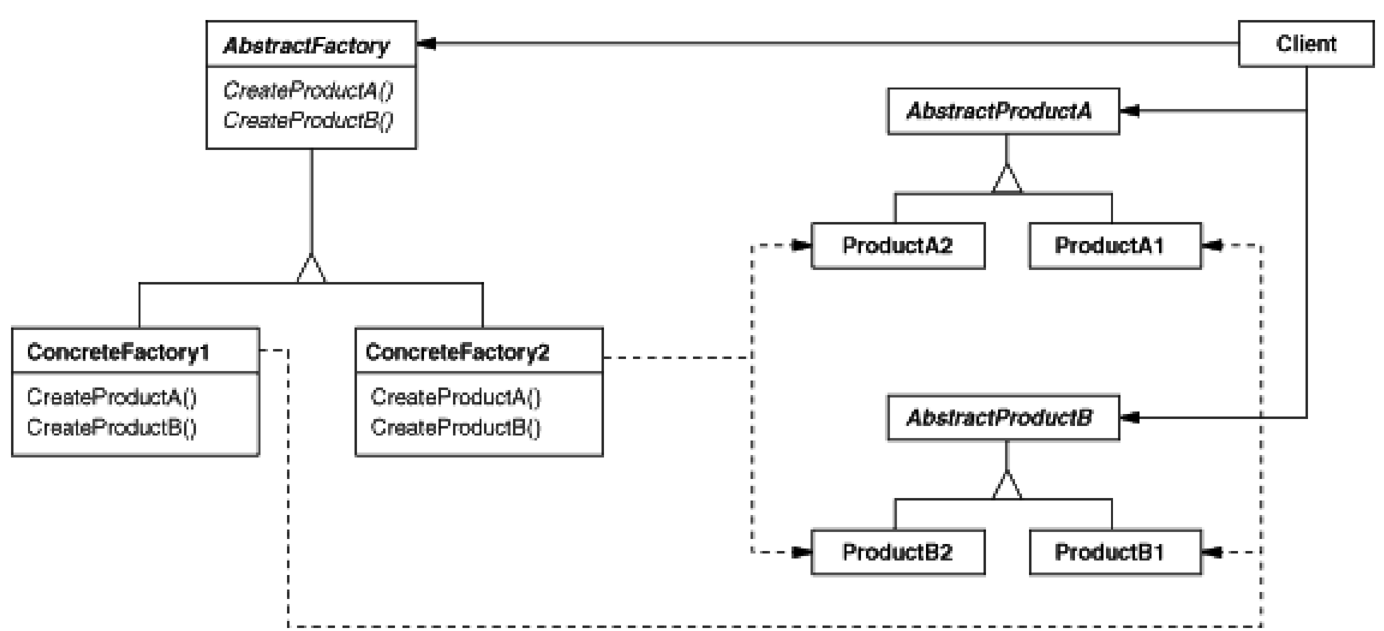
…also worthwhile reading!

List of design patterns

- Abstract Factory
- Adapter
- Bridge
- Builder
- Chain of Responsibility
- Command
- Composite
- Decorator
- Facade
- Factory Method
- Flyweight
- Interpreter
- Iterator
- Mediator
- Memento
- Observer
- Prototype
- Proxy
- Singleton
- State
- Strategy
- Template Method
- Visitor

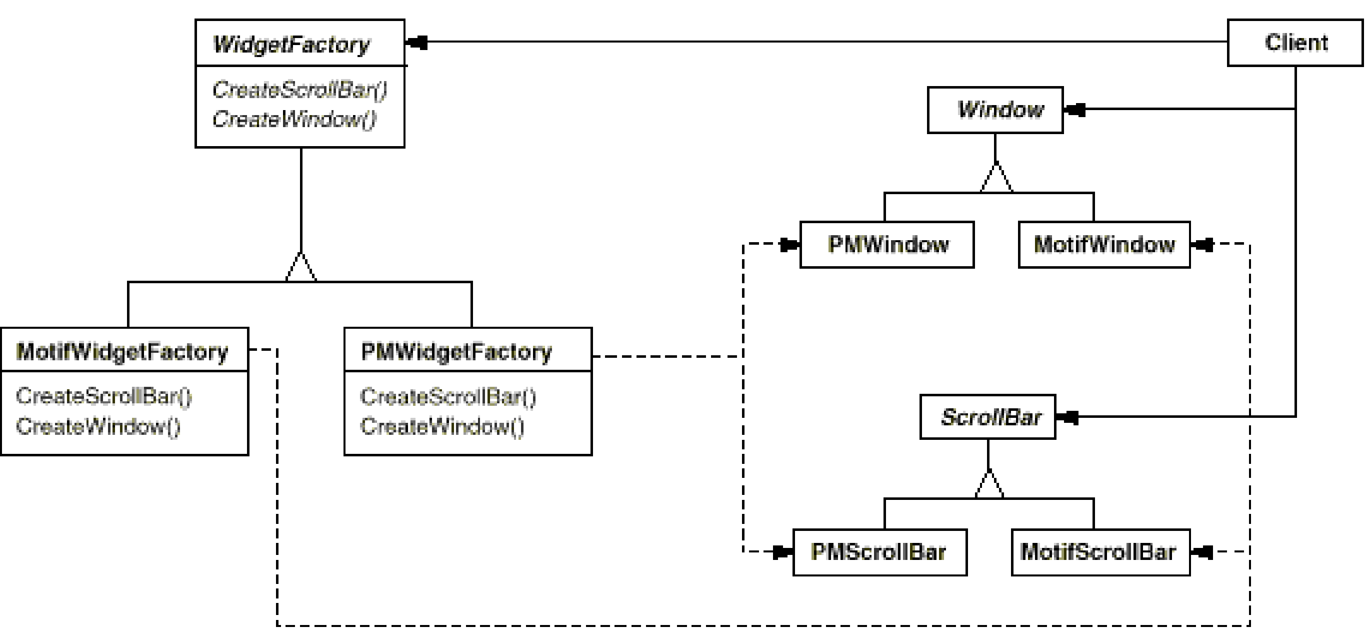
Abstract Factory

Provide an interface for creating families of related or dependent objects without specifying their concrete classes



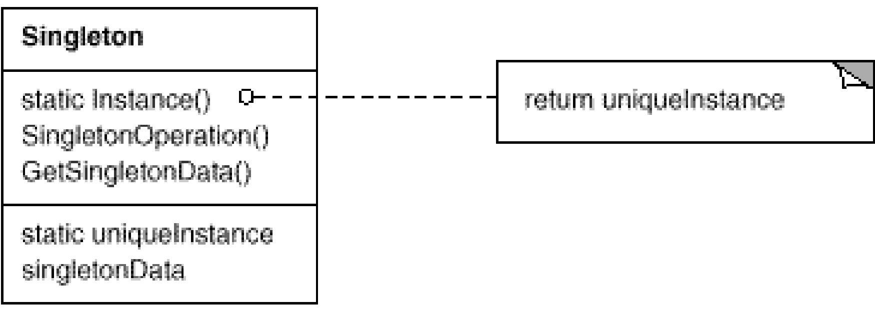
- AbstractFactory
  - declares an interface for operations that create product objects
- ConcreteFactory
  - implements the operations to create concrete product objects

Abstract Factory example

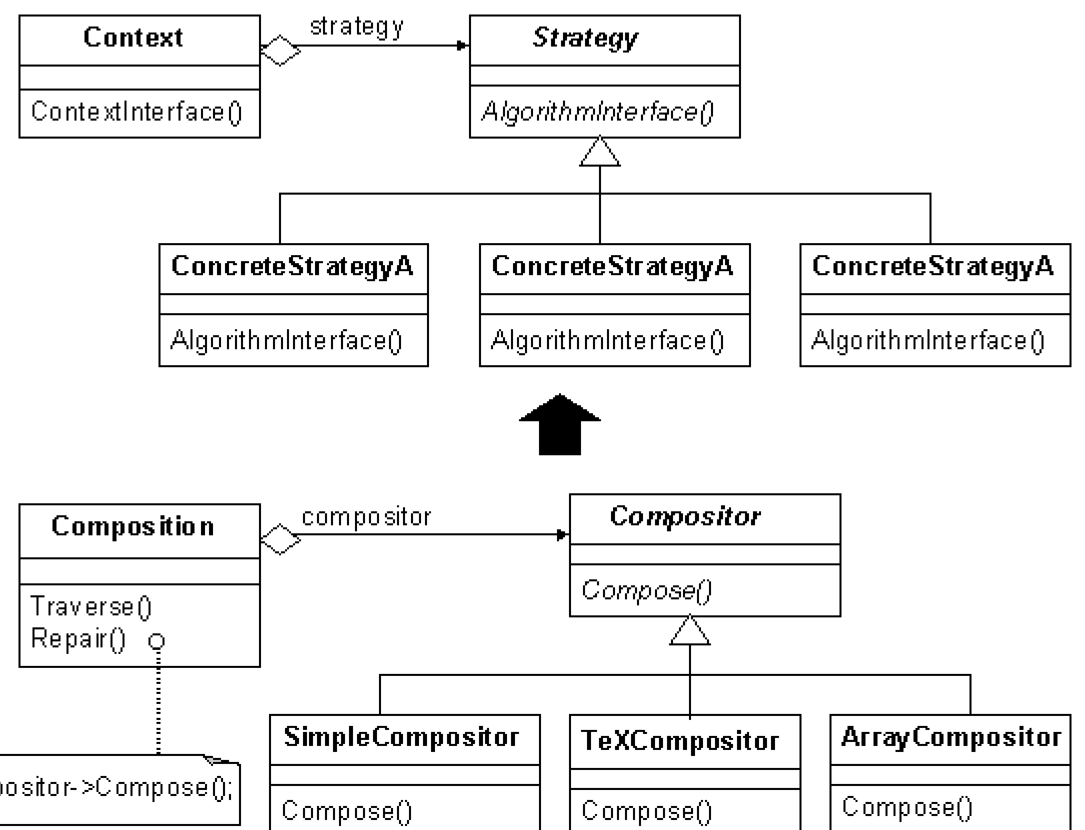


Singleton

- Ensure a class only has one instance, and provide a global point of access to it
  – Many times need only one instance of an object
    - one file system
    - one print spooler
    - …
- Singleton
  – defines a class-scoped instance() operation that lets clients access its unique instance
  – may be responsible for creating its own unique instance



Strategy



- Allow any one of a family of related algorithms to be easily substituted in a system
- Define a family of algorithms, encapsulate each one, and make them interchangeable
- Strategy lets the algorithm vary independently from clients that use it

Further reading

Books

+ Get a good mentor!

- There are many good C++, OOP, UML, OOAD books on the market
  - *The following is just a personal selection*

Introductory C++ book

- S. B. Lippman, J. Lajoie, C++ primer, Addison-Wesley

Reference STL book

- N. Josuttis, The C++ Standard Library, A Tutorial and Reference, Addison-Wesley

More advanced C++ books

- S. Meyers, Effective C++, Addison-Wesley
- S. Meyers, More effective C++, Addison-Wesley
- S. Meyers, Effective STL, Addison-Wesley

UML books

- M. Fowler, UML distilled, Addison-Wesley
- G. Booch et al., The Unified Modeling Language, User Guide, Addison-Wesley

Basic OOAD books

- G. Booch, OO analysis and design, Addison-Wesley
- R. Martin, Designing OO C++ applications using the Booch method, Prentice Hall

Advanced design books

- E. Gamma et al., Design Patterns, Addison-Wesley
- John Lakos, Large-Scale C++ Software Design, Addison-Wesley

Hardcore design book

- A. Alexandrescu, Modern C++ design, Addison-Wesley