POLYMORPHISM

There are three major concepts in object-oriented programming:

1. **Encapsulation** (Classes, Objects)
   Data and related functions are placed into the same entity.
   Provides **data abstraction** and **information hiding** (`public:` interface, `private:` implementation)
2. **Inheritance**
   Is-a relation, generalization-specialization
   Promotes code reusability.
   Enables the use of common interfaces for different classes (types).
3. **Polymorphism** (dynamic polymorphism, subtyping, or inclusion)
   The derived class can override the methods of the base class.
   Allows the object type to determine which specific implementation of a method to call at run time (dynamic method binding).
   Requires inheritance between classes.
   Improves the design with common interfaces.

In these lecture slides, what we refer to as "polymorphism" is runtime, dynamic polymorphism, formally known as subtyping (or inclusion polymorphism).

Types of Polymorphism: **Polymorphism** means "**taking many shapes**".

- Programming language theory defines various forms of polymorphism.
- Definition given by Bjarne Stroustrup:
  "Polymorphism is providing a **single interface** to entities of **different types**.
  Virtual functions provide dynamic (run-time) polymorphism through an interface provided by a base class.
  Overloaded functions and templates provide static (compile-time) polymorphism."
- In general, polymorphism is calling different functions with the same name based on the type of the related objects (the object for which the function is called and the parameters).

Two types of polymorphism:

A) Static (compile-time) polymorphism:
- Ad hoc polymorphism: function and operator overloading
  Examples: `void print(int);` `void print (sdt::string);` or `obj1 + obj2;` `obj1 + 5;`
- Parametric polymorphism: function and class templates
  Generic programming (see Chapter 09)

B) Dynamic (run-time) polymorphism:
- Which method to call is determined at **runtime** based on the type of the object that receives the message.

Polymorphism in real life:

- In real life, there is often a collection of different objects that, given identical instructions (messages), should take different actions based on their types.

Example: The dean is a professor. Professors and deans visit the rector.
- Sometimes, professors and deans may visit the university's rector.
- The rector is also a professor, but we will ignore this relationship for this example.
- When the rector meets with a visitor, they ask the visitor to print their information.
- The rector sends the same `print()` message to a professor or dean.
- Different types of objects (professor or dean) have to print different information.
- The rector **does not know the type** of visitor (professor or dean) and always sends the **same** `print()` message.
- Depending **on the type** of visitor (receiving object), **different actions** are performed.
- The same message (print) works for everyone because everyone knows how to print their information.
- The rector's single instruction is polymorphic because it works differently for different kinds of academic staff.

Dynamic (runtime) polymorphism in programming:

- In C++, dynamic (runtime) polymorphism means that a call to a member function will cause a **different function** to be executed depending on the **type of object** that receives the message.
- In runtime polymorphism, **the sender of the message does not need to know the type of the receiving object at compile time.**
- Dynamic polymorphism occurs in classes that are related by **inheritance**.

Example:

- Remember: A pointer (or reference) to base (e.g., `Professor`) can also point to derived (e.g., `Dean`) objects because `Dean` is a `Professor`.

```
Professor *ptr;           // ptr can point to Professor and Dean objects
...                       // The address pointed to by ptr will be determined at runtime
if (condition) ptr = &professor_obj;
     else      ptr = &dean_obj;

ptr->print();             // which print method at compile time (professor or dean)?
```

- If `print()` is a polymorphic function, the decision of which function to call will be made at **runtime** based on the type of object pointed to by the pointer `ptr`.

Calling redefined, nonvirtual member functions using pointers (name hiding, no polymorphism)

- The base and derived classes have methods with the same signature (name and parameters).
- The methods are **not virtual** (**no dynamic polymorphism**).
- We access methods of the base and derived classes using pointers.

Example: Professors and deans visit the rector

```
class Professor{                   // Base class: Professor
public:
  void print() const;
   :
};

class Dean : public Professor{     // Derived class: Dean
public:
  void print() const;              // redefined
   :
};
```

- Both classes have a function with the same signature: `print()`.
- They print different information. `Professor`: name and research area.
  `Dean`: name, research area, and faculty name.
- In this example, these functions are not `virtual` (**not polymorphic**).

Calling redefined, nonvirtual member functions using pointers (cont'd)

Example (cont'd): Professors and deans visit the rector

```
class Rector {              // User class: Rector
public:
   void meetVisitor(const Professor*) const;
};
```

Association between Rector and Professor

A pointer to the base class

```
// The input parameter is a pointer to Professor (Base)
void Rector::meetVisitor(const Professor* visitor) const
{
   visitor->print();       // which print?
}
```

Since the input parameter is a pointer to the `Professor` (base) class, we can call this method by sending the address of a `Professor` object or the address of a `Dean` object.

The visitor can be any professor, e.g., department head or dean.

Calling Redefined, nonvirtual member functions using pointers (cont'd)

Example (cont'd): Professors and deans visit the rector

Example e08_1a.cpp

```
int main(){
   Rector itu_rector;
   Professor prof1("Professor 1", "Robotics");
   Dean dean1("Dean 1","Computer Networks","Engineering Faculty");

   Professor *ptr;                          // A pointer to Base type
   char input_char;
   std::print("Professor or Dean (p/else)); std::cin >> input_char;
   if (input_char =='p') ptr = &prof1;      // ptr points to a professor
       else              ptr = &dean1;      // ptr points to a dean
   itu_rector.meetVisitor(ptr);             // which print?
```

- In this example, when the statement `visitor->print() calls print()`, the `print()` function of the base class (`Professor`) gets executed in both cases.
- `Professor::print()` is invoked for both of the objects (`prof1` and `dean1`).
- The compiler ignores the **contents** of the pointer and chooses the (nonvirtual) member function that matches the **type** of the pointer.   `meetVisitor(const **Professor* visitor**)`

Since the methods are **not virtual**, the decision in `meetVisitor` is made at **compile time**.
The same `print()` **function** is invoked **for all types**. This is **not polymorphism!**

Calling redefined, virtual member functions using pointers (Dynamic Polymorphism)

- We make a single change in the program `e08_1a.cpp` and place the keyword **`virtual`** in front of the declaration of the `print()` function in the base class.

Example:

```
class Professor{                     // Base class: Professor
public:
  virtual void print() const;        // A virtual (polymorphic) function
    :
};
class Dean : public Professor{       // Derived class: Dean
public:
  void print() const;                // It is also virtual (polymorphic)
    :
};
```

The `virtual` keyword is optional (not mandatory) for the derived class.
If a method of `Base` is `virtual`, the redefined method in `Derived` is also `virtual`.

```
// The input parameter is a pointer to Professor (Base) class
void Rector::meetVisitor(const Professor* visitor) const
{                                    // We did not change the methods of Rector
   visitor->print();                 // Which print?
}
```

Example e08_1b.cpp

Calling redefined, virtual member functions using pointers (Polymorphism) (cont'd)

- Since the `print()` functions are virtual, **functions** are executed depending on the **contents** of the pointer, **rather than** its **type**.
- The decision is made at **runtime** for `visitor->print()`.

Virtual (polymorphic) functions are called based on the **types of objects** that the pointer `visitor` points to, **not** the type of the pointer itself.

- The `meetvisitor` method of `Rector` does not "know" which `print` method to call at compile time.
- The type of the pointer `visitor` is `Professor` (Base). It is fixed.
- The types of objects that the pointer `visitor` points to can change at runtime.
  Based on the contents of the pointer, different functions are called.
  If `visitor = &prof1` then `Professor::print()`
  If `visitor = &dean1` then `Dean::print()`
- Runtime polymorphism provides flexibility in design, as we will cover in this chapter.

Using a reference to base class to pass arguments

- Note that, in C++, we prefer to use references instead of pointers to pass arguments to functions.
  Example:
  - We can write the `meetVisitor` method of the `Rector` class and the main function as follows:

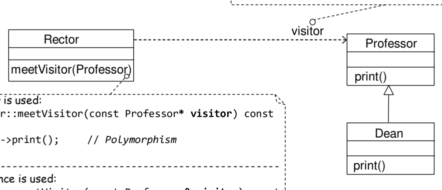
```
// The input parameter is a reference to the Professor (Base) class
void Rector::meetVisitor(const Professor& visitor) const
{
     visitor.print();         // Polymorphism if print() is virtual
}

int main() {
   Rector itu_rector;
   Professor prof1("Professor 1", "Robotics");
   Dean dean1("Dean 1","Computer Networks","Engineering Faculty");
   char input_char;
   std::print("Professor or Dean (p/d)"); std::cin >> input_char;
   if (input_char == 'p') itu_rector.meetVisitor(prof1);
   if (input_char == 'd') itu_rector.meetVisitor(dean1);
    :
```

Example e08_1c.cpp

UML Class diagram of the design:

Professors and deans visit the rector.

The pointer or reference, visitor, in the meetVisitor function can point to objects of the Professor and Dean



If a pointer is used:

```
void Rector::meetVisitor(const Professor* visitor) const
{
   visitor->print();    // Polymorphism
}
```

If a reference is used:

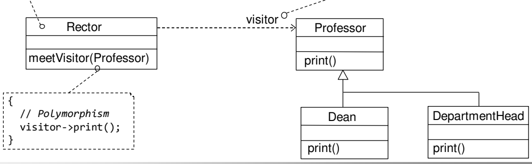
```
void Rector::meetVisitor(const Professor & visitor) const
{
   visitor.print();     // Polymorphism
}
```


Adding a new `Professor` type, e.g., department head, to the system:

- We often want to extend software systems by adding new features.
- While doing this, we do not want to modify the current system because this would increase costs.
- Since we designed the Rector class according to the `Professor` class, following the principle "**Design to Interface**", we can add a new `Professor` type, e.g., `Department Head`, without modifying the existing system (**Open-Closed** "open to extension, closed to modification" **Principle**).

We do not need to modify the `Rector` class.

The pointer, visitor, in the meetVisitor function can point to objects of **all classes** derived from Professor.




```
{
  // Polymorphism
  visitor->print();
}
```

Benefits of Polymorphism so far:

- The major advantage of polymorphism is flexibility.
- In our example, the rector is unaware of the type of visitor.
  They can talk to a professor and a dean the same way (`print()`).
  We do not need to insert a code into the `Rector` class to check the types of visitors.
- If we add a new professor type (a new class) to the system, for example, `DepartmentHead`, we do not need to change the `Rector` class.
- If a class derived from `Professor` is discarded from the system, we do not need to change `Rector`, either.
  The input parameter of the `meetVisitor` method is a pointer or reference to the `Professor` class.
  Therefore, we can call this method by sending either the address of a Professor object or the address of a `Dean` object.
  So, this function can be applied to any class derived from the `Professor`.
- Polymorphism supports important design principles such as "Design to Interface" and "Open-Closed".

Early (static) binding vs. late (dynamic) binding

Type of the pointer and type of the pointed-to object:

- A base-class pointer has two types associated with it: its **static type** and its **dynamic type**.
  Static type is the type it was declared to point to (the compiler knows this), while **dynamic type** is the type of the object it is currently (at runtime) pointing to (or `nullptr`).

Example: `Professor* visitor;`

- The ***static type*** of the pointer, `visitor`, is a pointer to `Professor` (`Professor*`).
- The ***dynamic type*** of the pointer, `visitor`, varies according to the object it points to at runtime.
  Remember, a base-class pointer can point to objects of all direct and indirect derived classes of that base.
  - When `visitor` is pointing to a `Professor` object, its dynamic type is a pointer to `Professor`.
  - When `visitor` is pointing to a `Dean` object, its dynamic type is a pointer to `Dean`.

Determining which function to call:

In our "Dean is a Professor" examples, there are two `print()` functions in memory, i.e., `Professor::print()` and `Dean::print()`.

How does the compiler know what function call to compile for the statement `visitor->print();` ?

```
call Professor::print()  or   call Dean::print()
```


Early (static) binding:

- In e08_1a.cpp, without polymorphism (methods are **not `virtual`**), the compiler has no ambiguity about it.
- It considers the (static) type of the pointer, `visitor`, and always compiles a call to `Professor::print()`, regardless of the object type pointed to by the pointer or reference (dynamic type).
- In ***early*** (***static***) ***binding***, the compiler matches the function call with the correct function definition at compile time.
- In C++, static binding is the default method of resolving function calls when the function is not a virtual function.
- Which function to call is determined at **compile time**.

Late (dynamic) binding:

- In e08_1b.cpp and e08_1c.cpp, since the `print` methods are `virtual`, the compiler does not "know" which function to call when compiling the program.
- The compiler cannot know it because **the decision is made at runtime**.
- So, instead of a simple function call, the compiler places a piece of code there.
- At runtime, when the function call is executed, the code that the compiler placed in the program finds out the type of the object whose address is in `visitor` and calls the appropriate `print()` function, i.e., `Professor::print()` or `Dean::print()`.
- Selecting a function at runtime is called **late binding** or **dynamic binding**.

How late binding (polymorphism) works: The virtual table

- The compiler creates a table—an array—of function addresses, called the **virtual table** for each class that has at least one `virtual` function.
  In examples e08_1b.cpp and e08_1c.cpp, the Professor and Dean classes each have their own virtual tables.
- Every `virtual` method in the class has an entry in the virtual table.

Example: Assume that the classes, Professor and Dean, contain two virtual functions.

```
class Professor{
public:
  virtual void readInfo();
  virtual void print() const;
private:
  std::string m_name;
  std::string m_researchArea;
};
```

```
class Dean : public Professor{
public:
  void readInfo();      // virtual
  void print() const;   // virtual
private:
  std::string m_facultyName;
};
```

Virtual Table of `Professor`
& Professor::readInfo
& Professor::print

Virtual Table of `Dean`
& Dean::readInfo
& Dean::print

Calling virtual methods:

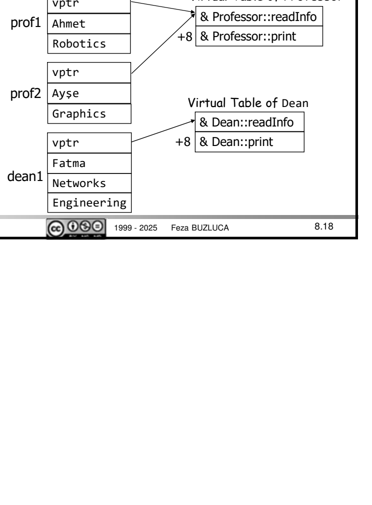
- For a statement that calls a `virtual` function, e.g, `visitor->print()`, the compiler does not (cannot) specify what function will be called at compile time.
- For a `virtual` function call, the compiler creates code that will look at the active object's virtual table to get the address of the appropriate member function to run.
- Thus, for virtual functions, the object itself (rather than the compiler) determines what function is called at runtime.
- Objects of classes with `virtual` functions contain a pointer (**vptr**) to the class's virtual table.
- The pointer, **vptr**, is used to access the object's virtual table at runtime.
  These objects are slightly larger than objects without virtual methods.

Calling virtual methods (cont'd):

Example:

```
int main(){
  Professor prof1("Ahmet", "Robotics");
  Professor prof2("Ayse", "Graphics");
  Dean dean1("Fatma","Networks","Engineering");
  :
```

The objects of `Professor` and `Dean` contain pointers to their virtual tables.



Calling nonvirtual and virtual methods:

Nonvirtual print() function:

- If the `print()` function was not virtual, the statement `visitor->print()` in the `meetVisitor()` method would be compiled as follows:

```
this ← visitor       ; this points to the active object
call Professor::print ; static binding, compile time
```

Virtual print() function (dynamic polymorphism):

- If the `print()` function is `virtual`, the statement `visitor->print()` in the `meetVisitor()` method will be compiled as follows:

```
this ← visitor       ; this points to the active object
ptr ← [this]         ; Read vptr from the object. ptr ← vptr
call [ptr + 8]       ; dynamic binding, run-time
```

`ptr` points to the first row of the virtual table.
The first rows of the tables store the addresses of the `readInfo()` methods.
If the address length is 8 bytes in our system, we add 8 to the pointer to access the second row that stores the address of the `print()` method.

- Late binding requires a small amount of overhead but provides an enormous increase in power and flexibility.
- A few additional bytes per object and slightly slower function calls are small prices to pay for the power and flexibility offered by polymorphism.

Dynamic Polymorphism does not work with objects!

- Be aware that the dynamic polymorphism works only **with pointers and references** to objects, **not with objects** themselves.
- When we use an object's name to call a method, it is clear at compile time which method will be invoked.
- There is no need to determine which function to call at runtime.
- Thus, dynamic polymorphism does not work when we use an object's name to call a method.

Example:

```
int main(){
  Professor prof1("Ahmet", "Robotics");
  Professor prof2("Ayşe", "Graphics");
  Dean dean1("Fatma", "Networks", "Engineering");
  prof1.print();       // not polymorphic. Professor::print()
  dean1.print();       // not polymorphic. Dean::print()
```

- Calling virtual functions has an overhead because of indirect calls via tables.
- Do not declare functions as `virtual` if it is not necessary.

The rules about `virtual` functions

- To create a `virtual` (polymorphic) function in a derived class, its definition must have the **same signature** as the `virtual` function in the base class.
- Note that `const` specifications must also be identical. For example, if the base class method is `const`, the derived class method must also be `const`.
- If the signatures (parameters or `const` specifiers) of methods are different, the program will **compile without errors**, but **polymorphism** (`virtual` function mechanism) **will not work**.
- In this case, the function in the derived class redefines the function in the base (name hiding) and operates with static binding.

Example:

```
class Professor{
public:
  virtual void print() const;
    :
};
class Dean : public Professor{
public:
  void print();   // Not virtual
    :
};
```

Different signatures!

- No compiler error
- No dynamic polymorphism

You can try it by deleting the `const` specifiers of the `print` function of the `Dean` class in the programs e08_1b.cpp and e08_1c.cpp.

The rules about `virtual` functions (cont'd)

- If the signature (name, parameter list, and `const` specifier) of a function in a derived class is the same as that of the `virtual` function declared in the base class, then their **return types** must also be the same.

  Otherwise, the derived class function will not compile.

  Therefore, the program on the right will cause a compiler error.

Example (same signatures, different return types):

```
class Professor{
public:
  virtual void print() const;
    :
};
class Dean : public Professor{
public:
  int print() const; // Error!
    :
```

Error: Same signatures but different return types

The signatures (including `const` specifiers) **are different, return type is also different:**

- This is name hiding, and the new function will operate with static binding.
  - No compiler error
  - Name hiding
  - Static binding
  - **No dynamic polymorphism**

Example (different signatures, different return types):

```
class Professor{
  virtual void print() const;
class Dean : public Professor{
  int print(int) const;  //OK! Name hiding
```


`override` Specifier

- Remember, to provide polymorphic behavior, the signatures (parameters or `const` specifiers) of `virtual` methods in base and derived classes must be the same.
- Otherwise, the program will compile without errors, but polymorphism (virtual function mechanism) will not work.
- However, it is easy to make a mistake (a typo) when specifying a virtual function in a derived class.

  For example, if we define a `void Print() const` method in the `Dean` class, it will not be virtual because the name of the corresponding method in the `Professor` class is different, i.e., `void print() const`.

  The program may still be compiled and executed but may not work as expected.
- Similarly, the same thing will happen if we forget the `const` specifier in the derived class method.
- It is difficult to detect these kinds of errors.
- To avoid such errors, we can use the **`override`** specifier for every `virtual` function declaration in a derived class.

`override` Specifier (cont'd)

Example:

```
class Professor{
public:
  virtual void print() const;
  virtual void readInfo();
    :
};
class Dean : public Professor{
public:
  void print() const override;   // OK. Same signature
  void readinfo() override;      // ERROR!
    :
};
```

Typo

- The `override` specification makes the compiler verify that the base class declares a `virtual` method with the same signature.
- If the base class does not have a `virtual` method with the same signature, the compiler generates an error.
- The `override` specification, like the `virtual` one, only appears within the class definition.

  It must not be applied to a method's definition (body).

- Always add an `override` specification to the declaration of a `virtual` function override.
- This guarantees that you have not made any mistakes in the function signatures.
- It safeguards you and your team from forgetting to change any existing function overrides when the signature of the base class function changes.

`final` Specifier

- Sometimes, we may want to prevent a method from being overridden in a derived class.
- We might want to limit how a derived class can modify the behavior of the base class interface, for example.
- We can do this by specifying that a function is `final`.

Example:

```
class Point {                    // Base Class (parent)
public:
  bool move(int, int) final;   // This method cannot be overridden
     :
};
```

Attempts to override `move(int, int)` in classes that have `Point` as a base will result in a compiler error.

`final` Specifier (cont'd)

- We can also specify an entire class as `final`.

Example:

```
class Parent final {         The Parent class cannot be used as a base class.
 ...
};

class Child : public Parent {  Compiler Error !
 ...
};
```

Example:

```
class ColoredPoint final : public Point {
  :
};
```

Now, the compiler will not allow `ColoredPoint` to be used as a base class.
No further derivation is possible from the `ColoredPoint` class.

Summary: Overloading, Name Hiding, Overriding/Polymorphism

Overloading:

- Remember, overloading occurs when two or more methods of the <u>same class</u> or multiple nonmember functions in the same namespace have the **same name but different parameters**.
- Overloaded functions operate with **static binding**.
- Which function to call is determined at **compile time**.
- Depending on the type of parameters, different functions are called.
- It is also called **static** polymorphism or ad hoc polymorphism.

Name hiding:

- Name hiding occurs when a derived class redefines the methods of the base class.
- The overridden methods may have <u>the same or different signatures</u>, but they will have different bodies.
- The methods **are not `virtual`**.
- Redefined methods operate with **static binding**.
- Which function to call is determined at **compile time**.

Summary: Overloading, Name Hiding, Overriding/Polymorphism (cont'd)

Dynamic polymorphism (Overriding):

- The overridden methods have <u>signatures identical to the base class's corresponding methods</u>.
- The methods are specified as **`virtual`**.
- Overridden virtual methods operate with **dynamic binding**.
- Which function to call is determined at **runtime**.
- It is also called **dynamic** polymorphism, subtyping, or inclusion polymorphism.

A heterogeneous linked list of objects with polymorphism

- Remember: In example e07_19.zip, we developed a heterogeneous linked list that can contain `Point` and `ColoredPoint` objects.
- We will extend this program by adding `virtual` (polymorphic) `print` methods to the `Point` and `ColoredPoint` classes.

```
class Point {
public:
  virtual void print() const;     // virtual method
    :

class ColoredPoint : public Point {
public:
  void print() const override;     // virtual method
    :
```

We do not need to modify the `Node` class.

A heterogeneous linked list of objects with polymorphism (cont'd)

- We add a new method, `printAll()`, to the `PointList` class that iterates over the list and calls `print()` methods of all elements consecutively.
- Since some elements are `Point` objects and some are `ColoredPoint` objects, different `print()` methods will be invoked depending on the type of the elements.

```
void PointList::printAll() const {
  if (m_head)                       // if the list is not empty
  {
    Node* tempPtr{ m_head };        // A pointer points to the first node of the list
    while (tempPtr) {
       tempPtr->getPoint()->print();  // POLYMORPHISM
       tempPtr = tempPtr->getNext();  // go to the next node
    }  Get the address of the object    Call the print() pointed by the pointer
       from the current node.          received from the current node.
  }
  else std::println("The list is empty");
}
```

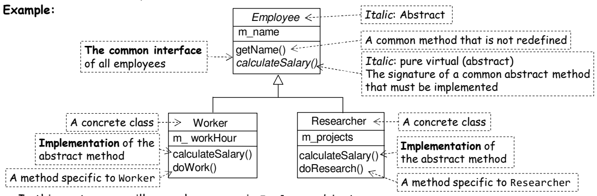
Example e08_2.zip

Remember, there is a **`std::list`** class in the C++ Standard Library. You do not need to write a class to define linked lists.

Abstract Classes

- Sometimes, we do not need to create base class objects; we only need derived ones.
- The base class exists only to store the common properties of derived classes and to present their common services (responsibilities).

Example:



- In this system, we will never have generic `Employee` objects.
- We will create either `Worker` or `Researcher` objects.
- This kind of base class (e.g., `Employee`) is called an ***abstract class***, meaning no actual objects will be created from it.

Abstract Classes (cont'd)

Pure `virtual` functions:

- When we decide to create an abstract base class, we can instruct the compiler to prevent any class user from ever making an object of that class.

  This would give us more freedom in designing the base class because we would not need to plan for actual objects of the class but only for data and functions that derived classes would use.
- To tell the compiler that a class is abstract, we define at least one ***pure virtual function*** in that class.
- A pure `virtual` function is a `virtual` function without a body.

  The body of the `virtual` function in the base class is removed, and the notation **=0** is added to the function declaration.

Example:

- The `Employee` class is abstract, and the method `calculateSalary()` is a **pure virtual** function.

```
class Employee{      // Abstract! It is not possible to create objects
public:
  virtual double calculateSalary() const = 0;      // pure virtual function

int main(){
  Employee  employeeObject{"Employee 1"};           // Compiler Error!
  employeePtr = new Employee {"Employee 1"};        // Compiler Error!
```


Example: Employee, worker, and researcher. `Employee` is an **abstract** class

```
class Employee{      // Abstract! It is not possible to create objects
public:
  Employee::Employee(const std::string& in_name) : m_name{ in_name }     // constructor
  {}
  const std::string& getName() const;              // 1. Not virtual. A  common method
  virtual void print() const;                      // 2. Virtual (but not abstract)
  virtual double calculateSalary() const = 0;      // 3. Pure virtual (abstract)
private:
  std::string m_name;
};

void Employee::print() const                       // The body of the virtual function
{
  std::println("Name: {}", m_name);
}
```

- The `calculateSalary()` method is not defined (implemented) in the `Employee` class.
- It is an **abstract** (pure virtual) method.

Creating instances (objects) of an abstract class is not possible.

Example: `Employee` is an **abstract** class (cont'd)

- The `Employee` class is an incomplete description of an object because the `calculateSalary()` function is not defined (it does not have a body).

  Therefore, it is abstract, and we are not allowed to create instances (objects) of the `Employee` class.
- This class exists solely for the purpose of deriving classes from it.

```
Employee  employeeObject{"Employee 1"};        // Compiler Error!
Employee * employeePtr;                        // OK. Pointer is not an object
employeePtr = new Employee {"Employee 1"};     // Compiler Error!
```

- Since you cannot create its objects, you cannot pass an `Employee` **by value** to a function or return an `Employee` **by value** from a function.

The derived classes specify how each pure virtual function is implemented:

Example: `Employee` is an **abstract** class (cont'd)

- The `Employee` class determines the signatures (interfaces) of the virtual functions.
- The creators of the derived classes (e.g., `Worker and Researcher`) specify how each pure virtual function is implemented.
- Classes derived from the `Employee` class will define (implement) the `calculateSalary()` function.
- If a pure virtual function of an abstract base class is not defined in a derived class, then the pure virtual function will be inherited as is, and the derived class will also be an abstract class.
- Classes without pure virtual methods are called **concrete classes**.

Example (cont'd): Employee, Worker, and Researcher

```
class Worker : public Employee{
public:
  void print() const override;                 // Redefined print function
  double calculateSalary() const override;   // Concrete virtual function
    :
};

void Worker::print() const                     // Redefined virtual function
{
   Employee::print();
   std::println("I am a worker");
   std::println( "My work Hours per month: {}", m_workHour);
}

// Concrete (implemented) virtual function
double Worker::calculateSalary() const
{
    return 1000* m_workHour;                   // 1000TL per hour
}
```

We can similarly derive a `Researcher` class from `Employee`.

Example (cont'd): Employee, Worker, and Researcher

```
int main(){
  // Employee employee1{"Employee 1"};                    // Error! Employee abstract
  Employee * employeePtr;                                 // OK. Pointer, not an object
  // employeePtr = new Employee {"Employee 1"};           // Error!

  Employee* arrayOfEmployee[5]{};                      // An array of 5 pointers to Employee
  Worker worker1{ "Worker 1", 160 };                   // Work hours per month = 160
  arrayOfEmployee[0] = &worker1;                       // Address of worker1 to the array
  std::println( arrayOfEmployee[0]->getName() );       // OK! common function

  Researcher researcher1{ "Researcher 1", 1 };         // The number of projects = 1
  arrayOfEmployee[1] = &researcher1;                   // Addr. of researcher1 to the array
    :
  for (unsigned int i = 0; i < 5; i++) {
     arrayOfEmployee[i]->print();                      // polymorphic method calls
     std::println("Salary = {}", arrayOfEmployee[i]->calculateSalary() );
  }
  return 0;
}
```

Example e08_3.cpp

A design principle: "Design to an interface, not an implementation"

- Software design principles are guidelines (best practices) offered by experienced practitioners in the design field.
- "*Design to an interface, not an implementation*" is a principle that helps us design flexible systems that can handle changes.
- Here, the **interface** refers to the signatures of the common services (behaviors) provided by different classes.

  For example, `Workers` and `Researchers` can both calculate their salaries and print their information.
- The **implementation** refers to how different classes define (implement) common services (or behaviors).

  For example, the `Worker` class has a unique method of calculating its salary.

  The `Researcher` class can also calculate the salary but in another way.

  The interfaces of some services are the same, but their implementations are different.

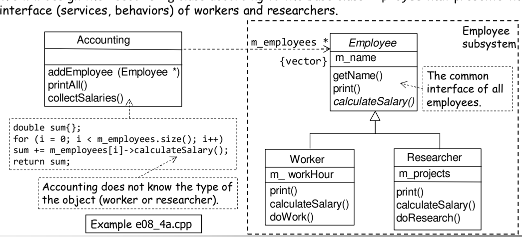
  For example, the signature (interface) of the virtual `calculateSalary()` function is the same for both `Workers` and `Resarchers`.

  However, the implementation (body) of this method is different in these classes.

A design principle: "Design to an interface, not an implementation" (cont'd)

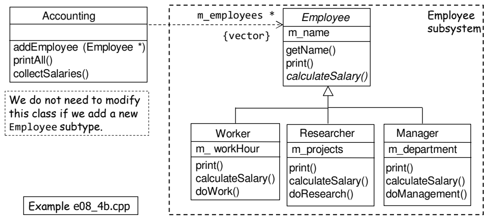
Example: Workers, researchers, and the accounting system in a company

- We need to design an accounting system that performs financial operations related to workers and researchers.
- We will design the `Accounting` class according to the base class `Employee` that presents the common interface (services, behaviors) of workers and researchers.



Example: Workers, researchers, and the accounting system in a company

- We designed the `Accounting` class according to a general `Employee` type (interface).
- Accounting <u>is not aware</u> of the concrete types (implementations) (`Worker` and `Researcher`).
- If we need to add a new type of employee, e.g., a `Manager`, to our system, we do not need to change the `Accounting` class.



The Open-Closed Principle

"Software entities (classes, modules, functions, etc.) should be **open for extension** but **closed for modification**".

- We should strive to write code that does not have to be changed every time the requirements change or new functionalities are added to the system.
- We should create flexible designs to take on new functionality to meet changing requirements without modifying the existing code.

The polymorphism concept in OOP and the principles "*Find what varies and encapsulate it*" and "*Design to interface not to an implementation*" support the "*Open-Closed Principle*".

For example, we can add a new type of employee, such as a `Manager`, to our system without changing the existing code.

Virtual Constructors?

Can constructors be virtual?

No, constructors cannot be virtual.

- When creating an object, we usually already know what kind of object we are creating and can specify this to the compiler.
- Thus, there is no need for virtual constructors.
- Also, an object's constructor sets up its virtual mechanism (the virtual table) in the first place.
- Of course, we do not see the source code for this, just as we do not see the code that allocates memory for an object.
- Virtual functions cannot even exist until the constructor has finished its job, so **constructors cannot be virtual**.

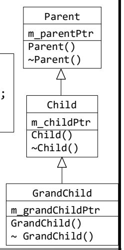
Virtual Destructors

- Recall that a derived class object typically contains data from both the base and derived classes.
- To ensure that such data is properly disposed of, it may be essential for destructors for both base and derived classes are called.

Example:

Example e08_5a.cpp

- The classes `Parent`, `Child`, and `GrandChild` contain pointers to integer arrays.
- Constructors allocate memory for arrays, while destructors release that memory.




```
Parent() {
  m_parentPtr = new int[10];
}
~Parent() {
   delete[] m_parentPtr;
}
```

```
Child() {
  m_childPtr = new int[10];
}
~Child() {
  delete[] m_childPtr;
}
```

```
int main() {
  GrandChild grandchild_object;
  std::println("..Program terminates..");
  return 0;
}
```

The Output:

```
Parent constructor
Child constructor
GrandChild constructor
..Program terminates..
GrandChild destructor
Child destructor
Parent destructor
```


Virtual Destructors (cont'd)

- In the previous example, destructors are **not virtual**. We defined **an automatic object** of the `GrandChild` class. Constructors and destructors were called in the correct order.
- When we create **a dynamic object** of the `GrandChild` class pointed to by a pointer to the `Parent` class, what happens if this object is deleted?

Example:

Example e08_5b.cpp

```
int main(){
  Parent* parentPtr{};
  parentPtr = new GrandChild;
  std::println("-----------------");
  delete parentPtr;
  std::println("..Program terminates..");
  return 0;
}
```

The Output:

```
Parent constructor
Child constructor
GrandChild constructor
------------------
Parent destructor
..Program terminates..
```

- In this example, `parentPtr` points to an object of the `GrandChild` class, but **only the `Parent` class destructor is called** while deleting the pointer. `Child` and `GrandChild` destructors are not called.

  We encountered the same problem when we previously called nonvirtual functions using a base pointer.
- Remember: If a function is not `virtual`, only the base class version will be called when it is invoked using a base class pointer, even if the pointer's content is the address of a derived class object (**static binding**).

  Thus, `Child` and `GrandChild` destructors are never called. This could be a problem if these destructors did something important.

Virtual Destructors (cont'd)

- To ensure that the destructors of derived classes are called **for dynamic objects**, we need to specify **destructors as `virtual`**.
- To implement a virtual destructor in a derived class, we just add the keyword `virtual` to the destructor declaration in the base class.

  This makes the destructors in every class derived from the base class `virtual`.
- The `virtual` destructor calls through a pointer or a reference have **dynamic binding**, so the called destructor will be selected at runtime.
- To fix the problem in example e08_5b.cpp, we add the `virtual` keyword to the destructor declaration in the `Parent` class.

Example e08_5c.cpp

```
class Parent{
public:
  Parent();
  virtual ~Parent(); // virtual destructor
   :
};
int main(){
   :
  delete parentPtr;
```

The Output:

```
Parent constructor
Child constructor
GrandChild constructor
------------------
GrandChild destructor
Child destructor
Parent destructor
..Program terminates..
```