EE 441 Data Structures

Lecture 5: Object-Oriented Programming, Classes

Abstract Data Type (ADT)

- Model used to understand the design of a data structure
- Implementation independent data description

→ Design data with pencil and paper before programming

- ADT specifies
  - Contents
  - Type of data stored
  - Legal operations on the data
- Benefit: Viewing a data structure as an ADT allows a programmer to focus on an idealized model of the data and its operations

ADT Format

- Name
  - Description of the data structure
- Operations
  - Construction operations
    - Initial values
    - Initialization processes
  - Other operations
    - Modification of values
    - Computations
    - etc.

Designing an ADT

- Example: A calendar software
- Questions
  - What kind of data organization do we need?
  - What kind of procedures do we need to manipulate this data?
- For a calendar software, we need to
  - Represent dates in the computer
  - Print dates on the screen
  - Update dates

ADT Example

ADT Date

Data

$1 \leq d \leq 31$ (day)

$1 \leq m \leq 12$ (month)

$1900 \leq y \leq 2100$ (year)

Operations

Constructor:

Input: day, month, year

Preconditions: none

Process: Assign initial values to d, m, y

Output: None

Postconditions: None

PrintDate:

Input: none

Preconditions: none

Process: Print formatted on screen

Output: none

Postconditions: none

JumpYear:

Input: year jump (j)

Preconditions: $j \leq 100$, $y \leq 2000$

Process: $JY = y + j$

Output: JY

Postconditions: none

SetDate:

Input: new month, new day, new year

Preconditions: (only basic check)

1 ≤ new day ≤ 31

1 ≤ new month ≤ 12 (month)

1900 ≤ new year ≤ 2100 (year)

Process: update day month year

Output: none

Postconditions: none

End ADT Date;

ADT Operation Description

- <u>Name of the operation</u>
  - Input: External data that comes from the user of this data
  - Preconditions: Necessary state of the system before executing this operation
  - Process: Actions performed by the operation on the data
  - Output: Data returned to client
  - Post conditions: state of the system after executing this operation

Object Oriented Programming: Classes and Objects

- A class
  - Is an actual representation of an ADT
  - Provides implementation details for the data structure used
  - Provides implementation details for the operations
  - Has members
    - Variables to store data
    - Operations (methods) for data handling

Class Example

- Class example in C++ syntax

```
class Date {
        private:
                int day; // Data representation of day
                int month; // Data representation of month
                int year; // Data representation of year
        public:
                // Constructor
                Date (int d=1, int m=1, int y=1900);
                // Method to print the current date
                void PrintDate(void);
                // Method to modify the year by j
                int JumpYear(int j) const;
                // Method to directly set the date
                void SetDate(int d, int m, int y);
};
```

Objects

- An object
  - is a self-contained entity that consists of data
  - has methods to manipulate the object's data as defined by the object's class
  - can be uniquely identified by its name
  - defines a state which is represented by the values of its data at a particular time
  - is also denoted as an instance of a class

    → A class is a blueprint, or prototype that defines properties and behavior of sets of objects

Object Example

- class Date is declared

```
class Date {
        private:
                int day; // Data representation of day
                int month; // Data representation of month
                int year; // Data representation of year
        public:
                // Constructor
                Date (int d=1, int m=1, int y=1900);
                // Method to print the current date
                void PrintDate(void);
                // Method to modify the year by j
                int JumpYear(int j) const;
                // Method to directly set the date
                void SetDate(int d, int m, int y);
};
```

- Objects (instances) of class Date

```
Date Today(3,10,2022); // Object that holds today's date
Date Tomorrow(4,10,2022); // Object that holds tomorrow's date
```

C++ Classes

- Class declaration
  - Member variables
  - Member function prototypes
- Class implementation
  - Member function definitions

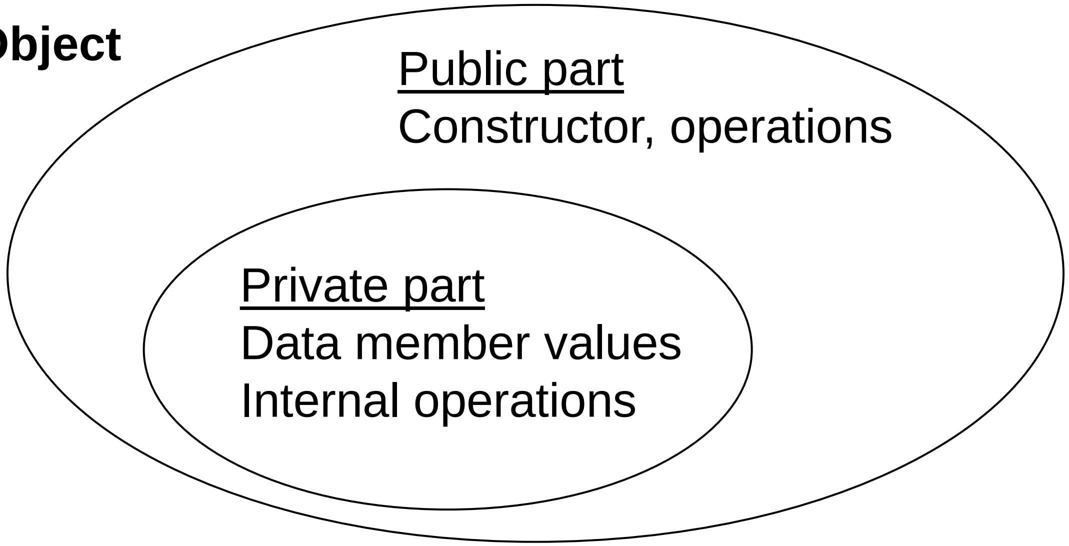
```
class <class_name>{
   private:
      <private data declarations>
      <private method declarations (prototypes)>
   public:
      <public data declarations>
      <public method declarations (prototypes)>
};
```

```
class Date{
   private:
      int day, month, year;
   public:
      Date (int d=1, int m=1, int y=1900);
      void PrintDate( );
      int JumpYear(int j) const;
      void SetDate(int d, int m, int y);
};
```

C++ Classes

- Members are variables and methods for data handling
- Classes can protect members from access by other objects
- Public and private sections in a class declaration allow program statements outside the class different access to the class members

Object



C++ Classes

- Members are variables and methods for data handling
- Classes can protect members from access by other objects
- Public and private sections in a class declaration allow program statements outside the class different access to the class members

```
class <class_name>{
   private:
      <private data declarations>
      <private method declarations (prototypes)>
   public:
      <public data declarations>
      <public method declarations (prototypes)>
};
```

```
class Date{
   private:
      int month, day, year;
   public:
      Date (int d=1, int m=1, int y=1900);
      void PrintDate( );
      int JumpYear(int j) const;
      void SetDate(int d, int m, int y);
};
```

Function Prototype

```
int JumpYear (int j) const;
```

const keyword

Output result type

Function name

Input parameter type

Formal input parameter name: place holder to stand for the actual parameter

- Prototype describes how the function is called
- Tells everything you need to know to make a function call
- Terminates with semi-colon
- Lets compiler know that we intend to call this function
- Lets compiler generate the correct code for calling the function
- Enables compiler to check up on our code
  (for example, it makes sure that we pass the correct number of arguments to each function we call)

Function Definition and Scope

```
/* Class implementation */
// constructor */
Date::Date(int d, int m, int y ){
            day = d;
            month = m;
            year = y;
}


int Date::JumpYear(int j) const{
    return  year + j;
}
```

Constructor:

- Creates an object (instance of the class)
- Initializes the object

MUST BE PUBLIC: can be called by the main or any function that is not class member

Member method "JumpYear":
Computation with private member "year"
Keyword "const" requires that no member is changed by the operation

Date Class Implementation

```
int Date::JumpYear (int j) const{
    return  year + j ;
}
```

<ReturnValueType><ClassName>::FunctionName(parameters)

- Example function returns data of type int
- Declaring a member function with the const keyword specifies that the function is a "read-only" function that does not modify the object for which it is called
- :: scope resolution operator: shows that the function JumpYear is in the scope of Date class
  - → JumpYear belongs to Date class
  - → JumpYear can access private members (accesses year)
- scope: The range of reference for an object or variable

Date Class Implementation

```
void Date::PrintDate() const{
    std::cout << "Day: " << day << " Month: "
    << month << "Year: " << year << std::endl;
};

void Date::SetDate(int d, int m, int y){
   day = d;
   month = m;
   year = y;
}
```

Member method “PrintDate”:
Controlled access to private members

No member changes → “const”

Member method “SetDate”:
Modify member variables

Keyword “const” cannot be used

Date Class Method Calls

- Example main program

```
int main()
{
    std::cout << "Let's use the Date class" << std::endl;
    Date Today(3,10,2022); // Construct object initialized with today's date
    Today.PrintDate(); // Print today's date using member method
    Date Tomorrow; // Construct default object
    Tomorrow.SetDate(4,10,2022); // Set the date of Tomorrow
    Tomorrow.PrintDate(); // print tomorrow's date
    std::cout << "Graduation Year: " << Today.JumpYear(1) << std::endl;
    return 0;
}
```

Date Class Method Calls

- Console output

```
Let's use the Date class
Day: 3 Month: 10 Year: 2022
Day: 4 Month: 10 Year: 2022
Graduation Year: 2023

Process returned 0 (0x0)   execution time : 0.025 s
Press any key to continue.
```

Use of Classes

- Classes are designed and implemented by designers for certain purposes
- The users (clients) reuse the classes in their own code without redesigning them
- Example
  - Ahmet designs and implements “Date” Class
  - Mehmet uses “Date” Class in his Calendar software

Access Control: Private and Public Members

- Example

```
class Date {
    private:
            int day; // Data representation of day
            int month; // Data representation of month
            int year; // Data representation of year
    public:
            // Constructor
            Date (int d=1, int m=1, int y=1900);
            // Method to print the current date
            void PrintDate(void);
            // Method to modify the year by j
            int JumpYear(int j) const;
            // Method to directly set the date
            void SetDate(int d, int m, int y);
};
```

private

public

C++ Classes: Private Members

- Most restrictive access level
- Data and internal methods needed to implement the class
- Private data members and methods can be accessed only by the methods of the class
  - → Use this access to declare members that should only be used by the class
- Example
  - Variables that contain information that if accessed by an outsider could violate security or put the object in an inconsistent state
  - Methods that, if invoked by an outsider, could jeopardize the state of the object or the program in which it's running

C++ Classes: Public Members

- Operations available to clients (who do not need to know anything about the private parts)
- Clients can only access the public part
- Interface of the object to the program

  → Any statement in a program block that declares an object can access a public member of the object
- The public parts hide information encapsulated in the private parts to
  - Protect data integrity
  - Enhance portability
  - Facilitate software reuse

Example for Controlled Access

```
class Date{
   private:
      int month, day, year;
   public:
      Date (int d=1, int m=1, int y=1900);
      void PrintDate( );
      int JumpYear(int j) const;
      void SetDate(int d, int m, int y);
};
```

```
void Date::PrintDate() const{
    std::cout << "Day: " << day << " Month: "
    << month << "Year: " << year << std::endl;
};
```

```
In function 'int main()':
error: 'int Date::day' is private within this context
note: declared private here
```

```
int main()
{
   Date Today(3,10,2022); // Today's date
   Today.PrintDate(); // print today's date
   std::cout << "Day: " << Today.day << std::endl;
   return 0;
}
```

Compiler error since „day“ is a private member variable

Why do we need access control

- Large programs involving more than one programmer
- A class can be very complex
  - Many member methods
  - Many data members
- One programmer creates a class

  → Knows all details
- Other programmers use the class in their code

  → Only need to know how to use it

  → Only know the public functions

Alternative Constructors

```
# include  <string>
class Date{
        private:
                int day, month, year;
        public:
                Date (int d = 1, int m = 1, int y = 1900);
                Date (char *dstr);
                // Other methods
};
```

- Two different constructors are defined
- The compiler will select the appropriate constructor according to the call parameters during object creation
- Recall: Constructor cannot be private
- Why?

Inline Definition

```
# include  <iostream>
# include  <string.h>
class Date {
    private:
        int day, month, year;
    public:
        Date (int d=1, int m=1, int y=1900);
        Date (char *dstr);
        void PrintDate(void);
        void SetDate(int d, int m, int y){
            //only does basic check
            if(m >= 1&& m <= 12)
                month = m;
            if(d >= 1&& d <= 31)
                day = d;
            if(y >= 0)
                year = y;
        }
};
```

INLINE DEFINITION:
Compiler inserts complete body of the function wherever it is called (instead of a jump instruction to the function definition)
→ Faster BUT makes the code larger

Inheritance in Object Oriented Programming

- Example: People database program
- Classes such as “Parent”, “Student”, “Worker”
- Observation: All these data types have common features

  → They all describe a Person with more specific properties
- Idea
  - Define a general “Person” first
  - Extend it to make it more specific

Inheritance: Example

- Class Declaration (Base Class)

```
enum Gender{male, female};

class Person{
    protected: //new access control level used for inheritance
        Gender gender; // either male or female
        int age; // Age of the person
    public:
        Person (int a = 0, Gender g = male); // Constructor
        void Info() const; // Print info about person
};
```

Inheritance: Example

- Implementation (Base Class)

```
Person::Person (int a, Gender g): age(a), gender(g){
}
// more general than:
//Person::Person(int a, Gender g){
//   age=a;
//   gender= g;
//}
void Person::Info() const{
     std::cout << " Age: " << age;
          std::cout << ", Gender: ";
          if(gender == male)
           std::cout << "male";
     else
           std::cout << "female";
     std::cout << std::endl;
}
```

Member initializer list

Constructor body initialization

Inheritance: Example

- Declaration (Inherited Class)

```
class Parent:public Person { //Derived Class
    private:
      int children; // Additional member variable
    public:
      Parent(int a = 20, Gender g = female, int c = 0); //Constructor
      void Info() const; //Overwrite member method Info
      void update(); //New public member method
};
```

Derived from Person class

Inheritance: Example

- Implementation (Inherited Class)

```
Parent::Parent(int a, Gender g, int c):Person(a,g),children(c){
}
```

Member initializer: Constructor of Base class

Member initializer for
Additional member variable

```
void Parent::Info() const{ //OVERWRITE
    Person::Info(); // Call function from Base class
    std::cout << ", Number of Children: " << children << std::endl;
}
```

Inheritance: Example

- Implementation (Inherited Class)

```
void Parent::update( ){ //BRAND NEW
        std::cout << "Age: ";
        std::cin >> age;
        int gender_input;
        std::cout << "Gender (male=0, female=1): ";
        std::cin >> gender_input;
        if(gender_input == 0)
            gender = male;
         else
            gender = female;
        std::cout << "Number of Children: ";
        std::cin >> children;
}
```

Inheritance: Example

- Main Function

```
#include "Person.hpp"

int main(){
    Parent p;
    Person q;
    std::cout << "parent info:";
    p.Info(); // Show default parent info
    std::cout << "person info:";
    q.Info(); // Show default person info
    std::cout << "change:" << std::endl;
    p.update(); // Update parent info
    p.Info(); // Show updated parent info
    return 0;
}
```

```
parent info:
Age: 20, Gender: female
Number of Children: 0
person info:
Age: 0, Gender: male
change:
Age: 33
Gender (male=0, female=1): 1
Number of Children: 2
Age: 33, Gender: female
Number of Children: 2
```

Construct with default member variable values

Inheritance and Access Control

- Case 1: Person is a public base class of Parent
  - Private members of Person cannot be accessed by Parent
  - Public members of Person are also public in Parent
  - Protected members of Person are also protected in Parent

```
class Person{
    private: //
        Gender gender;
        int age;
};
```

```
class Parent:public Person {
    private:
        int children;
    public:
        Parent(int a = 20, Gender
            g = female, int c = 0){
         gender = g; age = a};
        void Info() const;
};
```

- Compiler error since Parent tries to access age and gender

```
error: 'int Person::age' is private within this context
```

Inheritance and Access Control

- Case 2: Person is a protected base class of Parent

  ```
  class Parent:protected Person
  ```

  - Private members of Person cannot be accessed by Parent
  - Public members of Person are protected in Parent
  - Protected members of Person are also protected in Parent
- Case 3: Person is a private base class of Parent

  ```
  class Parent:private Person
  ```

  - Private members of Person cannot be accessed by Parent
  - Public and protected members of Person are private in Parent

Creating Objects

- When a derived class object is created
  - Base class constructor is first called and initializes the members from the base class
  - Derived constructor is called next to initialize the new members of the derived class or overwrite the base initialization as required
- Example: Call constructor of Base class

```
Parent::Parent(int a, Gender g, int c):children(c){}
```

```
parent info:
Age: 0, Gender: male, Number of Children: 0
```

Default values of Base class

```
Parent::Parent(int a, Gender g, int c):Person(a,g), children(c){}
```

```
parent info:
Age: 20, Gender: female, Number of Children: 0
```

Overwrite default values of Base class

Abstract Classes and Polymorphism

- Abstract class
  - Only specifies an interface
  - Typically has one or more pure virtual member functions
- A pure virtual member function declares an interface only
  - Specifies the set of operations
  - There is no implementation defined

→ It is not possible to create object instances of abstract classes

Abstract Classes and Polymorphism

- Abstract class is a base class from which other classes are derived
- Declaring a member function virtual makes it possible to access the implementations provided by the derived classes through the base-class interface
- We don't need to know
  - How a particular object instance is implemented
  - Of which derived class a particular object is an instance
- This design pattern uses the idea of polymorphism

Polymorphism Example

```
class Polygon{
  protected:
    int width, height;
  public:
    Polygon(int w=0, int h=0){
      width = w;
      height = h;
  };
    void set_values(int w, int h);
    virtual int Area() const{
        return (0);
    }
};
```

```
class Rectangle:public Polygon{
    public:
        Rectangle(int w = 0, int
         h = 0):Polygon(w,h){}
    int Area() const{
        return width*height;
    }
};

class Triangle:public Polygon{
    public:
        Triangle(int w = 0, int
        h = 0):Polygon(w,h){}
    int Area() const{
        return width*height/2;
    }
};
```

virtual member method with default implementation

Implementation in derived class

Polymorphism Example

```cpp
int main(){
    Rectangle r(4,5);
    Triangle t(7,8);
    std::cout << "Rectangle Area: " << r.Area() << std::endl;
    std::cout << "Triangle Area: " << t.Area() << std::endl;
    // Make use of polymorphism
    Polygon *p_poly; // Pointer to object of Polygon class
    p_poly = &r; // Assign address of r to p_polygon
    std::cout << "Access member method Area from Base class" << std::endl;
    // Access member method Area from Base class
    std::cout << "Rectangle Area: " << p_poly->Area() << std::endl;
    p_poly = &t; // Assign address of t to p_polygon
    // Access member method Area from Base class
    std::cout << "Triangle Area: " << p_poly->Area() << std::endl;
    return 0;
}
```

```
Rectangle Area: 20
Triangle Area: 28
Access member method Area from Base class
Rectangle Area: 20
Triangle Area: 28
```

Casting: static

- static_cast
  - Used for conversions known at compile time
  - Safe for upcasting (derived → base)

```
Rectangle r(4, 5);
// Upcast: Rectangle* → Polygon*
Polygon* p = static_cast<Polygon*>(&r);
cout << p->Area();  // Calls Rectangle::Area() because of virtual
```

- Downcasting with static_cast compiles but is not type-safe

```
Polygon* poly = new Polygon(2,3);

// Wrong: downcasting Polygon* to Rectangle*
Rectangle* r2 = static_cast<Rectangle*>(poly);
cout << r2->Area();  // Undefined behavior
```

Casting: dynamic

- dynamic_cast
  - Safe downcasting (base → derived)
  - Requires at least one virtual function in base

```
Polygon* p = new Triangle(4,5);

// Correct downcast
Triangle* t = dynamic_cast<Triangle*>(p);
if (t) cout << "Triangle area: " << t->Area();  // OK

// Wrong downcast
Rectangle* r = dynamic_cast<Rectangle*>(p);
if (r == nullptr) cout << "Not a Rectangle";  // Safe check
```

  - dynamic_cast checks the runtime type and avoids undefined behavior
  - dynamic_cast is slower than static_cast due to the check

Casting: Other Types

- dynamic_cast
  - Used to add/remove const from a type

```
const Polygon* cp = new Rectangle(4,5);
// Cast away const
Polygon* p = const_cast<Polygon*>(cp);
p->set_values(6,7);   // allowed after const_cast
cout << p->Area();    // 42
```

- reinterpret_cast
  - Reinterprets the bits of a pointer as another type
  - Dangerous, almost never used in polymorphism

```
Polygon* p = new Rectangle(3,4);

// Force reinterpret to unrelated type
long addr = reinterpret_cast<long>(p);   // get raw address
Polygon* p2 = reinterpret_cast<Polygon*>(addr); // back

cout << p2->Area();  // Might work, but unsafe
```

Template Classes in C++

Template Class Explanation

- Defines a blueprint for a class that can work with any data type
- The compiler generates the concrete version when an object is created

Example

```
template <typename T>
class Box {
    T value;
public:
    Box(T v) : value(v) {}
    T get() { return value; }
};
```

Usage

```
Box<int> b1(42);        // Box specialized for int
Box<double> b2(3.14);  // Box specialized for double
Box<char> b3('X');      // Box specialized for char
```

Remarks

- T is a placeholder type
- Compiler generates Box<int>, Box<double>, etc. automatically
- Reduces repetition, enables generic containers (see for example STL)

EE 441 Data Structures

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