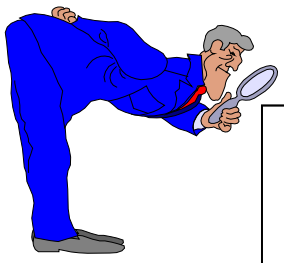

객체지향 프로그래밍 : 개념 및 언어
(Object-Oriented Programming : Concepts and Languages)

In this talk, I will present
- *the basic concepts of object-oriented programming,*
- *an introduction to C++ with some examples as a case study of object-oriented programming language, and finally*
- *advantages and disadvantages of object-oriented programming*

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Sogang University

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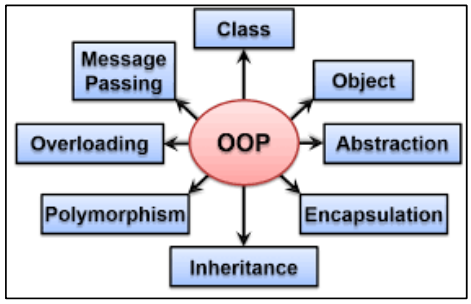
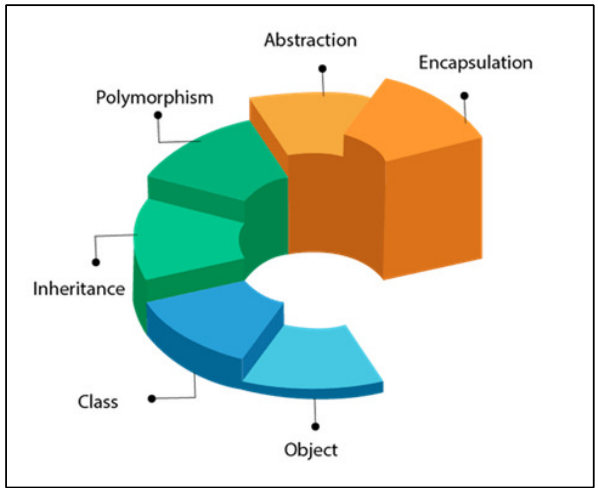
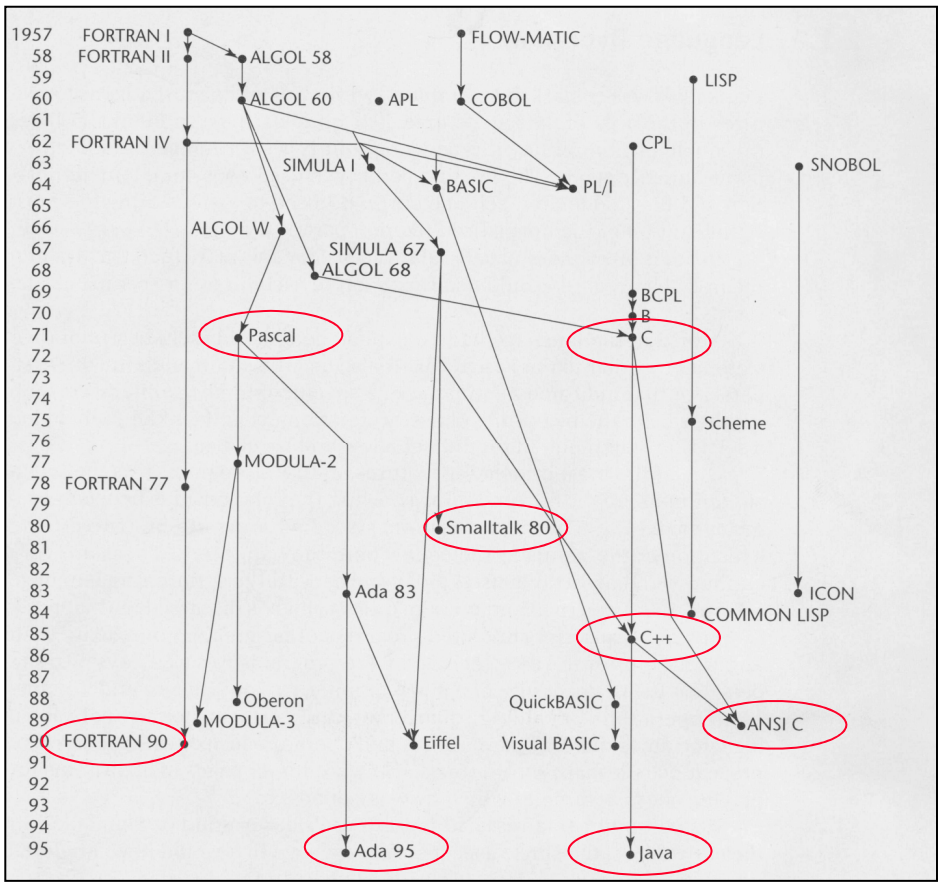




I. Introduction

Evolution of Programming Languages

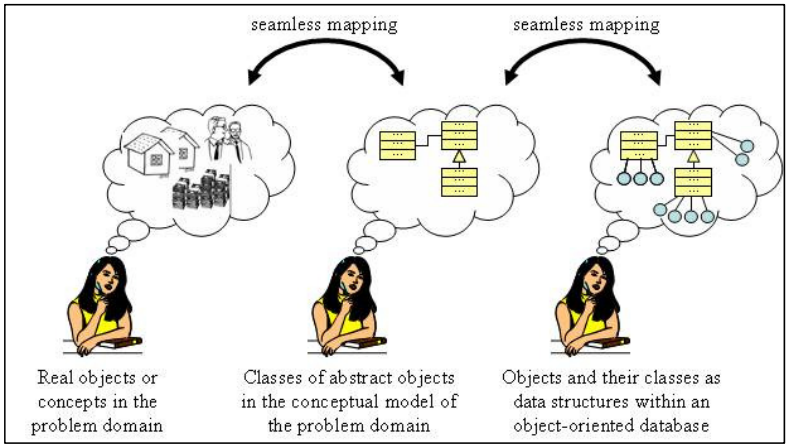


Programming Language Paradigms

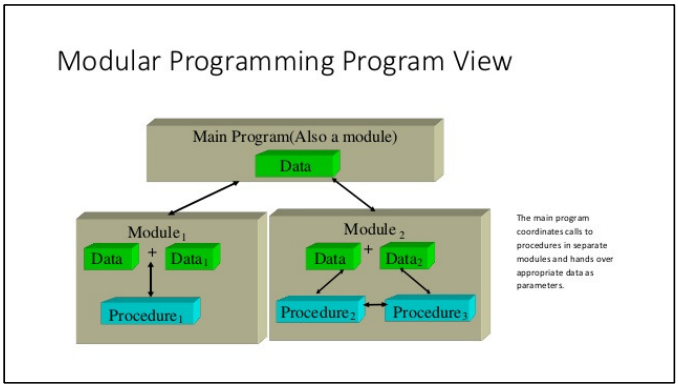
- **Block Structure, Procedure-Oriented Paradigm**
  - Program is a nested set of blocks and procedures
  - Primary Paradigm in the 1960s and 1970s (Algol, Pascal, PL/I, Ada, Modula)
- **Object-Based, Object-Oriented Paradigm**
  - Program is a collection of interacting objects
  - Simula (67), Smalltalk (70s), Many Languages (80s) (Simula, Smalltalk, C++, Eiffel, CLOS, ..)
- **Concurrent, Distributed Programming Paradigm**
  - Multiple threads, synchronization, communication
  - fork-join (60s) -> Ada-CSP (70s) -> Linda (CSP, Argus, Actors, Linda, Monitors)
- **Functional Programming Paradigm**
  - Program is a set of function definitions (rewrite rules)
  - Clear semantics, a lot of implicit parallelisms (LISP, ML, Miranda, Haskel, ..)
- **Logic Programming Paradigm**
  - Program is a set of theorems (resolution principles)
  - Clear semantics, a lot of implicit parallelisms (Prolog, Parlog, GHC, ..)

Why Object-Oriented Programming ?

- **Natural Modeling of Real-World Problems**
  - Several autonomous entities
  - Simulation systems

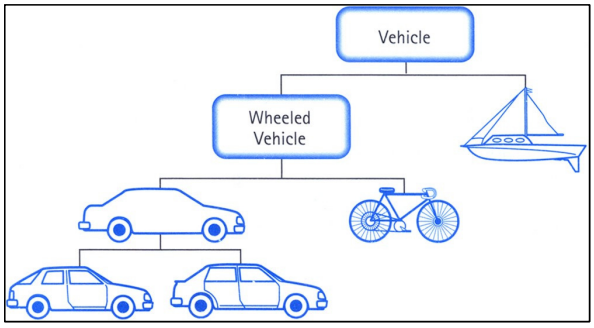


- **Modularity**
  - Data + Procedures
  - Problem decomposition (Software Engineering)
  - Information Hiding (Encapsulation)



Why Object-Oriented Programming ?

- **Software Re-usability**
  - Using Inheritances
  - A lot of useful class libraries (Smalltalk)

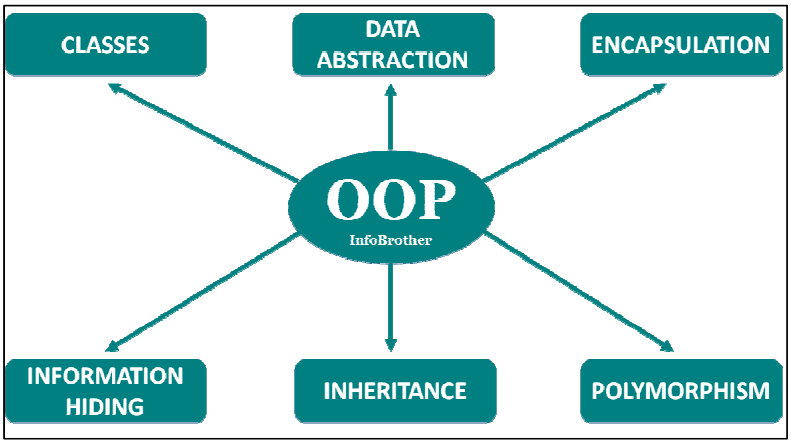


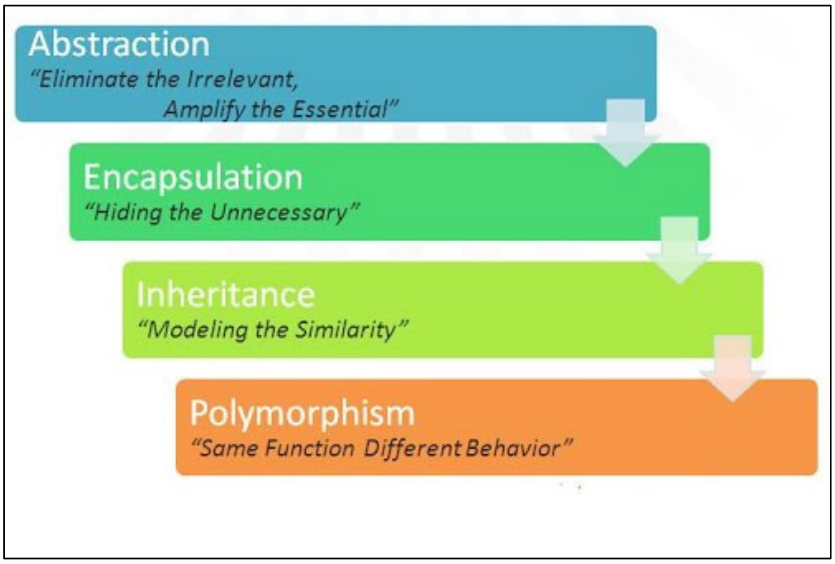
- **Parallelism**
  - Each object can be executed in parallel

- **Just a New Programming (Computing) Paradigm !**

II. Basic Concepts of Object-Oriented Programming

- **What is Object-Oriented Programming ?**
  - *Object-oriented programming* is a method of implementation in which programs are organized as *cooperative collection of objects*, each of which represents *an instance of some class*, and whose classes are all member of a hierarchy of classes unites via *inheritance relationships*
- **Object-oriented Programming Paradigm :**
  - Decide which classes you want
  - Provide a full set of operations for each class
  - Make commonality explicitly using inheritance



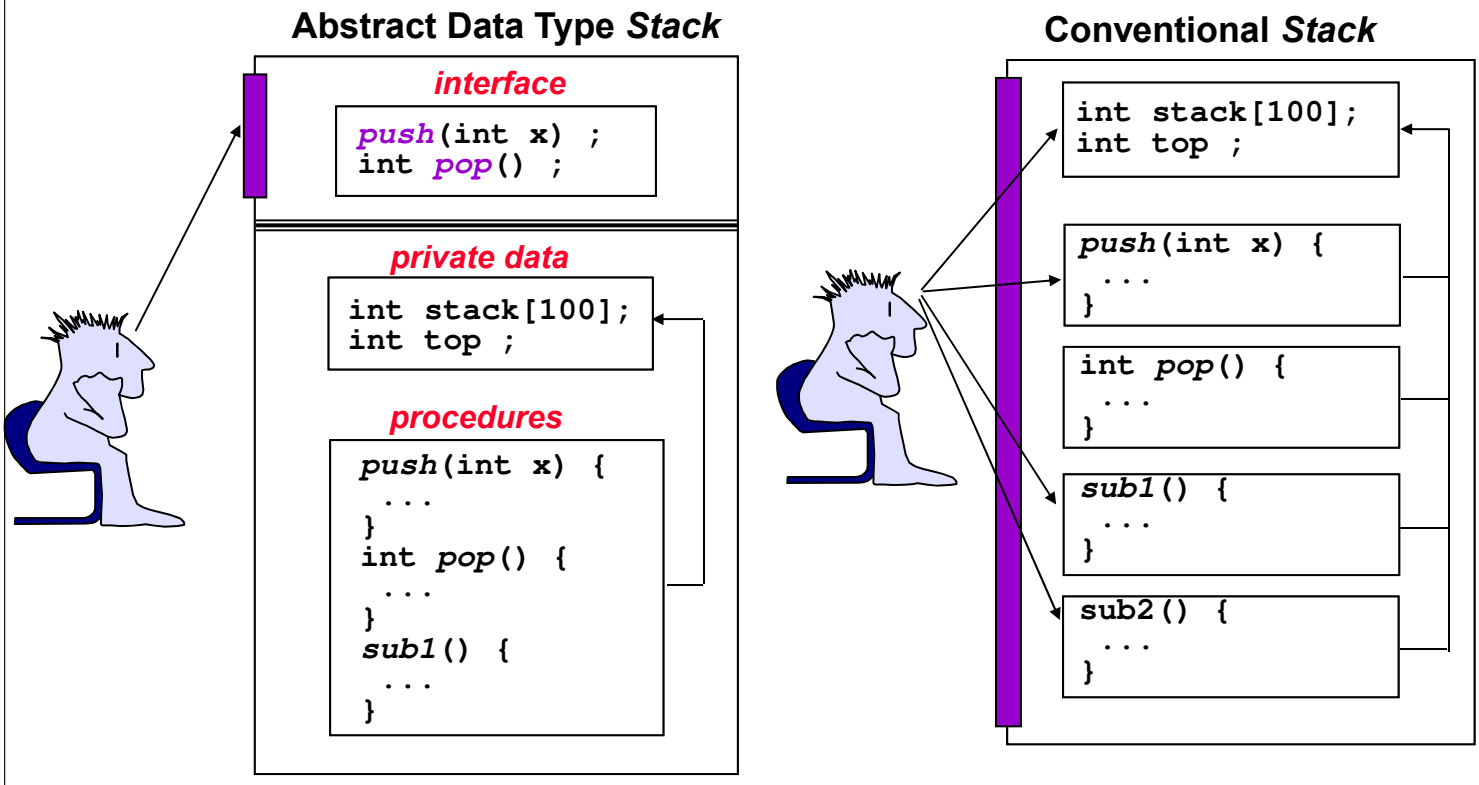


2.1 Abstract Data Type

- Abstract Data Type
  - ⇔ a data structure that supports both of *encapsulation* and *information hiding*

- **Encapsulation**
  - data and code that manipulates it are defined together, and that data cannot be separated from or accessed separately from the associated code
  - data is encapsulated within the code
  - only a localized set of procedures directly manipulate the data
  - important for ensuring reliability and modifiability of systems by reducing interdependencies between software components

- **Information Hiding**
  - it is the principle that states that program should not make assumptions about implementations and internal representations
  - a way of using encapsulation
  - emphasis is on *what* rather than *how*
  - procedure abstraction (subroutine) vs. data abstraction (abstract data type)
- Abstraction helps people to think about what they are doing, whereas encapsulation allows program changes to be reliable with limited effort



Old Programming Technique: Structures

```
struct queue{
    int a[5];
    int head;
    int tail;
};

struct stack{
    int a[5];
    int top;
}

void main()
{
    struct queue Q;
    struct stack S;

    print( Q.a[2] );
    print( S.a[2] );

    add(S, 3);
    add(Q, 2);
}
```

?

```
void add(queue Z, int x){
    <codes for
    adding queue
    elements here>
}

void remove(queue Z, int x){
    <codes for
    removing queue
    elements here>
}
```

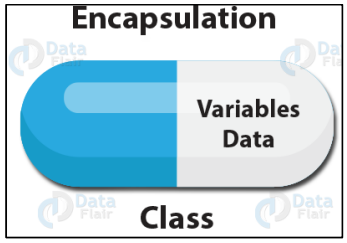
```
void add(stack Z, int x){
    <codes for
    adding stack
    elements here>
}

void remove(stack Z, int x){
    <codes for
    removing stack
    elements here>
}
```

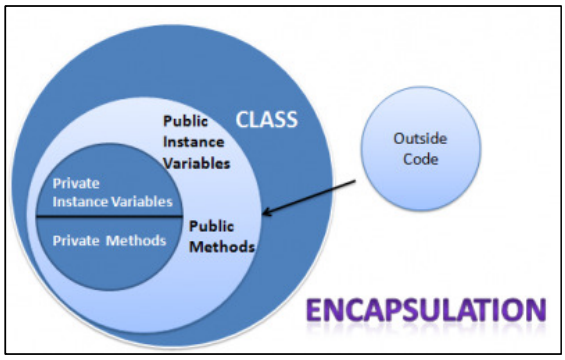
New Programming Technique: Object-Oriented

```
void main()
{
    queue Q;
    stack S;

    print( Q.a[2] );
    print( S.a[2] );

    S.add(3);
    Q.add(2);
}
```

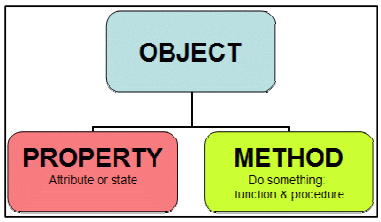
```
class stack{
    int a[5];
    int top;

    void add(int x){
        <codes here>
    }

    void remove(int x){
        <codes here>
    }
}
```

```
class queue{
    int a[5];
    int head;
    int tail;

    void add(int x){
        <codes here>
    }

    void remove(int x){
        <codes here>
    }
};
```

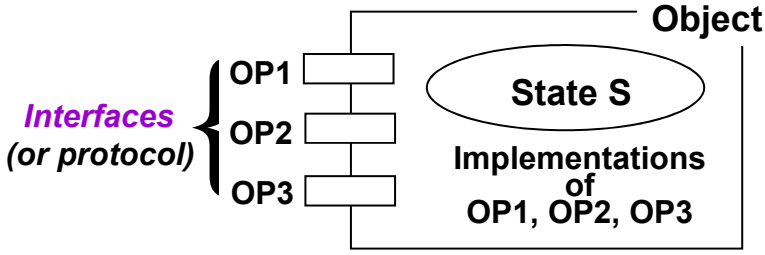




2.2 Object and Message Sending

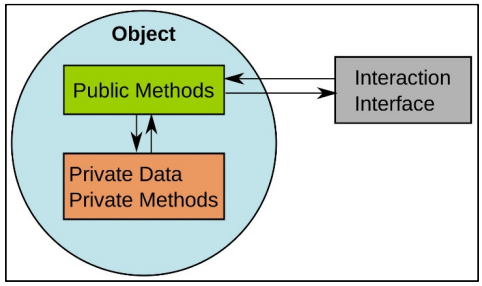


- **What is Object ?**
  - an entity with its private data and methods
    - ⇔ states (instance variable : private data)
    - ⇔ a set of operations (method : procedure handling private data)

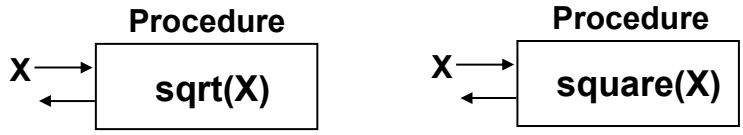



```
point : object
x := 0; y := 0 ;
read_x : ^x ; - return value of x
read_y : ^y ; - return value of y
change_x(dx) : x = x + dx ;
change_y(dy) : y = y + dy ;
```

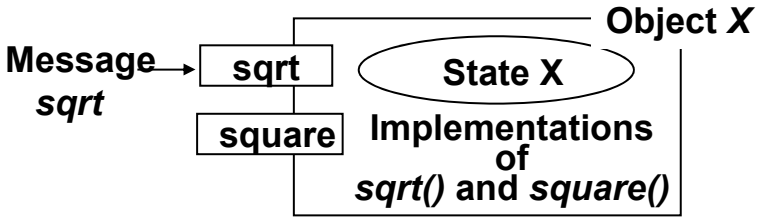
- **Message Sending**
  - data are obtained from an object : by sending message to object
  - a form of indirect procedure call
    - ⇔ dynamic vs. static message binding
  - all of actions in object-oriented programming comes from sending messages between objects
  - a *selector* in the message specifies the kind of operation

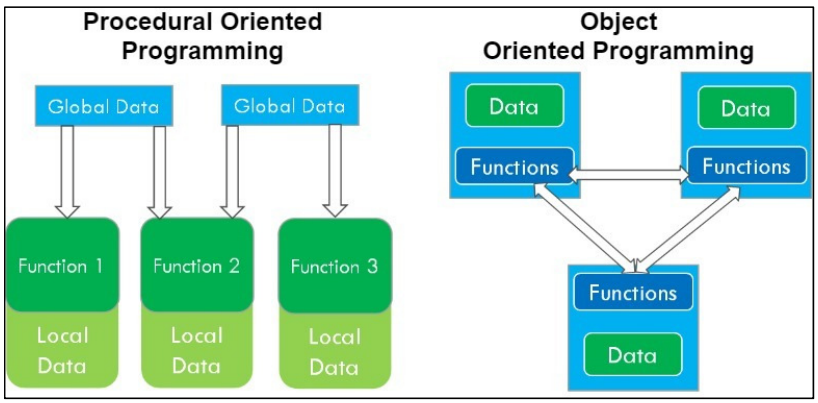


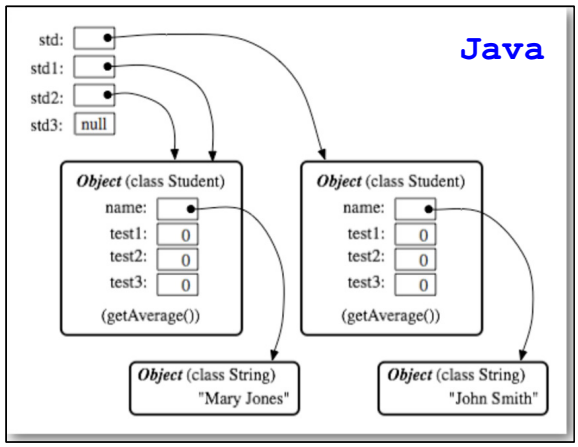
- **Traditional Programming vs. Object-Oriented Programming**
  - **Traditional Programming**
    - ⇔ a collection of procedures which are independent of data
    - ⇔ function values are completely determined by their arguments being precisely the same for each invocation
    - ⇔ typically procedures act only on certain type of data

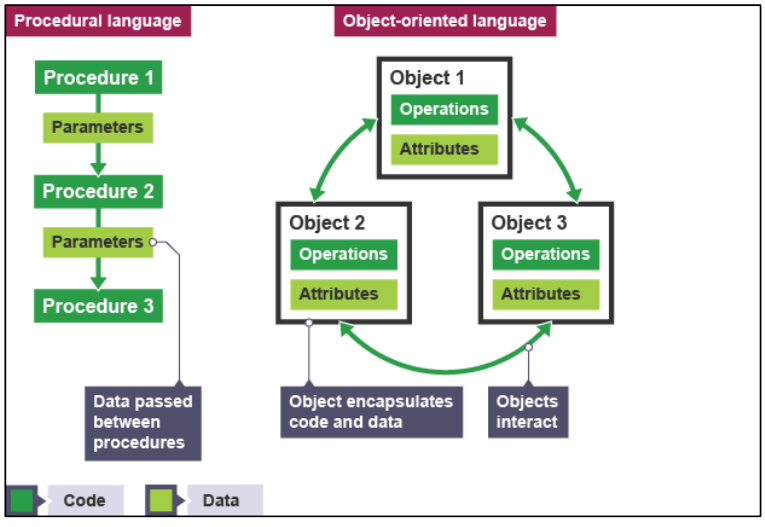


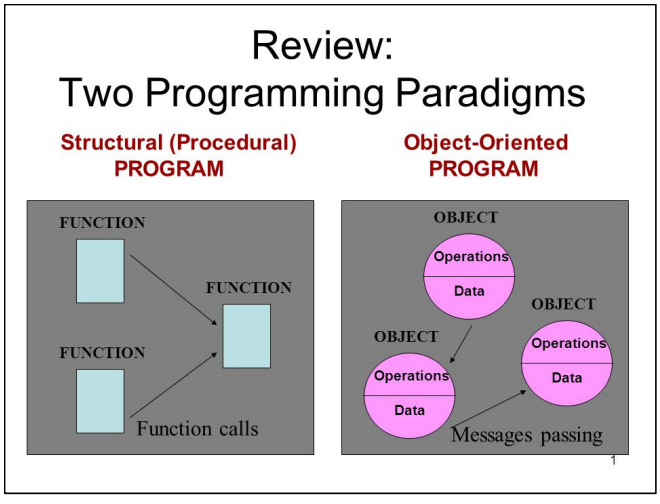
  - **Object-Oriented Programming**
    - ⇔ a collection of objects (data + procedure)
    - ⇔ the value returned by an operation on an object may depend on its state as well as its arguments (invocation history)
    - ⇔ finding the correct procedure to execute is handled by the support system of language

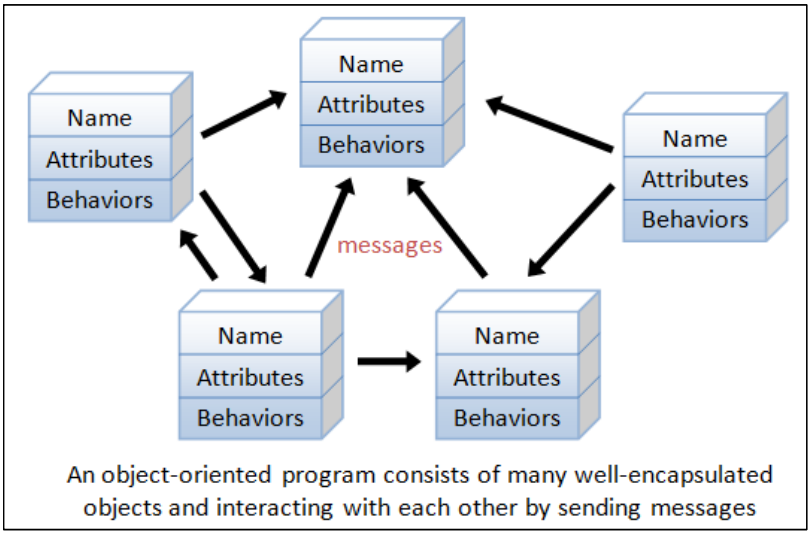


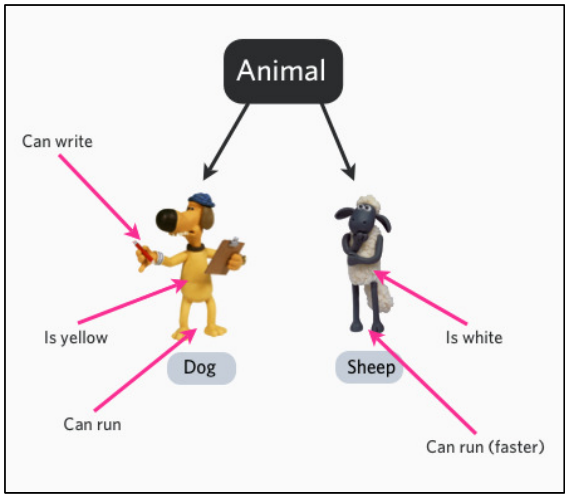


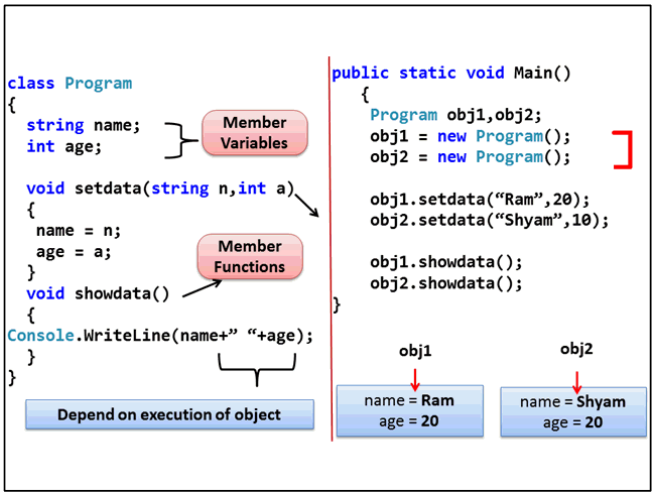






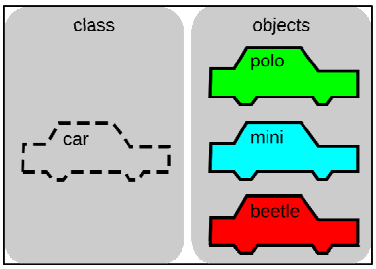


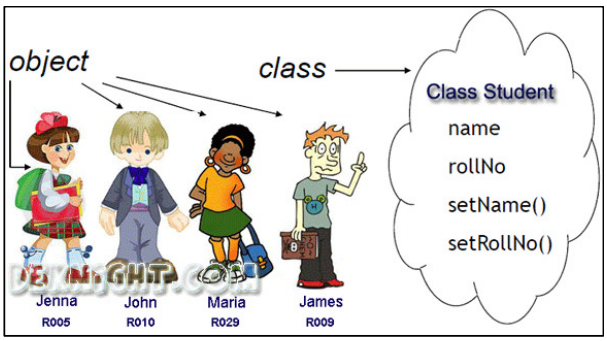




2.3 Classes and Instances

- **What is Class ?**
  - a specification of structure (instance variable), behavior (method), and inheritance (parent) ;
  - a class is a template (cookie cutter) from which objects may be created by "new" or "create" operation
  - objects are created from classes through instantiation
    - ⇔ an object of given class is called an *instance* of that class
  - two kinds of variables
    - ⇔ *Class variable* : a variable stored in the class whose value is shared by all instance of class
    - ⇔ *Instance variable* : a variable for which local storage is available in instances
  - if a class is an object, then class must have a class, called *metaclass*
    - ⇔ class?class



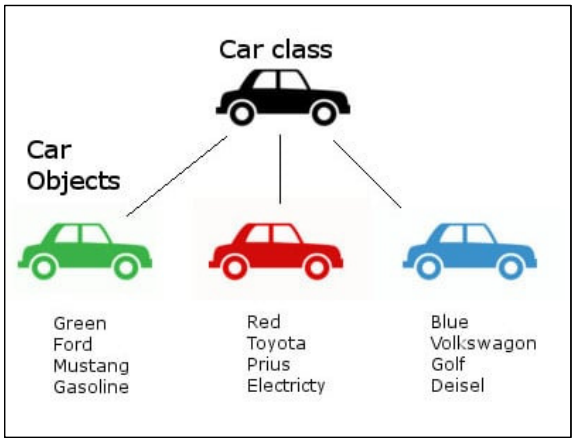


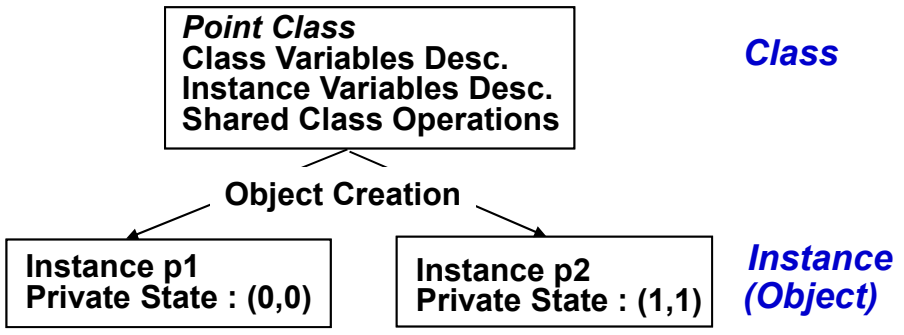
- **Example**
  - **Definition of Class**

```
point : class
Description of instance variables
operations or methods
```

  - **Creation of Object**

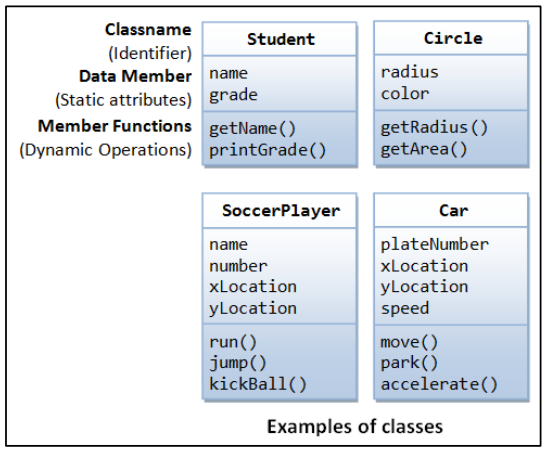
```
p1 := make_instance point(0,0)
p2 := make_instance point(1,1)
```





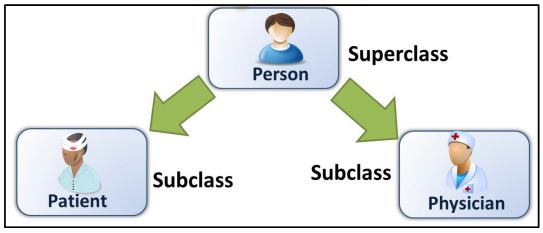
Class

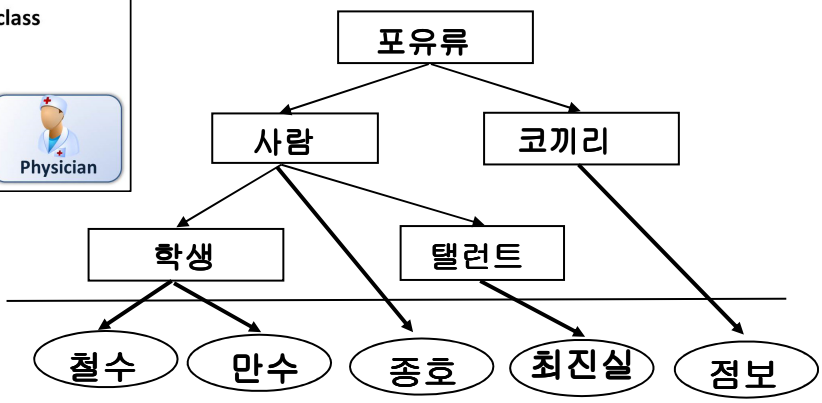
Instance (Object)



2.4 (Multiple) Inheritance

- **Inheritance**
  - a relation ship between classes where one class is the parent (or base) class of another
  - supports refinement and software reuse in Object-Oriented Programming ;
    - ⇔ the ability to inherit state structures and behaviour from an existing class allows the programmer to define new objects in the system not only in terms of existing objects, but also by modifying and mixing the descriptions of *existing classes* (*superclass*)
  - Classification and Specialization
  - Example of Inheritance Hierarchy



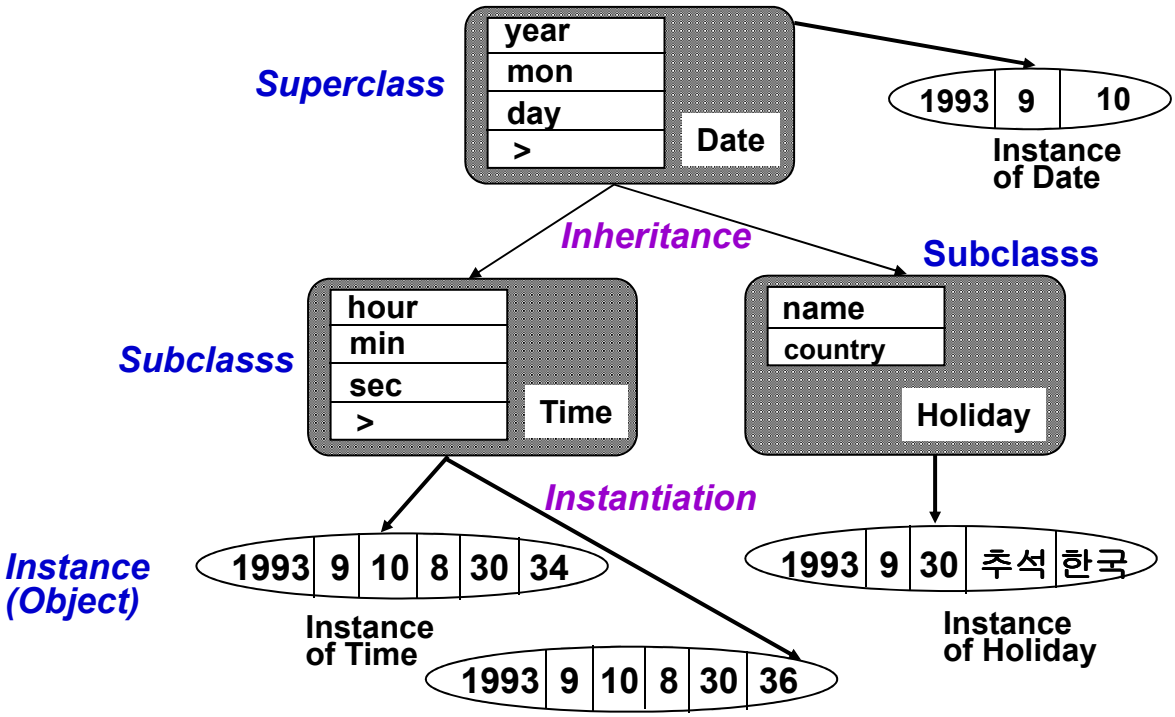


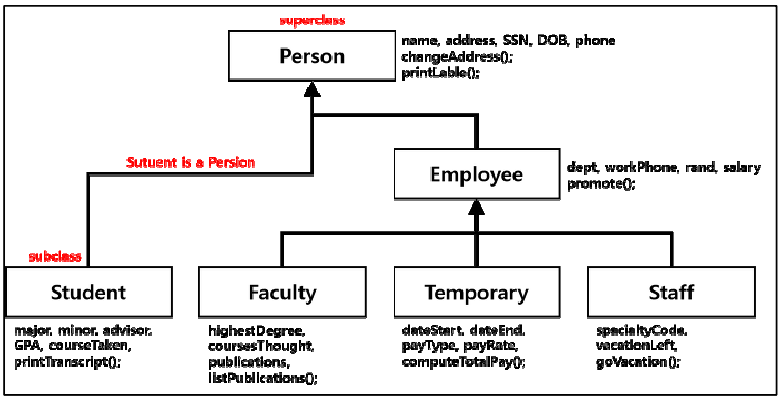
Superclass

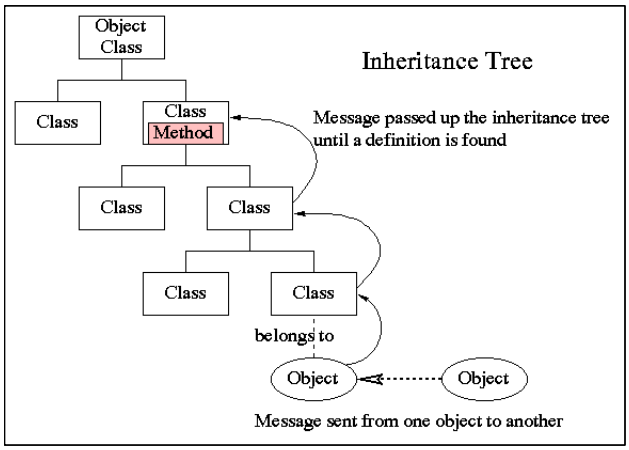
Subclass

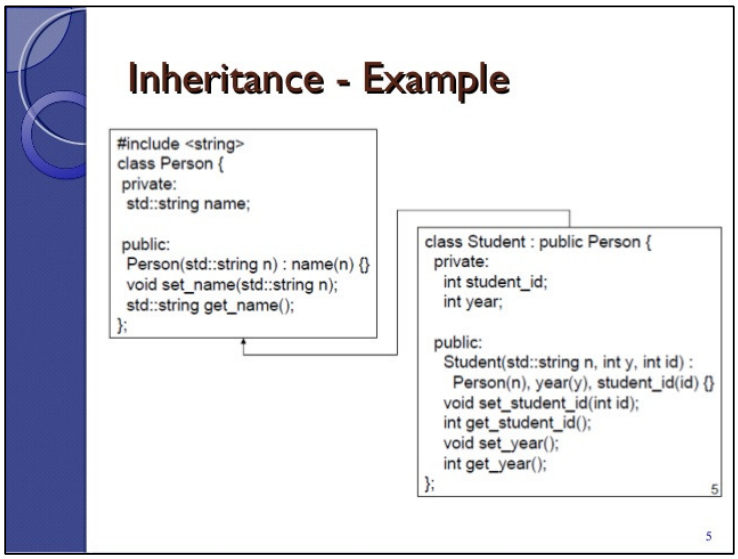
Object

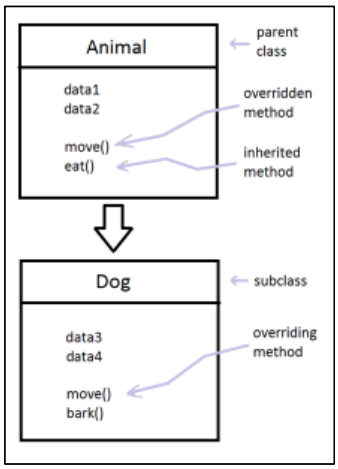
- **Example of Class, Inheritance, and Instance**



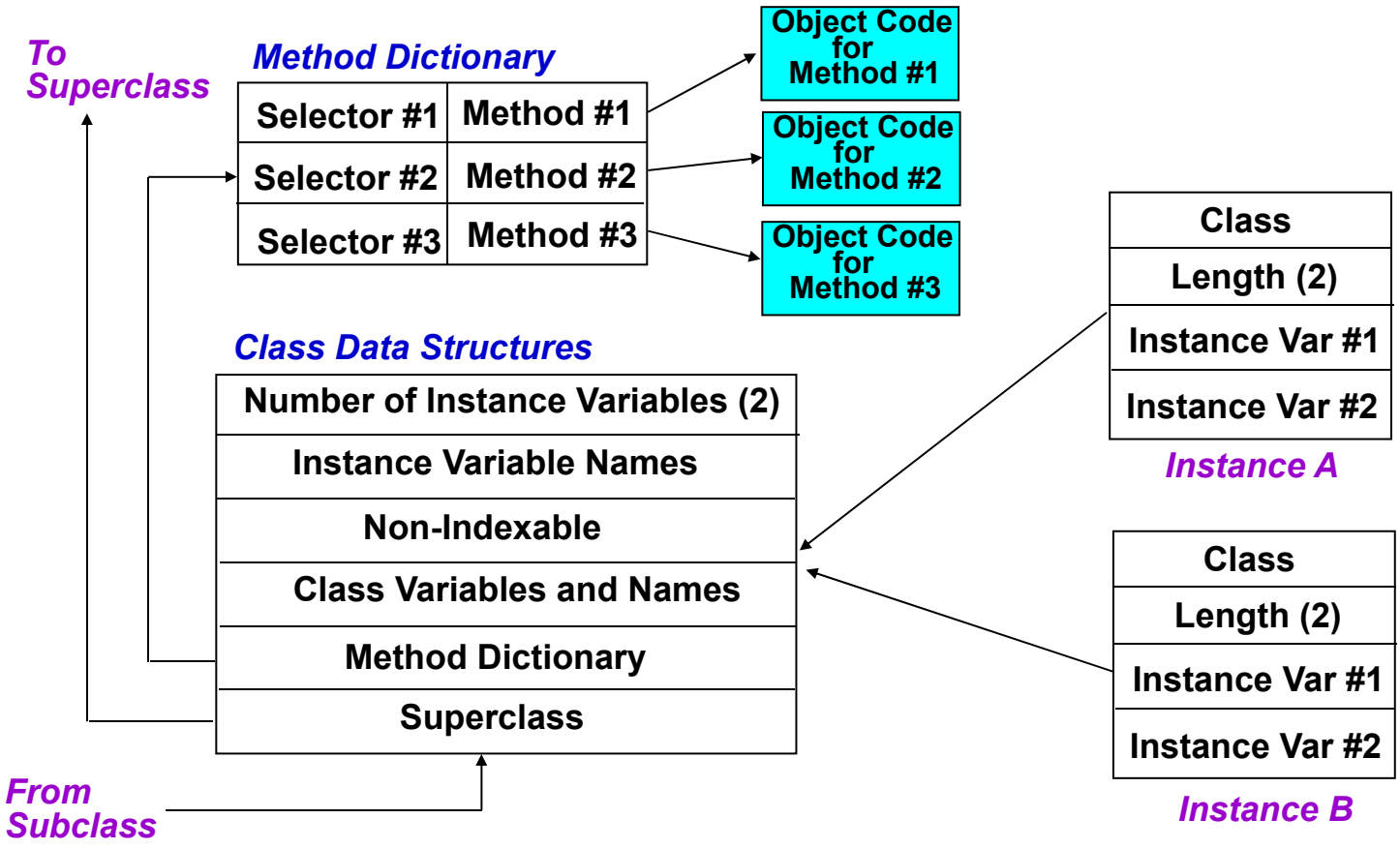






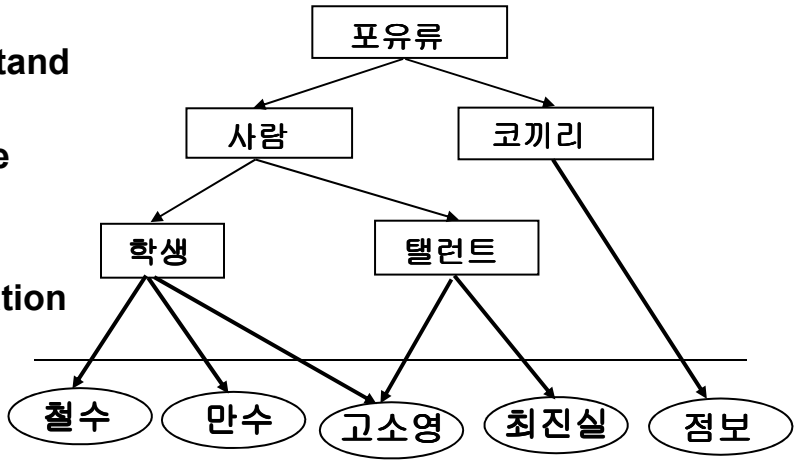


- Data Structures Illustrating Concepts Related to OOP

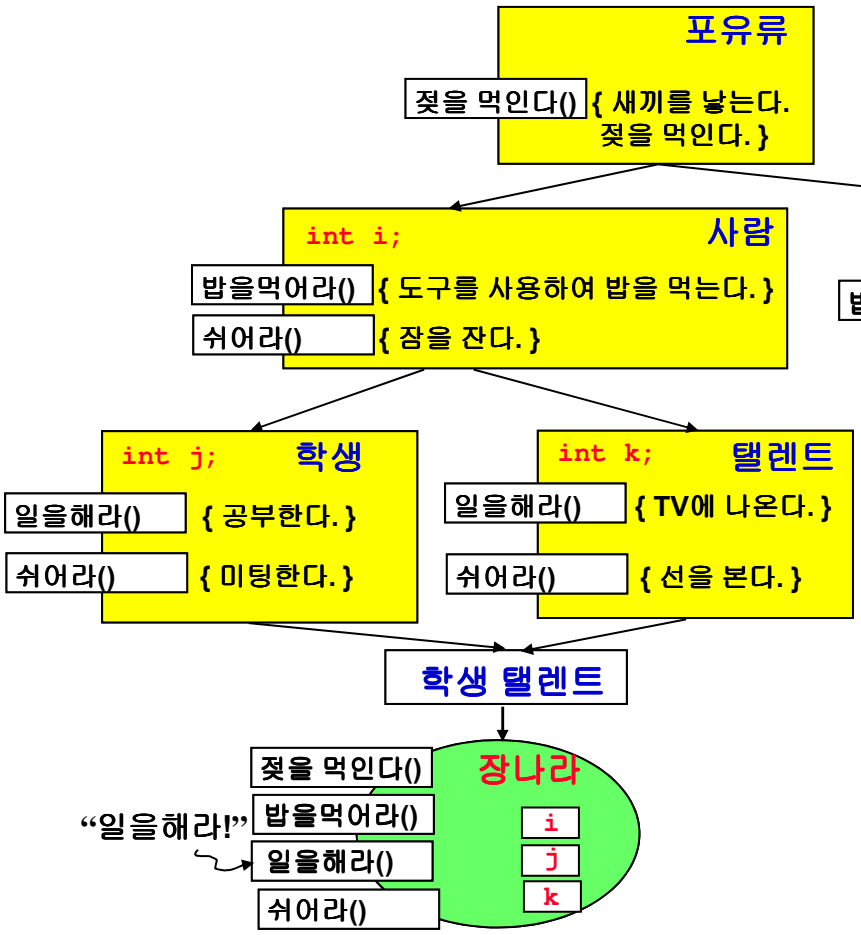


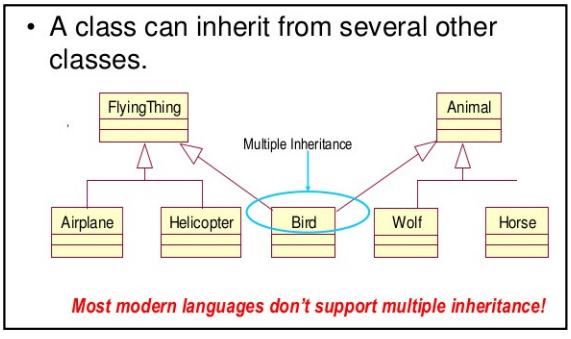
- What is Inherited ?
  - a class inherits instance variable declarations as well as method from its superclass
  - Specialization Method
    - ⇔ Adding : introducing new instance variables and new methods
    - ⇔ Substitution (or Overriding) : class's attributes (variables or methods) may be refined using the superclass as base
    - ⇔ Class Precedence List : accessing closest superclass or ...
- Inheritance Structures
  - Hierarchical Inheritance
    - ⇔ classes may inherit only from a single superclass
    - ⇔ most widely used inheritance (Smalltalk)
    - ⇔ simple and efficient, but limited in expressibility
  - Inheritance by Delegation
    - ⇔ each object is responsible for both choosing which messages it will handle, and for choosing an object to handle those messages that it is not prepared to handle
  - Multiple Inheritance
    - ⇔ a class inherits from more than one parent
    - ⇔ increase the sharing

- **Multiple Inheritance**
  - a class inherits from more than one parent
  - increase the sharing
  - a class inherits the union of variables and methods from all its superclasses
  - if there is conflict, then we use a class precedence list to determine precedence for variable description or method (*depth-first up-to-joins*)
- **Advantages of Inheritance**
  - Better Conceptual Modeling
    - ⇔ direct modeling of everyday life
    - ⇔ hierarchical modeling make the program easier to understand
  - Factorization
    - ⇔ describe only once and reuse when needed
  - Stepwise Refinement in Design
    - ⇔ top-down design and verification
  - Polymorphism



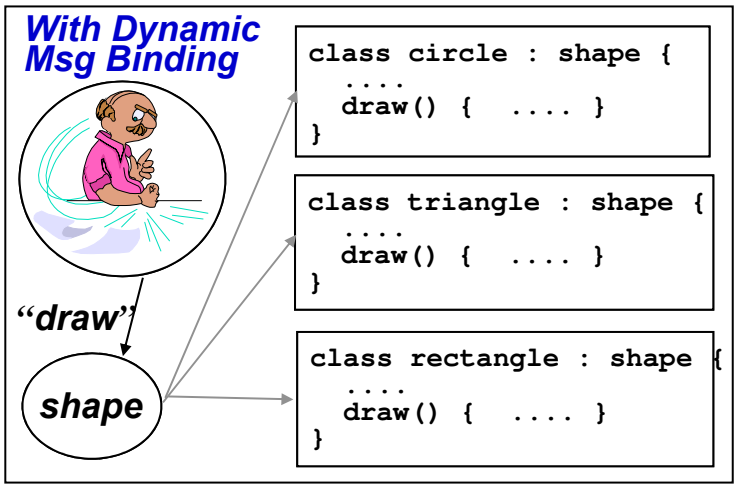
- **Multiple Inheritance Example**

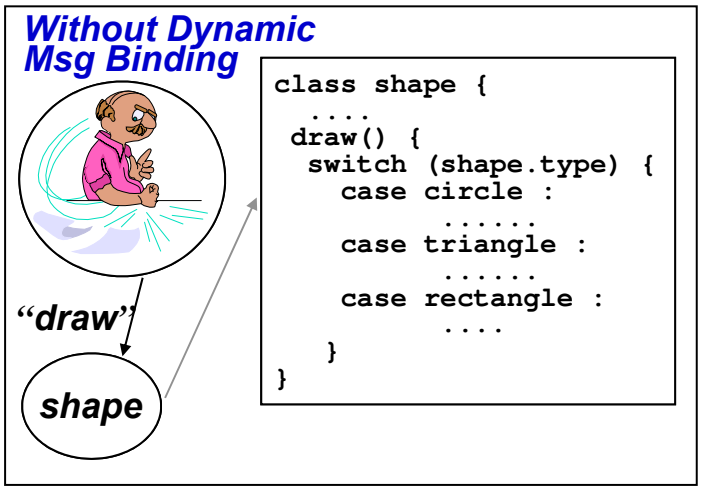




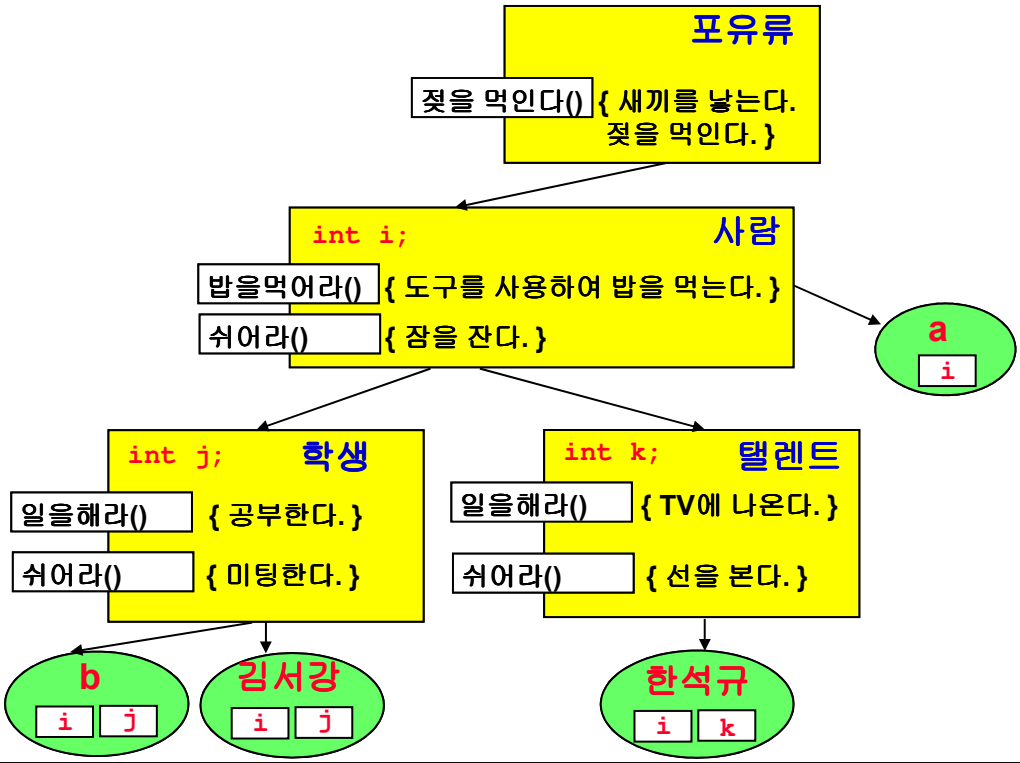
2.5 Dynamic Method Binding and Polymorphism

- **Dynamic Method Binding**
  - **static message binding :**
    - ⇔ the binding of message to a particular method of an object takes place at compile time (statically typed language)
  - **dynamic message binding :**
    - ⇔ the binding of message to a particular method of an object takes palce at compile time (untyped languages)
    - ⇔ a powerful mechanism for supporting **polymorphism**

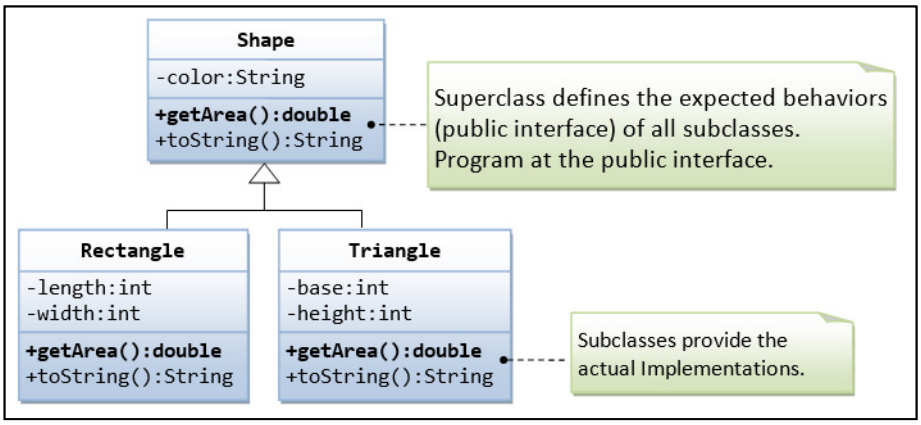


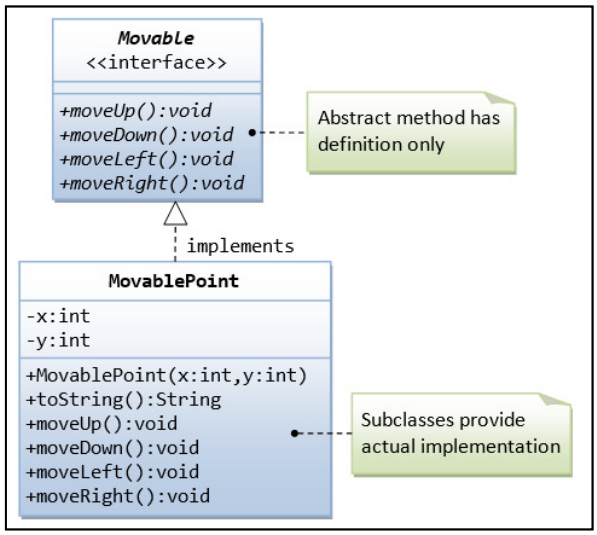


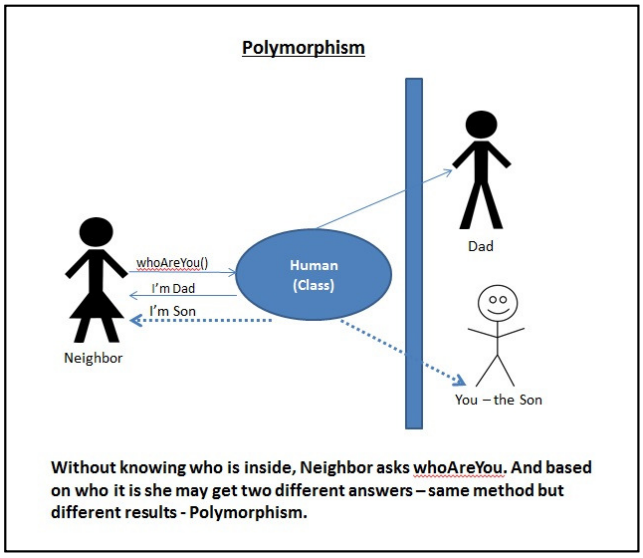
- **Polymorphism (다양성)**
  - ability for operations to operate on more than one type (or class)
  - classification
    - ⇔ **ad hoc polymorphism** : coercion, operator overloading
    - ⇔ **universal polymorphism** : parametric, inclusion (inheritance)




```
int i;
사람 a;
학생 김서강, b;
탤런트 한석규;

b = a; /* ? */

a.쉬어라();
a = 김서강;
a.쉬어라();
a = 한석규;
a.쉬어라();
```



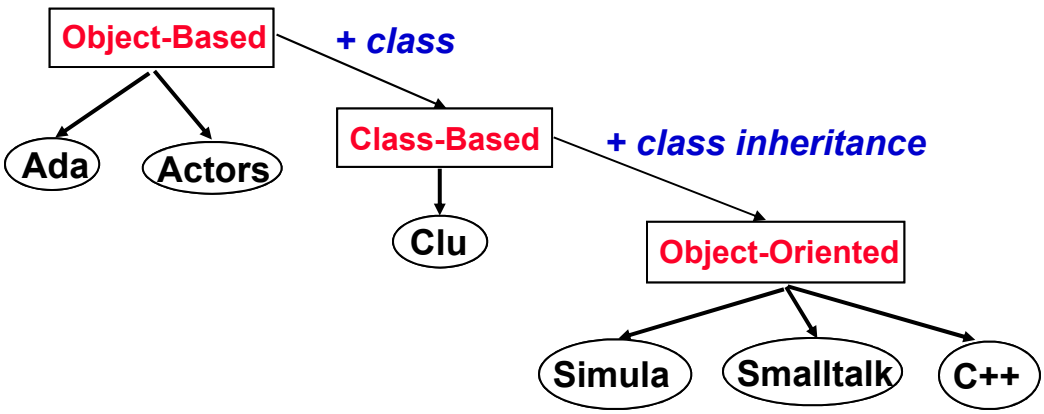




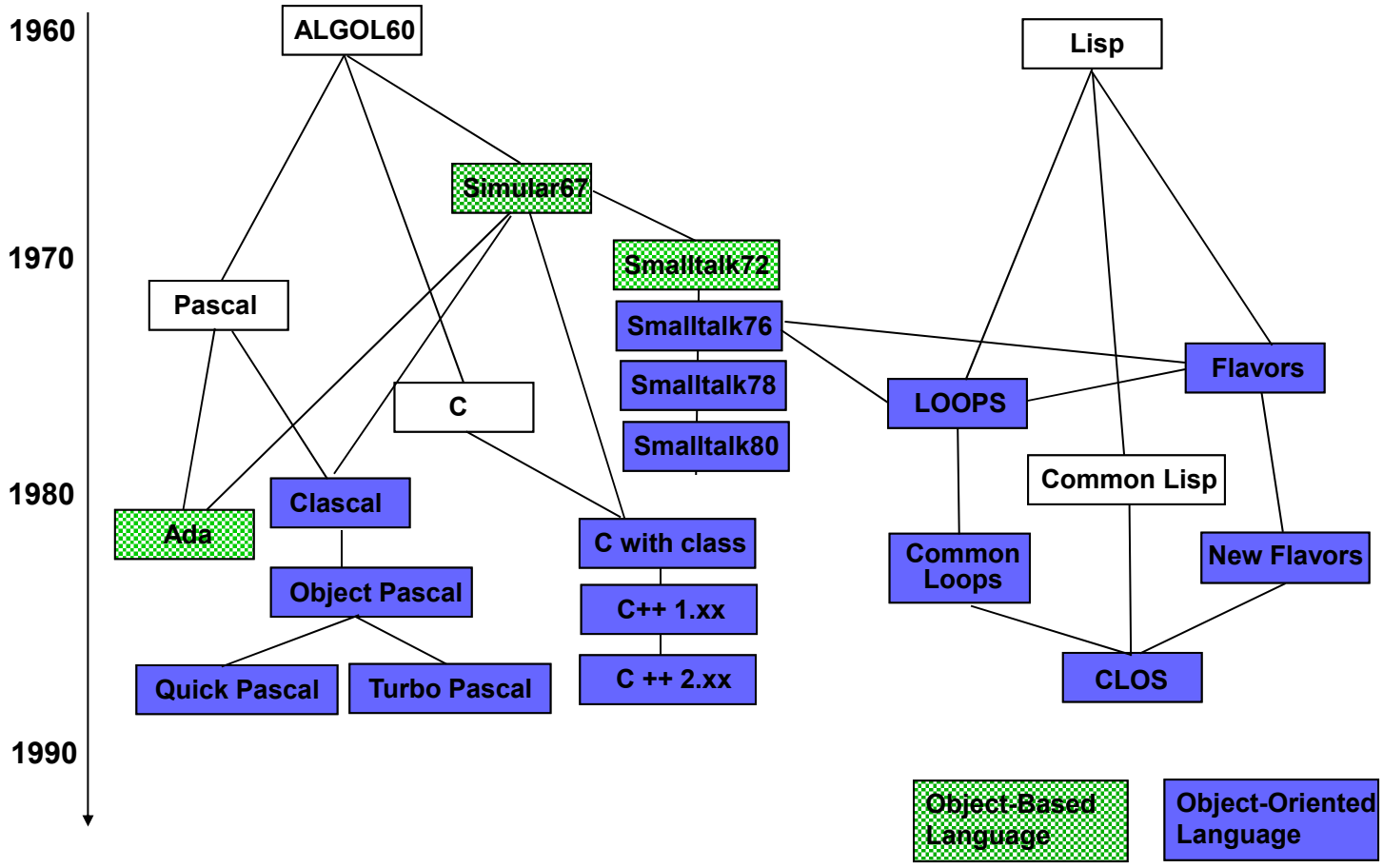
III. Object-Oriented Programming Languages

3.1 Classification

- Do they support : Object ? Classes ? Inheritance ?
  - *Object-based Language*
    - ⇔ the class of all language that support object
  - *Class-based Language*
    - ⇔ the subclass that requires all objects to belong to a class
  - *Object-oriented Language*
    - ⇔ the subclass that requires classes to support inheritance
      - ⇒ Extending Conventional Languages
        - → C++, Objective C, Object Pascal, Object COBOL, CLOS
      - ⇒ Pure Object-Oriented Languages
        - → Eiffel, Simula, Smalltalk

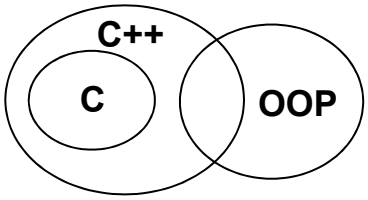


- Genealogy of Object-Based and Object-Oriented Programming Languages



3.2 A Case Study : C++

- What is C++ ?
  - developed by B. Stroustrup's Group at Bell Lab. early 1980
  - based on C (compatible with C, Superset of C)
  - incorporate object-oriented concepts, class, inheritance, etc.
  - extend C with other high-level features such as generic function, reference type, etc.
  - most popular object-oriented programming language
  - emphasize on efficiency and compatibility with C
- C++ History



C with class (1981)

AT&T C++ Release 1.0 (1985)

AT&T C++ Release 2.0 (1989)

GNU C++

ANSI C++ Language Committee(1989)

AT&T C++ Release 3.0 (1991)

MS-C/C++ 7.0

Borland C++ 3.1

- Characteristics of C++
  - Classes
  - Access Levels

  → Data Abstraction

  - Subtyping
  - Virtual Functions

  → Dynamic Binding

  - Multiple Inheritance
  - Virtual Base Classes

  → Inheritance

  - Template Functions
  - Template Classes
  - Operator Overloading

  → Polymorphism

(1) Data Abstraction

constructor
desstructor

C Programming

```
#define MAXSIZE 100

char stack[MAXSIZE];          global variable
int top = 0;

push(char x) {
  if ((top+1) == MAXSIZE)
       error("stack is full\n");
  stack[++top] = x;
}

char pop() {
  if (top == 0)
       error("stack is empty\n");
  return(stack[top--]);
}

main() {
  char x, y;
  push('a'); push('b');
  x = pop(); y = pop() ;
  printf("%c, %c \n", x,y);

}
```

C++ Programming

```
const int MAXSIZE = 100;
class stack {
  private:
    char stack[MAXSIZE];          local variable
    int top;
  public:
    stack() {top = 0;}
    void push(char);
    char pop();
};

void stack::push(char x) {
   if ((top+1) == MAXSIZE)
        error("stack is full\n");
   stack[++top] = x;
}

char stack::pop() {
   if (top == 0)
       error("stack is empty\n");
   return(stack[top--]);
}

stack st1;   /* static object creation*/
main() {
  char x, y;
  st1.push('a'); st1.push('b');
  x = st1.pop(); y = st1.pop();
 printf("%c, %c \n", x,y);
}
```

(2) Operator Overloading

– the same symbol or function name can be used for different meaning

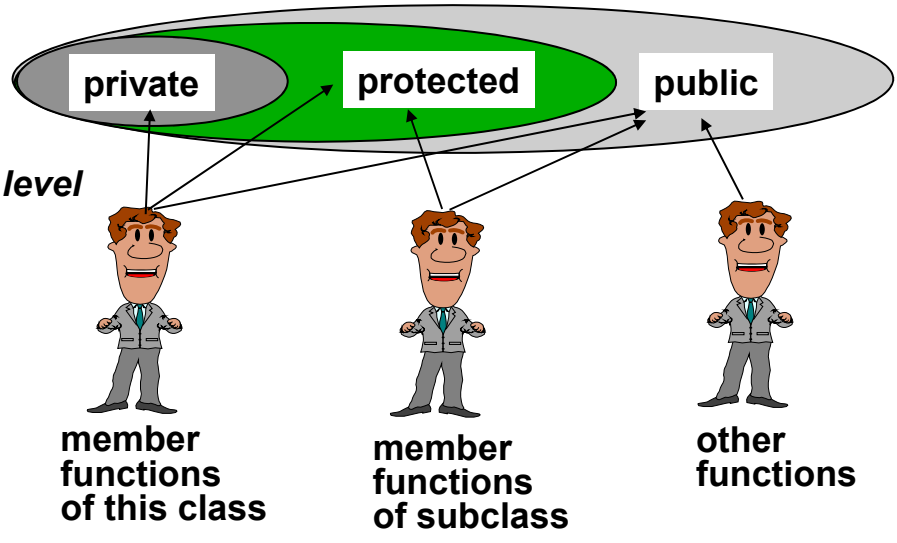
```
#include <iostream.h>
#include <string.h>

class String {
  char* str; int len;
public:
  String(const char*);
  ~String() {delete[] str;}
  char* getString() {return str;}
  String& operator += (String&);
}

String::String(const char* s) {
  len = strlen(s);
  str = new char[len+1];
  strcpy(str,s);
}
```

```
String& String::operator+= (String& s){
  len += s.len ;
  char *p = new char[len+1];
  strcpy(p, str);
  strcat(p, s.str);
  delete str;
  str = p;
  return *this;
}

main() {
  String s1("I am");
  String s2("hungry");
  String s3("and sleepy");
  s1 += s2;
  cout << "The result is";
  cout << s1.getString() << "\n";
}
```


(3) Inheritance, Access Level, and Dynamic Message Binding

- **Access Level**
  - **private members** : accessible only by member functions and friends of the class where they are declared
  - **protected** : like private members, excepts in derived class (subclass)
  - **public** : accessible by any function
- **Access Mode**
  - **public derived class** : the same as the superclass
  - **private derived class** : both the public and protected members of the superclass are private

```
class A {
  private:
      ….
  protected:
      ….
  public:
      ….
}
```



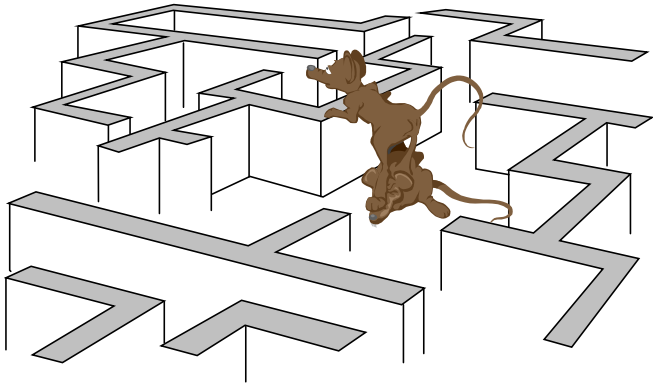
- **Examples**

```
class employee {
  private:
    static employee* list;
  protected:
    char* name;
    char* dept;
    employee* next;
  public:
    employee(char*, char*);
    print_list();
    virtual print();
}

class manager: public employee {
  protected:
    short level;
  public:
    manager(char*, int, char*);
    print();
};

employee::print_list() {
  for (employee* p=list; p; p->next)
     p->print();
}
```

```
class A {
  public:
    virtual display(int i) {
       printf("in A %d\n", i); }
}

class B {
  public:
    virtual display(double d) {
       printf("in B %d\n", d); }
}

class C : public B, public A {
   public:
     virtual display(int i) {
        A::display(i);
     }
     virtual display(double d) {
        B::display(d);
     }
}
main() {
  C c;
  c.display(13);
  c.display(3.14);
}
```

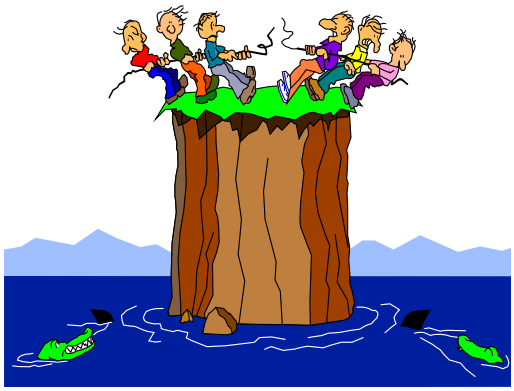

(3) Built-in Class Libraries

- A lot of built-in class libraries for various applications
  - Borland C++
    - ⇔ Container Class Library
    - ⇔ Object Window Library (OWL)
  - MSC 7.0
    - ⇔ Microsoft Foundation Class (MFC)

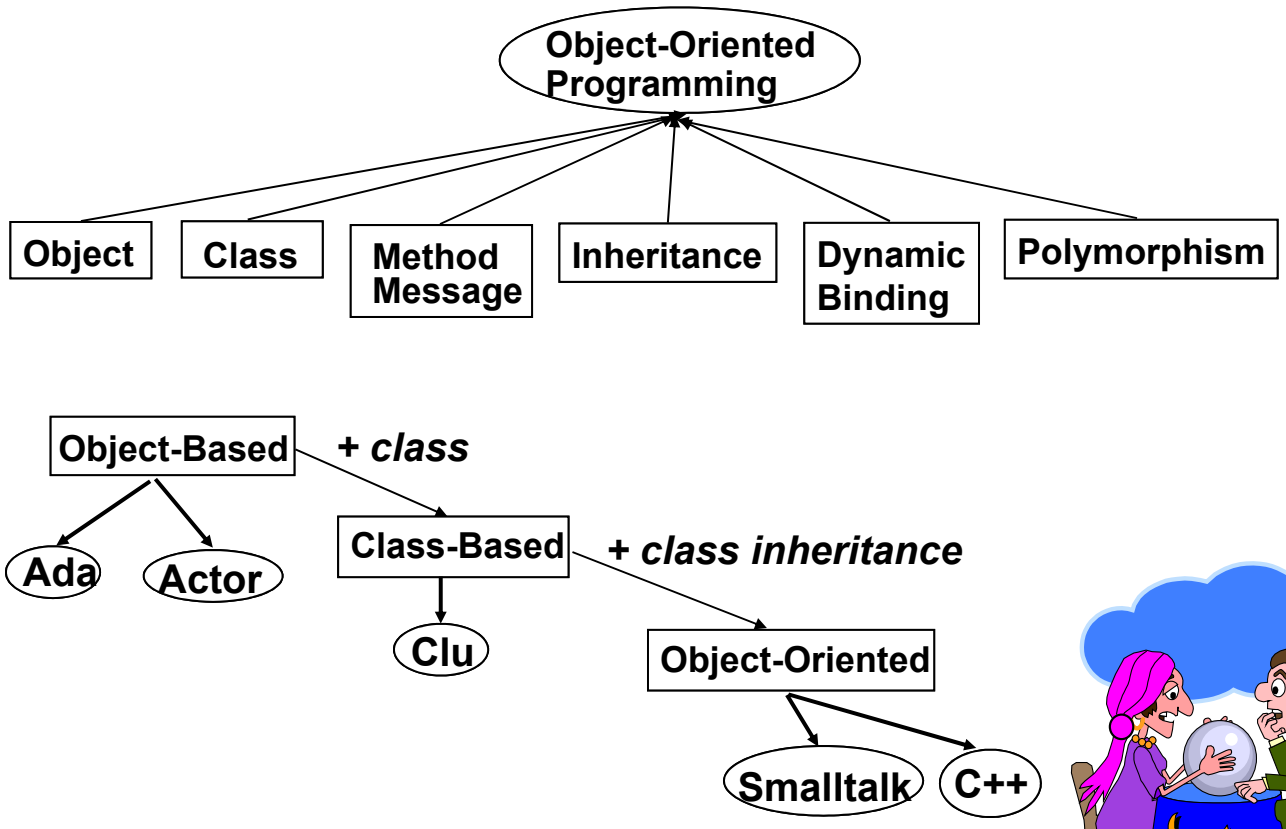


3.3 Analysis

- Advantages of Object-Oriented Programming Languages
  - Encapsulation and Data Abstraction
    - ⇔ increase reliability
    - ⇔ help to decouple procedural and representational specification from implementation
  - Dynamic Binding
    - ⇔ increasing flexibility
  - Inheritance
    - ⇔ increase software reusability
- Disadvantages
  - High run-time costs for
    - ⇔ dynamic binding
    - ⇔ message Passing (1.7 times)
  - Implementation is harder
    - ⇔ semantic gap
    - ⇔ software simulation
  - Programmer must learn extensive class libraries
    - ⇔ hard to learn (Smalltalk, ...)

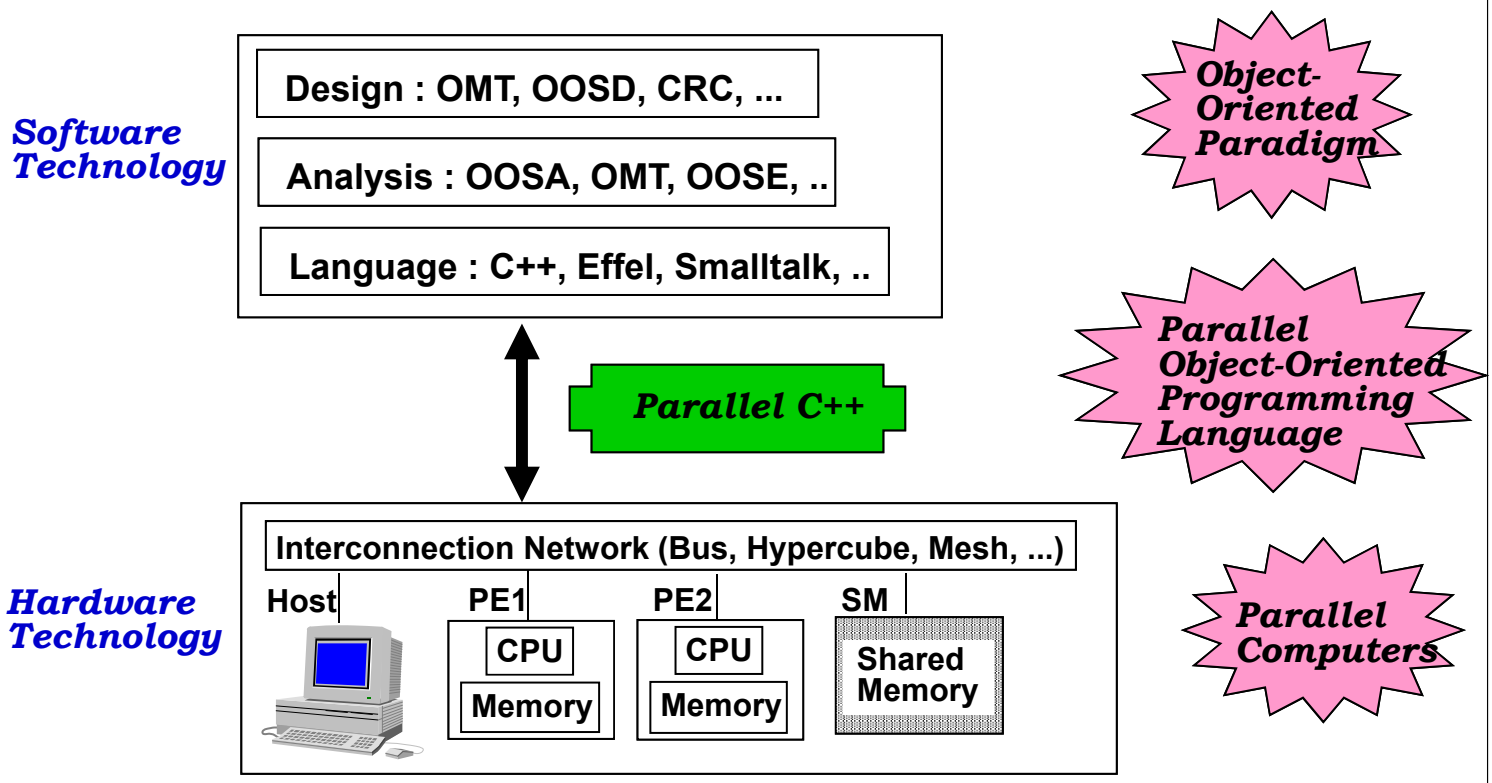


IV. Summary



- **Future Researches**

"Design and Implementation of Parallel C++



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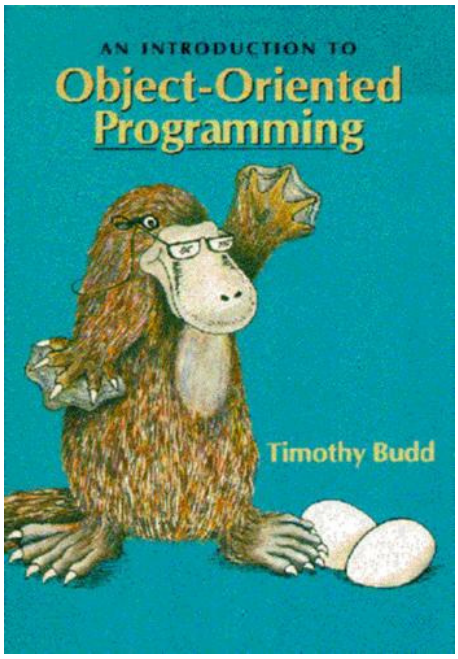
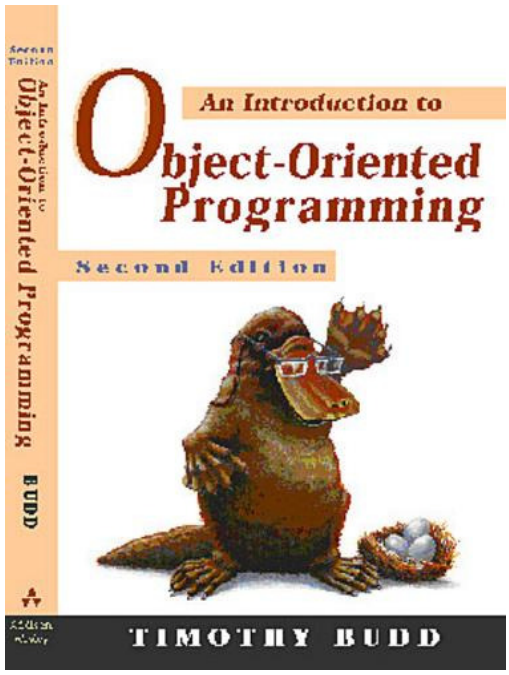




Timothy Budd, *An Introduction to Object-Oriented Programming*, Addison Wesley, 2nd Edition, 1997(?).

C++ as a Better C

- C++ extends the C programming language in a number of important ways
- Its features make it more reliable and easier to use than C

- Comment Style : "//"
  - one-line comment
  - everything on a single line after the symbol "//" is treated as a comment

```
// The computation of circumference and area of circle
#include <iostream.h>

const float pi = 3.14159; // pi accurate to six places
const int true = 1;

inline float circum(float rad) {return (pi*2*rad);}
inline float area(float rad) {return (pi*rad*rad);}

main() {
  float r;
  while (true) {
    cout << "\n Enter radius: "  // prompt for input
    cin >> r;
    cout << "\n Area is " << area(r);
    cout << "\n Circumference is " << circum(r) << endl;
  }
  return(0);
}
```

'<<' : *put to*
'>>' : *get from*
endl : *new line and flush*

- **Avoiding the Preprocessor : *inline* and *const***
  - **inline**
    - ⇔ a request to the compiler that the function be compiled without function call overhead
    - ⇔ inline *vs.* macro
      - ⇒ `#define SQ(X) X*X /* macro */`
      - ⇒ `SQ(a+b) ==> a+b*a+b`
      - ⇒ type checking
  - **const**
    - ⇔ a type specifier
    - ⇔ a variable declared as *const* cannot have its value changed

```
const false = 0;                    // implicit type is int
const double e = 2.71828;           // natural logarithm base
const int M_size = 100;             // used in array declaration
const* p = &M_size;                 // a pointer to a constant int
char* const s = "abcd";             // a constant pointer to char

const double pi=3.141592;
const double *d_p1 = &pi;           // legal: pi is an lvalue
const double *d_p2 = &3.1           // illegal : 3.1 is not an lvalue
pi = 3.141596 ;                     // illegal because pi is nonmodifiable
```


- **Declaration**
  - C++ allows declarations to be intermixed with executable statements

```
for (int i=0; i,52; ++i) {
  int k = rand()%52;
  card t = d[i] ;
  d[i] = d[k] ;
  d[k] = t;}
```

- **Scope Resolution Operator : "::"**
  - *static scoping rule* : a name in an inner block hides the outer block or external use of the same name
  - however, when used in form *::variable*, it allows access to the externally named variable

```
#include <iostream.h>
int i = 1 ;          // external i

main() {
  int i = 2;     // re-declares i locally
  {
    cout << "enter inner block\n"
    int n = i;
    int i = 3;
    cout << i << "i <> ::i" << ::i << "\n";
    cout << "n = " << n << "\n";
  }
  cout << "enter outer block\n"
  cout << i << "i <> :: i" << ::i << endl;
}
```

Output

```
enter inner block
3 i <> ::i 1
n = 2
enter outer block
2 i <> ::i 1
```

- **Function Prototyping**
  - by *explicitly* listing the type and number of arguments, strong type checking and assignment-compatible conversions are possible in C++
  - Example

```
double sqrt(double x);
void make_str(char*, int);
void print(const *char s);     // s is not modified
int printf(char* format, ...) // variable number of arguments
```

  - C prototyping vs. C++ prototyping

in C

```
double sqrt() ;
main() {
 ...
 printf("%f is sqrt of 4\n",
                      sqrt(4));
 ...
}
```

output

```
0 is sqrt of 4
```

in C++

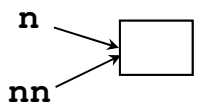
```
double sqrt(double) ;
main() {
 ...
 printf("%f is sqrt of 4\n",
                      sqrt(4));
 ...
}
```

output

```
2.0 is sqrt of 4
```


- **Reference Declarations and Call-by-Reference**
  - declare the identifier to be an alternative name for an object specified in an initialization of reference
  - Example

```
int n ;
int& nn = n ; // nn is an alternative name for n
double a[10];
double& last=a[9]; // last is an alias for a[9]
const char& newline='\n' ;
```



  - it allows C++ to have call-by-reference argument directly

```
int greater(int&, int&) ;
mani() {
 int a = 5;
 int b = 4;
 ...
 greater(a,b);
 printf("a=%d, b=%d\n", a, b);
}
```

output

```
a=4, b=5
```

```
int greater(int& x, int& y)
{
  if (x > y) {  // exchange
     int temp = a;
     a = b;
     b = temp;
     return(1);
  }
  else
     return(0);
}
```

- **Default Arguments**
  - *a formal parameter* can be given a default argument
    ⇔ this is usually a constant that occurs frequently when the function is called

```
int mult(int n, int k=2) // k=2 is default
{
  if (k==2)   return (n*n);
  else        return (mult(n,k-1) * n);
}
main() {
  ..
  mul(i+5)   // compute (i+5)*(i+5)
  mult(i+5,3) // compute (i+5)^3
}
```

  - *only trailing parameters* of a function can have default values

```
void foo(int i, int j=7);              // legal
void goo(int i=3, int j);              // illegal
void hoo(int i, int j=3, int k=3);     // legal
void moo(int i=1, int j=2, int k=3);   // legal
void noo(int i, int j=2, int k);       // illegal
```


- **Overloading Function**
  - the term *overloading* refers to using the same name for multiple meaning of an operator or function
  - the meaning selected depends on the types and number of arguments used by the operator or function
  - Example

```
double average(const int a[],int size) {
  int sum=0;
  for (int i=0; i<size; i++) {
    sum = sum + a[i]; // int arithmetic
  }
  return((double) sum/size);
}
double average(const double a[],int size){
  double sum=0.0;
  for (int i=0; i<size; i++) {
    sum = sum + a[i]; // double arith
  }
  return(sum/size);
}
double average(const int a[], double b[],
               int size) {
  double sum=0.0;
  for (int i=0; i<size; i++) {
    sum = sum + a[i] + b[i]; //double arith
  }
  return(sum/size);
}
```

the compiler chooses the function with matching types and arguments

```
main() {
 int w[5]={1,2,3,4,5};
 double x[5]={1.1,2.1,3.1
              4.1,5.2}

 cout << average(w,5);
 cout << average(x,5);
 cout << average(w,x,5);

 return(0);
}
```

- **Free Store Operators `new` and `delete`**
  - the unary operator `new` and `delete` are available to manipulate *free store*
    - ⇔ free store is a system-provided memory pool for objects whose lifetimes are directly managed by the programmer
    - ⇔ replace the standard library functions `malloc`, `calloc`, `free`
  - Example

```
int* prt_i, *v;
double (*)[N] q;
ptr_i = new int(5); // allocate and initialize, so *ptr_i is 5
v = new int[40] ; // allocate a vector of 40 integers, v == &v[0]
q = new double[n][N]; // allocate an n by N vector of integer,
                      // q == &q[0][0]
```

```
main() {
  int *data ; int size ;

  cout << "\nEnter array size:"; cin >> size;
  data = new int[size];
  for (int j=0; j< size; j++) {
    cout << (data[j] = j) << "\t";
  cout << endl;

  delete []data;
  data = new int[size];
  for (int j=0; j< size; j++) {
    cout << (data[j] = j) << "\t";
  }
}
```

print different values???

- **`Stack` Example -1**

```
class stack {
 private:
   char s[max_len];
   int top;
   enum{EMPTY=-1, FULL=max_len-1};
 public:
   void reset() {top = EMPTY;}
   void push(char c) {top++; s[top]=c;}
   void pop() {return(s[top--]);}
   void top_of() {return(s[top]);}
   void empty() {return (top==EMPTY);}
   void full() {return (top==FULL);}
}
```

```
main() {
  statck ss;
  char str[40] =
        {"Sogang Univ!"};

  cout << str << "\n";
  ss.reset();
  while(str[i])
     if (!ss.full())
        ss.push(str[i++]);
  while (!ss.empty())
     cout << ss.pop();
  cout << "\n";
}
```

output

```
Sogang Univ!
!vinU gnagoS
```

- Stack Example -2

```
class stack {
 private:
   char *s;
   int top, max_len;
   enum{EMPTY=-1, FULL=max_len-1};
 public:
   void stack() {max_len=100;
                 s = new char[max_len];
                 top = EMPTY;}
   void stack(int size) {
                 max_len=size;
                 s = new char[max_len];
                 top = EMPTY;}
   void ~stack() {
                delete []s;
   }
   void push(char c) {
                top++; s[top]=c;}
   void pop() {
                return(s[top--]);}
   void top_of() {
                return(s[top]);}
   void empty() {
                return (top==EMPTY);}
   void full() {
                return (top==FULL);}
}
```

overloaded constructor

```
main() {
  statck ss, tt(20);
  char str[40] =
        {"Sogang Univ!"};

  int i=0;
  cout << str << "\n";
  while(str[i])
     if (!ss.full())
          ss.push(str[i++]);
  while (!ss.empty())
     cout << ss.pop();
  cout << "\n";
}
```

output

```
Sogang Univ!
!vinU gnagoS
```


C++ as an Object-Oriented Programming Language

- **Classes and Abstract Data Type**
  - a class provides the means for implementing a user-defined data type and associated functions and operators
  - class can be used to to implement an ADT

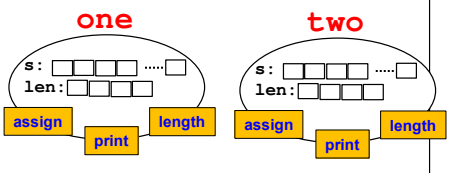
```
#include <string.h>
#include <iostream.h>
const int max_len = 255;

class string {
  public:  // univeral access
    void assign(const char* st) {
      strcpy(s, st); len = strlen(st);
    }
    int length() {
      return(len);
    }
    void print() {
      cout << s <<
      "\nLength: " len << "\n";
    }
  private:
    char s[max_length];
    int len ;
}
```

```
main() {
  string one, two;
  char three[40]={"Sogang Univ."};
  one.assign("Dept. of CS");
  two.assign(three);
  cout << three;
  cout << "\nLength:" <<
        strlen(three) << endl ;
  if (one.length()<= two.length())
      one.print();
  else
      two.print();
}
```

output

```
Sogang Univ.
Length: 12
Dept. of CS
Length: 11
```



- **static Member**
  - ⇔ a data member that is declared *static* is *shared* by all variables of that class and is stored uniquely in one place
    - ⇒ nonstatic data members are created for each instance of the class
  - ⇔ since a static member is independent of any particular instance, it can be accessed in the form *class_name*::identifier

```
class str {
  public:
    static int how_many;   // declaration
    void print();
    void assign(const char*);
    ...
  private:
    char s[100];
}
```

```
main() {

   str s1, s2, s3, *p;
   str::how_many = 3;
   ...
   str t ;
   t.how_many++;
   ...
   p = new str;
   p->how_many++;
   ...
   delete p;
   str::how_many--;
}
```

- **nested class**

```
char c;                    // external scope ::c
class X {
  public:
    class Y{
      public:
        void foo(char e) { ::c = X::c = c = e;}
      private:
        char c; // X::Y::c
    }
 private:
   char c;                 // X::c
};
```


- **Constructor and Destructor**
  - **Constructor**
    - ⇔ a member function whose job is to initialize a variable of its class
    - ⇔ is invoked anytime an object of its associated class is created
  - **Destructor**
    - ⇔ a member function whose job is to deallocate or finalize a variable of its class
    - ⇔ is called implicitly when an automatic objects goes out of scope
  - **new**
    - ⇔ allocates the appropriate amount of memory to store this type from free store and returns the pointer value that addresses this memory

```
class string {
 public:  // univeral access
  string() {len=255; s = new char[255];}
  string(int n) { s = new char[n+1]; len = n;}
  string(const char* p) {
     len = strlen(p) ; s = new char[len+1];
     strcpy(s, p); }
  ~string() { delete []s; }
  void assign(const char* st) {
     strcpy(s, st); len = strlen(st);}
  int length() { return(len);}
  void print() {
     cout << s << "\nLength: " len << "\n";}
 private:
    char *s;
    int len ;
}
```

```
main() {
   ....
   string a,b(10);
   string c("Sogang");
   ...
}
```

```
// ADT Conversion
x = float(i) ; // C++ function notation
x = (float) i ;
```

```
// automatical type conversion from char* to string
string::string(const char* p) { /* constructor */
  len = strlen(p);
  s = new char[len+1];
  strcpy(s, p);
}

.....
string s;
char* logo = "Sogang Univ.";
s = string(logo) ; // perform conversion then assign
s = logo // implicit invocation of conversion
```


- **Overloading**
  - refers to the practice of giving several meanings to an operator or a function
  - the meaning selected depends on the types of the arguments used by the operator or function

```
class string {
    ...
    void print() {
      cout << s <<
      "\nLength: " len << "\n";
    }
    void print(int n) {
      for (int i=0;i<n;i++){
        print();
      }
    }
    ...
}
```

```
main() {
   string three;
   three.print();
   three.print(9);
   three.print(-2);
}
```

  - *operator* overloading and *friend* function
    - ⇔ `operator` : precedes the operator token and replaces what would otherwise be a function name in a function declaration
    - ⇔ `friend` :
      - ⇒ the keyword `friend` gives a function access to the private members of a class variable
      - ⇒ a friend function is not a member of the class but has the privileges of function in the class in which it is declared

```
#include <string.h>
#include <iostream.h>
const int max_len = 255;

class string {
 public:  // univeral access
  void assign(const char* st) {
     strcpy(s, st); len = strlen(st);}
  int length() {
     return(len);}
  void print() {
     cout << s <<
     "\nLength: " len << "\n";}
  friend string operator+(const string& a,
                          const string& b);
 private:
     char s[max_length];
     int len ;
}

string operator+(const string& a,
                 const string& b){
  string temp;
  temp.assign(a.s);
  temp.len = a.len + b.len;
  if (temp.len < max_len)
     strcat(temp.s, b.s);
  else
     cerr << "Max length exceeded
              in concatenation.\n";
  return(temp);
}
void print(const char* c) {
  cout << c << "\nlength: " <<
          strlen(c) << "\n";
}
```

not a member function of string class,but can access len variable

```
main() {
 string one, two, both;
 char three[40]={"Sogang Univ."};

 one.assign("Dept. of CS");
 two.assign(three);
 print(three);

 if (one.length()<=two.length())
      one.print();
 else
      two.print();
 both = one + two ;
 both.print();
 return(0);
}
```

output

```
Sogang Univ.
length: 12
Dept. of CS
Length: 11
Dept. of CSSogang Univ.
Length:23
```



```
// a safe vect with [] overloaded
#include <iostream.h>
#include <stdio.h>

class vec {
  public:
     vect();
     vect(int n);
     vect(const vect& v);
     vect(const int a[], int n);
     ~vect() {delete []p;}
     int ub() const {return (size-1);}
     int& operator[](int i) const;
  private:
     int* p;
     int size;
}

vect::vect() {
  size = 10; p = new int[size];
}

vect::vect(int n) {
  if (n <= 0) {
     cerr<<"illegal vect size:"<<n<<"\n";
     exit(1);
  }
  size = n ; p = new int[n];
}

vect::vect(const int a[], int n) {
  if (n <= 0) {
     cerr<<"illegal vect size:"<<n<<"\n";
     exit(1);
  }
  size = n ; p = new int[size] ;
  for (int i=0; i<size; i++) p[i] = a[i];
}

vect::vect(const vect& v) {
  size = v.size ; p = new int[size];
  for (int i=0 ; i<size; i++)
        p[i] = v.p[i]; /* IS IT OK ?? */
}
```

```
int& vect::operator[](int i) const {
  if (i<0 || i>ub()) {
     cerr << "illegal vect index:"
          << i << "\n";
     exit(0);
  }
  return(p[i]);

vect& vect::operator=(const vect& v) {
  int s = (size<v.size)?size:v.size;
  if (v.size != size)
     cerr << "copying different size"
          << size << " and " << v.size;
  for (int i=0; i<s; i++)
     p[i] = v.p[i];
  return(*this);
}

vect vect::operator+(const vect& v) {
  int s = (size<v.size)?size:v.size;
  vect sum(s);
  if (v.size != size)
     cerr << "adding different size"
          << size << " and " << v.size;
  for (int i=0; i<s; i++)
     sum.p[i] = p[i] + v.p[i];
  return(sum);
}
.....
vect a(10), b(5);
a[1] = 5; a[12] = b[4]+3;
a = b        // a, b are type vect
a = b = c ; // a,b,c are type vect
a = vect(data, DSIZE) // data[DSIZE]
a = b+a;
a = b + (c = a) + d ;
```

```
// friend function

class vect {
  public:
    friend vect mpy(const vect& v, const matrix& m);
    ...
  private:
    int*  p;
    int size;
};

class matrix {
  public
    friend vect mpy(const vect& v, const matrix& m);
    ...
  private:
    int ** p;
    int s1, s2;
};

vect mpy(const vect& v, const matrix& m) {
  if (v.size != m.s1) { // incorrect sizes
    cerr << "multiply failed - size incorrect" << v.size
         << " and " << m.s1 << "\n";
    exit(1);
  }
  // use privilleged access to p in both classes
  vect ans(m.s2)
  int i, j;
  for (i=0; i<=m.ub2;i++) {
    ans.p[i] = 0;
    for (j=0; j<=m.ub1; j++) ans.p[i] += v.p[j] * m.p[i][j];
  }
  return(ans);
}
```


- **Inheritance**
  - many types are variants of one another, and it is frequently tedious and error prone to develop new code for each
  - deriving a new class from an existing one called ***base class*** : ***inheritance***

    ⇔ the base class can be ***added*** to or ***altered*** to create the derived class

```
enum support {ta, ra, fellowship, other} ;
enum year {fresh, soph, junior, senior, grad};

class student {
  public:
    student (char* nm, int id, double g, year x);
    void print();
  private:
    int student_id;
    double gpa ; year y; char name[30];
}

class grad_student: public student {
  public:
    grad_student(char *nm, int id, double g, year x,
                 support t, char *d, char *th);
    void print();
  private:
    support s;
    char dept[10];
    char thesis[80];
}
```

```
enum year {fresh, soph, junior, senior, grad};
class student {
  public:
    student (char* nm,int id,double g year x);
    void print() const;
  protected:
    int student_id; double gpa;
    year y; char name[30];
};

enum support{ta, ra, ga, fellowship, other};
class grad_student : public student {
  public:
    grad_student(char* nm, int id, double g,
       year x, support t, char *d, char* th);
    void print() const;
  protected:
    support s; char dept[10]; char thesis[80];
};

student::student(char* nm, int id, double g,
     year x): student_id(id), gpa(g), y(x) {
  stcpy(name, nm);
}

grad_student::grad_student(char* nm, int id,
   double g,year x,support t,char *d,char* th):
    student(nm,id,g,x), s(t) {
  strcpy(dept,d); strcpy(thesis, th);
}

student:: print() const {
  cout << "\n" << name << ", " << studnet_id
       << ", " << y << gpa << endl;
}

grad_student::print() const {
  student::print();
  cout << dept << ", " << s << "\n" << thesis
       << endl ;
}
```

```
// Test pointer conversion rule

main() {
  student s("Nang", 821102,
            3.412, fresh),
         *ps = &s ;
  grad_studnet gs("Kim", 811102,
    2.523, grad, ta, "Computer",
    "on PC"), *pgs;

   // student::print
   ps->print() ;

   ps = pgs = &gs;

   // student::print
   // static mgs binding
   ps->print();


   // grad_student::print
   pgs->print();
   return(0);
}
```

a pointer whose type is pointer to base class can point to objects having the derived class type


```
// Multiple Inheritance
class tools{
  public:
    tools(char*);
    int cost();
    ...
};

class parts {
  public:
    parts(char*);
    int cost();
    ..
};
class labor {
  public:
    labor(char*);
    int cost();
    ...
};

class plans: public tools, public parts, public labor {
  public:
    plans(int m): tools("lathe"), parts("widget"), labor(m), a(m) {
       ...
    }
  tot_cost() {return (parts::cost() + labor::cost());}
  ...
}
```

- **Polymorphism**
  - *virtual function* allows run-time selection from a group of functions overridden within a type hierarchy (dynamic msg binding)
  - abstract base class

```
// virtual function selection
#include <iostream.h>

class B {
  public:
    int i;
    virtual void print_i() { cout << i << "inside B\n";}
};
class D : public B {
  public:
    void print_i() {cout << i << "inside D\n";}
};
main() {
  B b;
  B* pb = &b;
  D f;
  f.i = 1 + (b.i = 1);
  pb->print_i()    // call B::print_i()
  pb = &f;         // points at a B object
  pb->print_i();   // call D::print_i();
  return(0);
}
```

output

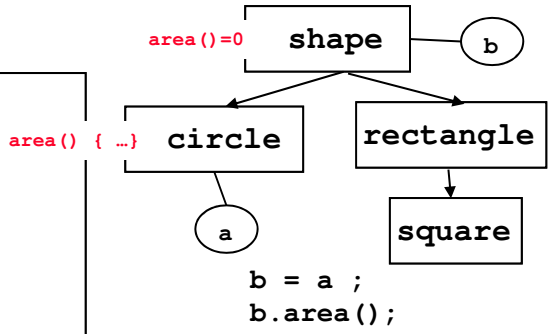
```
1 inside B
2 inside D
```



```
// shape is an abstract base class
class shape {
  public:
    virtual double area()=0;
};

class rectangle: public shape {
  public:
    rectangle(double h,double w):
                        height(h),width(w) {}
    double area() { return(height*width);}
  private:
    double height, width;
}
class circle : public shape {
  public:
    circle(double r): radius(r) { }
    double area() {return(3.14*radius*radius);}
  private:
    double radius;
}
class square : public rectangle {
  public:
    square(double h) : rectagle(h,h) { }
    double area() { return(rectangle::area());}
}
```

만약 이것을 정의하지 않으면??




```
b = a ;
b.area();
```

Client Code

```
...
shape *ptr_shape;
...
cout << "area =" <<
   ptr_shape->area();
...
```

Client Code

```
shape* p[N];
...
for (int i=0;i<N;i++){
  tot_area +=
        p[i]->area();
}
```

the client code does not need to change if new shapes are added to the system

• Overloading, Overriding, and Dynamic Method Binding

```
class B {
  public:
    virtual foo(int);
    virtual foo(double);
};

class D : public B {
  public:
    foo(int);
};

main() {

  D  d;
  B  b, *pb = &d ;

  b.foo(9);     // B::foo(int)
  b.foo(9.5);   // B::foo(double)
  d.foo(9);     // D::foo(int)
  d.foo(9.5);   // D::foo(int)
  pb->foo(9);   // D::foo(int)
  pb->foo(9.5);  // B::foo(double)
```

the declaration of an identifier in a scope hides all declarations of that identifiers in outer scopes (static scoping rule), and a base class is outer scope of any class drived from it.

d.B::foo(5.2) // B::foo(double)

static scoping rule, and coercion

dynamic msg binding

• Templates

- provide *parametric polymorphism*
  - ⇔ allows the same code to be used with respect to *different types*, where the type is a parameter of the code body
- the template is used to generate different actual class when class T is substituted for with an actual type
- a stack container class as a parameterized type

```
template <class LALA>
class stack {
  public:
    stack(int size=100):max_len(size) {
      s=new LALA[SIZE];top=EMPTY;}
    ~stack(){delete []s;}
    void reset { top = EMPTY;}
    void push(LALA c) {s[++top]=c;}
    void pop{return(s[top--]);}
    boolean empty() {
       return(boolean(top==EMPTY));}
    boolean full() {
       return{boolean(top==max_len-1);}
  private:
    enum {EMPTY = -1};
    LALA* s;
    int max_len;
    int top;
}
```

```
main() {

  // 100 element char stack
  stack<char> stk_ch ;

  // 200 element char* stack
  stack<char*> stk_str(200);

  // 100 element complex stack
  stack<complex> stk_cmplx(100);

  ...
}

reverse( char* str[], int n) {
  stack<char*> stk(n);
  for (int i=0;i<n;i++)
    stk.push(str[i]);
  for (i=0;i<n;i++)
    str[i] = stk.pop()
}
```

- **Exceptions**
  - the exception is handled by invoking the appropriate handler selected from a list of handlers found immediately after the handler's `try` block
  - an exception is raised by using the `throw` expression
  - not an extension for OOP

```
// stack constructor with exception
stack::stack(int n) {
  if (n<1) throw(n)
  p = new char[n];
  if (p == 0) throw("FREE STORE EXHAUSTED");
}

void g() {
  ...
  try {
    stack a(n), b(m) ;
    ...
  }
  catch(int n) { ... } // an incorrect size
  catch(char* err) { ... } //free store exhaustion
```

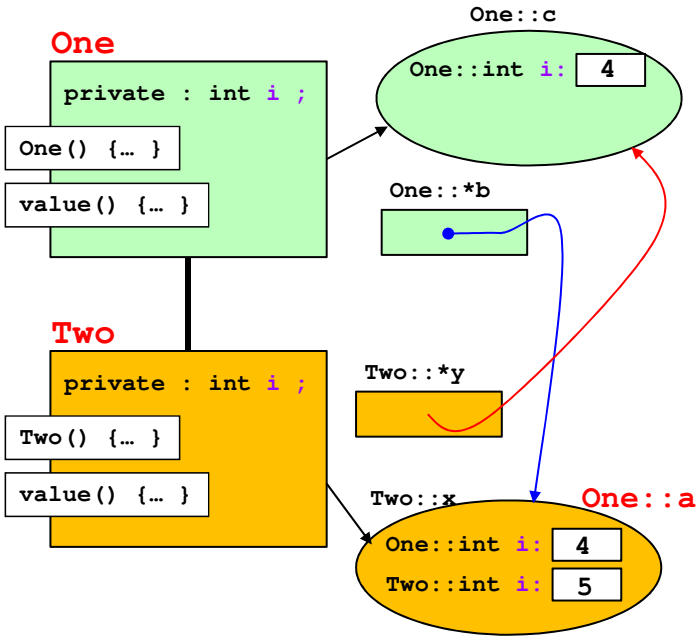

5. 오른쪽과 같은 C++프로그램을 이용하여 아래의 물음에 답하라. (15점)
(a) 이 프로그램에 error가 2개 있다 어느 부분이 왜 error인가 설명하라. (5점)
(b) Error 문정을 comment 처리한 후 프린트 되는 결과는 무엇인가 ? (5점)
(c) 만약 virtual 키워드를 없애면 프린트되는 결과는 무엇인가 ? (5점)

```
#include <iostream.h>
class One {
     private: int i ;
     public:
       One() { i = 4;}
       virtual int value() {
           i = Two::value() + 1;
           return(i);}
} ;
class Two : public One {
        private: int i ;
        public:
           Two() { i = 5;}
           int value() {
              i = One::value() + 7;
              return(i);}
} ;
main() {
 Two x, *y ; One &a = x ; One *b ; One c;
 b = &x ;y = &c ; c = x ;
 cout << "a.value():" << a.value() << "\n"
   << "b->value():" << b->value() << "\n"
   << "c.value():" << c.value()   << "\n";
}
```

5. 오른쪽과 같은 C++프로그램을 이용하여 아래의 물음에 답하라. (15점)
(a) 이 프로그램에 error가 2개 있다 어느 부분이 왜 error인가 설명하라. (5점)
(b) Error 문정을 comment 처리한 후 프린트 되는 결과는 무엇인가 ? (5점)
(c) 만약 virtual 키워드를 없애면 프린트되는 결과는 무엇인가 ? (5점)

```
#include <iostream.h>
class One {
     private: int i ;
     public:
       One() { i = 4;}
       virtual int value() {
           i = Two::value() + 1;
           return(i);}
} ;
class Two : public One {
        private: int i ;
        public:
           Two() { i = 5;}
           int value() {
              i = One::value() + 7;
              return(i);}
} ;

main() {
 Two x, *y ; One &a = x ; One *b ; One c;
 b = &x ;y = &c; c = x ;
 cout << "a.value():" << a.value() << "\n"
   << "b->value():" << b->value() << "\n"
   << "c.value():" << c.value()    << "\n";
}
```



x.value() ??

5. 오른쪽과 같은 C++프로그램을 이용하여 아래의 물음에 답하라. (15점)
(a) 이 프로그램에 error가 2개 있다 어느 부분이 왜 error인가 설명하라. (5점)
(b) Error 문정을 comment 처리한 후 프린트 되는 결과는 무엇인가 ? (5점)
(c) 만약 virtual 키워드를 없애면 프린트되는 결과는 무엇인가 ? (5점)

```
#include <iostream.h>
class One {
     private: int i ;
     public:
       One() { i = 4;}
       virtual int value() {
           i = Two::value() + 1;
           return(i);}
} ;
class Two : public One {
        private: int i ;
        public:
           Two() { i = 5;}
           int value() {
              i = One::value() + 7;
              return(i);}
} ;
main() {
 Two x, *y ; One &a = x ; One *b ; One c;
 b = &x ;y = &c ; c = x ;
 cout << "a.value():" << a.value() << "\n"
   << "b->value():" << b->value() << "\n"
   << "c.value():" << c.value()    << "\n";
}
```

(a) 이 프로그램에 error가 2개 있다 어느 부분이 왜 error인가 설명하라. (5점)
(정답)
1) i = Two::value() + 1; //* One에서는 subclass인 Two가 보이지 않는다. (inner scope)
2) y = &c // 서브클래스 포인터인 y가 superclass 객체인 c를 포인트하지 못한다.

(b) Error 문정을 comment 처리한 후 프린트되는 결과는 무엇인가 ? (5점)
(정답)

```
jhnang@cspro:~/testcode$ ./a.out
a.value():11
b->value():11
c.value():4
jhnang@cspro:~/testcode$
```

(b) 만약 virtual 키워드를 없애면 프린트되는 결과는 무엇인가 ? (5점)

```
jhnang@cspro:~/testcode$ ./a.out
a.value():4
b->value():4
c.value():4
jhnang@cspro:~/testcode$
```

7. 다음과 같은 C++ 프로그램에 대하여 아래의 물음에 답하라. (15점)

```
class A {
  private:
      int i ;
  public:
    A() { i = 99; }
    virtual test() {
           this->aa(i); }

    virtual aa(int k) {
       printf("%d", i+k);}
}
```

```
class B : public A {
  private:
   int i ;
  public:
   B() { i = 88;}
   aa(int k) {
     A::i = 19 ;
    printf("%d", i+k);}
}
```

```
main()
  A a, *ap ; B b;
  ap = &b ;
  a.test() ;
  b.test() ;
  ap->test() ;
}
```

(a) 이 프로그램은 error가 있다. 어느 문장이 왜 error인지 설명하라. (5점)
(b) 위의 error 문장을 comment처리하고 난 후에 이 프로그램에 의하여 print되는 결과를 써라. (10점)

7. 다음과 같은 C++ 프로그램에 대하여 아래의 물음에 답하라. (15점)

```
class A {
  private:
      int i ;
  public:
    A() { i = 99; }
    virtual test() {
           this->aa(i); }

    virtual aa(int k) {
       printf("%d", i+k);}
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```

```
class B : public A {
  private:
   int i ;
  public:
   B() { i = 88;}
   aa(int k) {
     A::i = 19 ;
    printf("%d", i+k);}
}
```

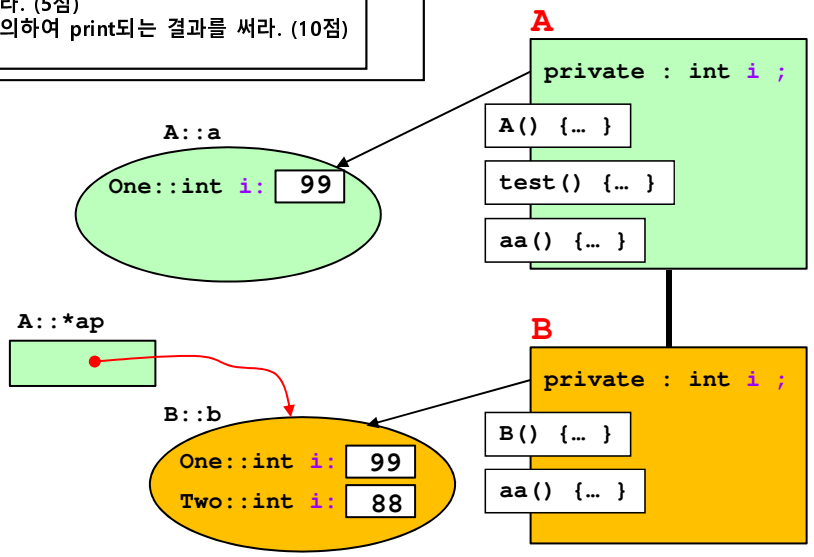
```
main()
  A a, *ap ; B b;
  ap = &b ;
  a.test() ;
  b.test() ;
  ap->test() ;
}
```

(a) 이 프로그램은 error가 있다. 어느 문장이 왜 error인지 설명하라. (5점)
(b) 위의 error 문장을 comment처리하고 난 후에 이 프로그램에 의하여 print되는 결과를 써라. (10점)
(c) 만약 virtual 키워드를 없애면 프린트되는 결과는 무엇인가 ?

a.test() ; ➔ ??

b.test() ; ➔ ??

ap->test() ; ➔ ??



7. 다음과 같은 C++ 프로그램에 대하여 아래의 물음에 답하라. (15점)

```
class A {
  private:
      int i ;
  public:
    A() { i = 99; }
    virtual test() {
           this->aa(i); }

    virtual aa(int k) {
       printf("%d", i+k);}
}
```

```
class B : public A {
  private:
   int i ;
  public:
   B() { i = 88;}
   aa(int k) {
     A::i = 19 ;
    printf("%d", i+k);}
}
```

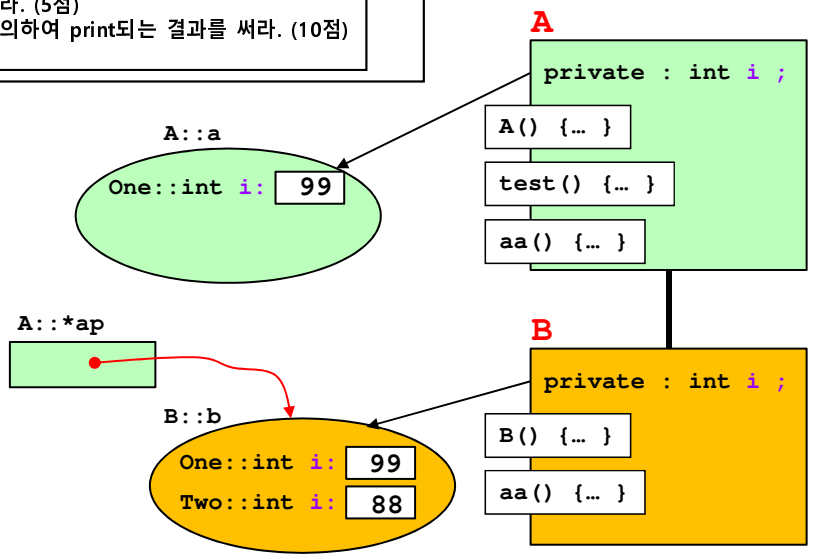
```
main()
  A a, *ap ; B b;
  ap = &b ;
  a.test() ;
  b.test() ;
  ap->test() ;
}
```

(a) 이 프로그램은 error가 있다. 어느 문장이 왜 error인지 설명하라. (5점)
(b) 위의 error 문장을 comment처리하고 난 후에 이 프로그램에 의하여 print되는 결과를 써라. (10점)
(c) 만약 virtual 키워드를 없애면 프린트되는 결과는 무엇인가 ?

a.test() ; ➔ 198

b.test() ; ➔ 187

ap->test() ; ➔ 187



7. 다음과 같은 C++ 프로그램에 대하여 아래의 물음에 답하라. (15점)

```
class A {
  private:
      int i ;
  public:
    A() { i = 99; }
    virtual test() {
           this->aa(i); }

    virtual aa(int k) {
       printf("%d", i+k);}
}
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class B : public A {
  private:
   int i ;
  public:
   B() { i = 88;}
   aa(int k) {
     A::i = 19 ;
    printf("%d", i+k);}
}
```

```
main()
  A a, *ap ; B b;
  ap = &b ;
  a.test() ;
  b.test() ;
  ap->test() ;
}
```

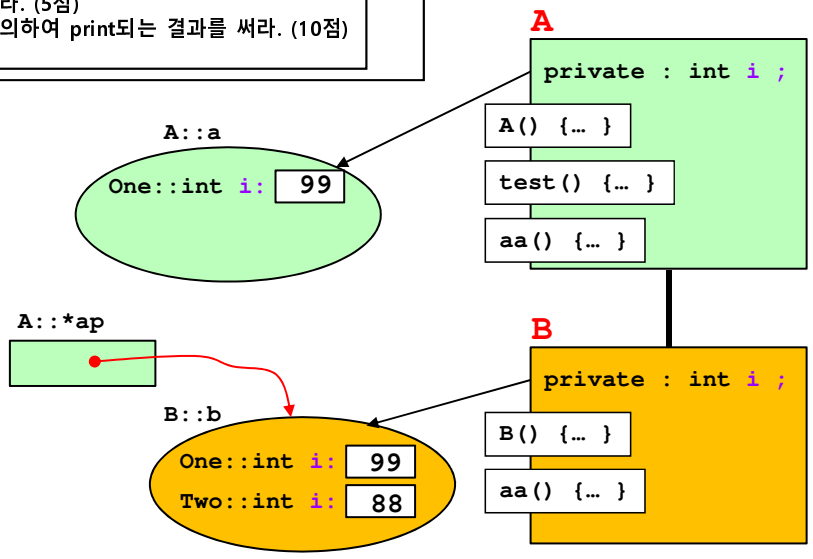
(a) 이 프로그램은 error가 있다. 어느 문장이 왜 error인지 설명하라. (5점)
(b) 위의 error 문장을 comment처리하고 난 후에 이 프로그램에 의하여 print되는 결과를 써라. (10점)
(c) 만약 virtual 키워드를 없애면 프린트되는 결과는 무엇인가 ?

a.test() ; ➔ 198

b.test() ; ➔ 187

ap->test() ; ➔ 187

a.aa(55) ➔ ??
b.aa(55) ➔ ??
a=b; b.aa(55) ➔ ??
ap->aa(55) ➔ ??



7. 다음과 같은 C++ 프로그램에 대하여 아래의 물음에 답하라. (15점)

```
class A {
  private:
      int i ;
  public:
    A() { i = 99; }
    virtual test() {
           this->aa(i); }

    virtual aa(int k) {
       printf("%d", i+k);}
}
```

```
class B : public A {
  private:
   int i ;
  public:
   B() { i = 88;}
   aa(int k) {
     A::i = 19 ;
    printf("%d", i+k);}
}
```

```
main()
  A a, *ap ; B b;
  ap = &b ;
  a.test() ;
  b.test() ;
  ap->test() ;
}
```

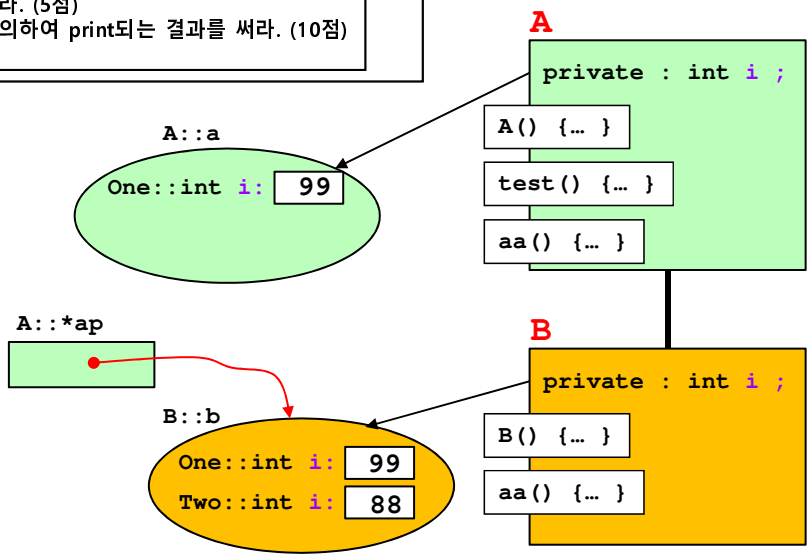
(a) 이 프로그램은 error가 있다. 어느 문장이 왜 error인지 설명하라. (5점)
(b) 위의 error 문장을 comment처리하고 난 후에 이 프로그램에 의하여 print되는 결과를 써라. (10점)
(c) 만약 virtual 키워드를 없애면 프린트되는 결과는 무엇인가 ?

a.test() ; ➔ 198

b.test() ; ➔ 187

ap->test() ; ➔ 187

a.aa(55) ➔ 154
b.aa(55) ➔ 143
a=b; a.aa(55) ➔ 154
ap->aa(55) ➔ 143



7. 다음과 같은 C++ 프로그램에 대하여 아래의 물음에 답하라. (15점)

```
class A {
  private:
      int i ;
  public:
    A() { i = 99; }
    virtual test() {
           this->aa(i); }

    virtual aa(int k) {
       printf("%d", i+k);}
}
```

```
class B : public A {
  private:
   int i ;
  public:
   B() { i = 88;}
   aa(int k) {
     A::i = 19 ;
    printf("%d", i+k);}
}
```

```
main()
  A a, *ap ; B b;
  ap = &b ;
  a.test() ;
  b.test() ;
  ap->test() ;
}
```

(a) 이 프로그램은 error가 있다. 어느 문장이 왜 error인지 설명하라. (5점)
(b) 위의 error 문장을 comment처리하고 난 후에 이 프로그램에 의하여 print되는 결과를 써라. (10점)

(정답)
(a) A::i = 19 /* A 클래스에서 i는 private member이다. */ (5점)

(b) Class A : 198 (3점)
Class B : 187 (3점)
Class B : 187 (4점)