Note 8

Object-Oriented Programming Methodology

Yunheung Paek
Associate Professor
Software Optimizations and Restructuring Lab.
Seoul National University

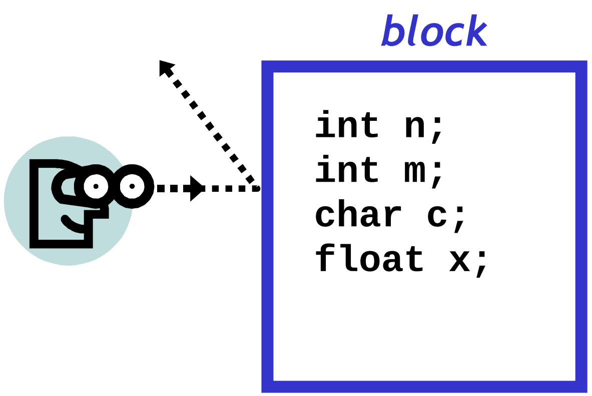
Topics

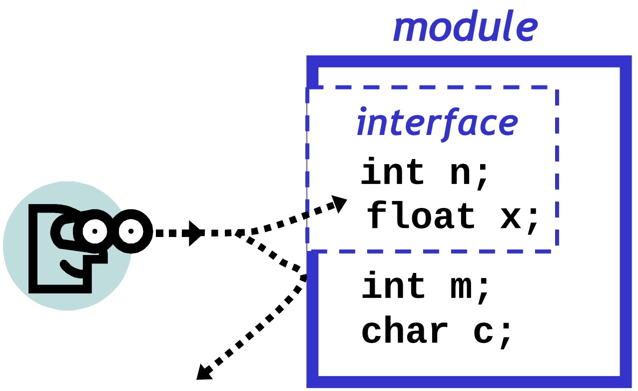
- Fundamental concepts of object-oriented programming
  - block (already discussed earlier)
  - module: an extension of a block
  - data abstraction
  - object abstraction
  - parametric polymorphism
- Language features employed in existing object-oriented languages
  - construction/destruction of abstract objects
  - type inheritance
  - virtual functions
  - memory managements and other miscellaneous features
- Object-oriented problem solving

Modules

- A **module** is similar to a **block** in that both are a collection of declarations and statements.
- A module is different from (or we may say, more sophisticated than) a block because a module can **export** a subset of the declarations to outside the module.

  Cf: all the declarations of a block are visible only inside the block.
- The exported declarations in a module is called the **interface** of the module.





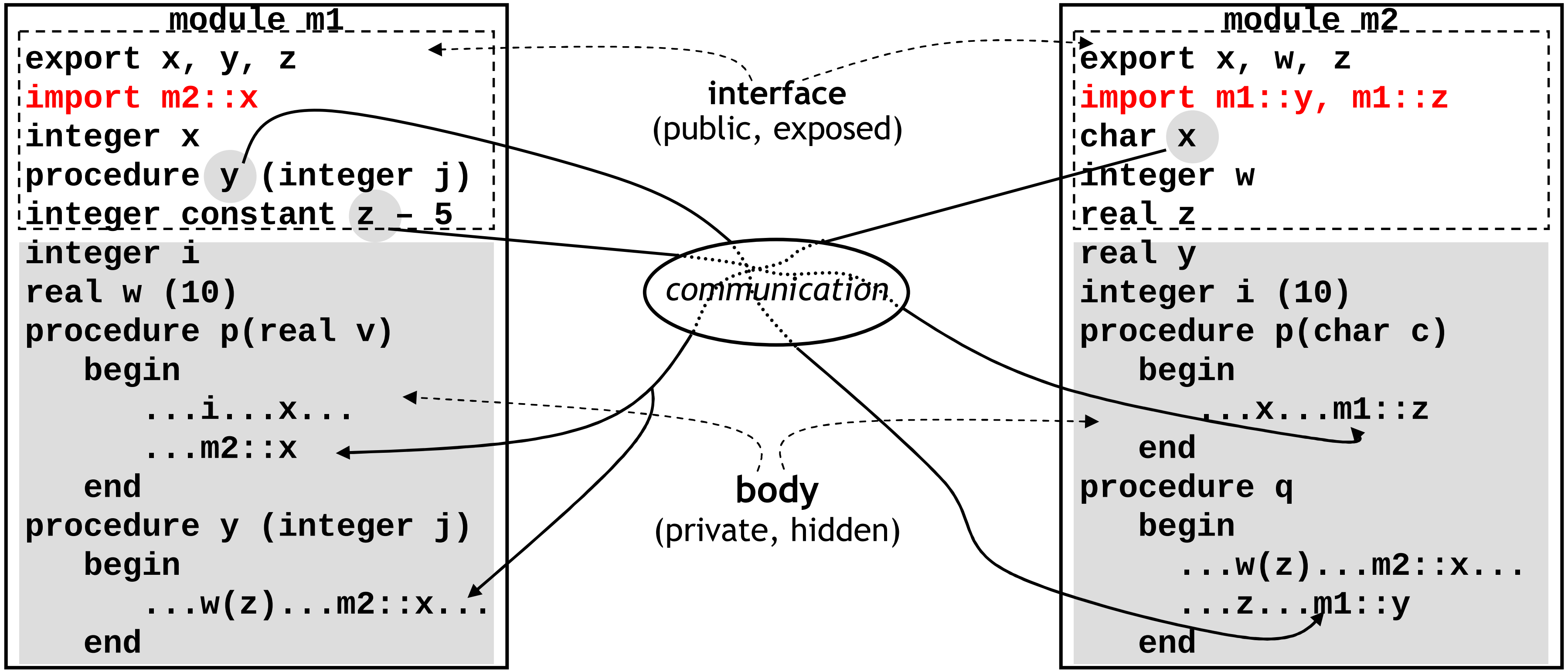
Modules

- The declarations specified in an interface can be accessed by other modules or objects.
- The remaining declarations are hidden from others.
- In this sense, a module serves as a **black box**.
  → A module interacts with the rest of the program through an high-level interface while hiding low-level implementation details.

C++

```
class demo {
  public:
    ...        //the interface open to the outside
  private:
    ...        //the rest of the module hidden from the outside
};
```

Naming control in modules



- Many newer languages (esp. object-oriented) provide modules.
  - → *modules (Modula), classes (C++, SmallTalk), packages (Ada), clusters (CLU)*
  - → In some languages, import list is not explicitly specified since it is deducible.

Advantages of modules over blocks

- Globals (or non-locals) are necessary for communication between blocks.
- In modules, globals are discouraged because modules can communicate through parameters specified in the interface.
  → Thus, data sharing is explicit in modules, which solves the problems of side effects, indiscriminate access and screening

```
int many;
f() {
   .. many ..
}
g() {
   .. many ..
}
h() {
   int mary;
   .. g() .. many
   ... f() ..
}
```

no error detected, but any semantic error?

blocks

```
module p
export f, g, many;
procedure f()
procedure g()
int many;

f() {
   .. many ..
}
g() {
   .. many ..
}
```

```
module q
import p.f, p.g;

h() {
   int mary;
   ..p.g()..many
   ... p.f() ...
}
```

naming error detected

modules

Advantages of modules over blocks

- Modules provide natural unit for *separate compilation*.
  - Only the change in the interface of a module affect other modules.
  - A module with objects imported from other modules can be compiled without knowing the detailed implementation of the imported objects.

  → What's the advantage of separate compilation in terms of efficiency?

- Modules can be data **objects** or variables.

  (ex: class objects in C++)

Modules in the Modula language

```
module main;
   from m1 import x, f;
   from m2 import x, w;
   var x : real;
   begin
     m1.f(m2.x);
     x = m1.x * 3.5 + m2.w;
     ...
   end main.
```

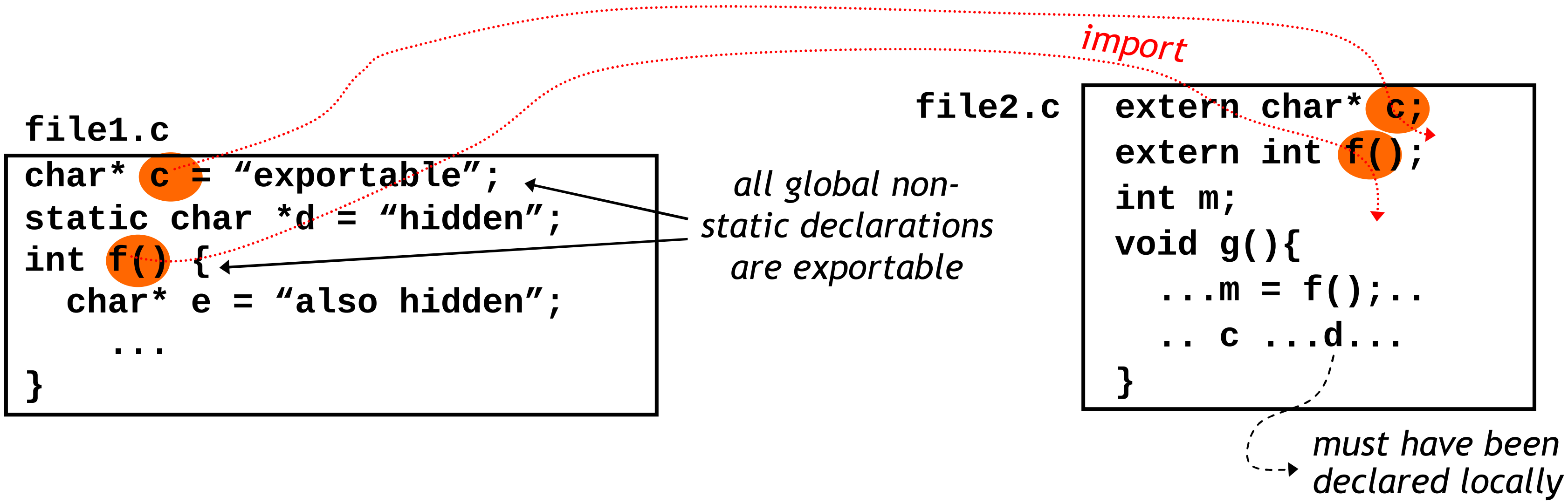
- Modula has a similar syntax to that of Pascal.
- No explicit export statement. All declarations in a definition module are exported.
- A reference to an imported object is qualified with the name of the imported module in a importing module.

```
definition module m1;
   var x : integer;
   procedure f(var j :character);
   const z = 5;
end m1.
implementation module m1;
   from m2 import x;
   var i : integer;
   var w : array [1..10] of integer;
   procedure p(var v :real);
     begin
       ... i ... x ...
       ... m2.x …
     end p;
   procedure f(var j: character);
     begin
       .. w[z] .. m2.x ..
     end f;
end m1.
```

```
definition module m2;
   var x : character;
   var w : integer;
   var z : real;
end m2.
implementation module m2;
   from m1 import y, z;
   var y : real;
   var a : array [1..10] of integer;
   procedure p(var c :character);
     begin
       ... x ... m1.z ...
     end p;
   procedure q;
     begin
       .. a[w] .. y ..
       .. z ... m1.y ..
     end q;
end m2.
```

Primitive form of modules in C

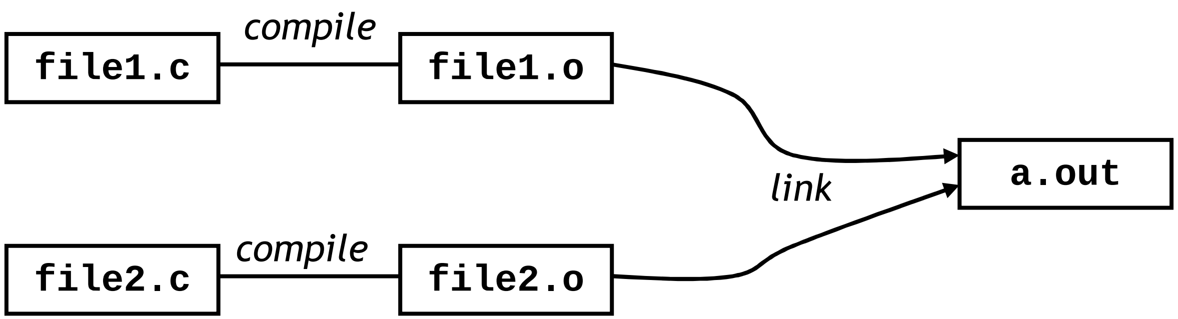
- **Files** in C language can be thought of as modules because they provide a facility to export and import declarations.



- The default is to put all global declarations in a file into the interface of the file.
  - All global declarations are exported by default.
  - Names exported by files have to be unique since file names are not part of exported names unlike ordinary modules.

Primitive form of modules in C

- To hide a declaration within a file, it must be declared static.
- Declarations from other files can be *imported* by extern declarations.
- Similarly to modules, files in C can also be *compiled separately* with ease.



Modules in C++

- The class type can be used to implement modules.

```
class Complex {
   public:  Complex(float rl, float im) { r = rl; i = im; }      // contructor
            float real_part() { return r; }
            float imaginary_part() { return i; }
            Complex &operator+(const& Complex);
            Complex &operator-(const& Complex);
                    ...
   private: float r, i;
};    ...
Complex object1(7.6,3);          // object1 is 7.6+3.0i
Complex object2(5,1.1);          // object2 is 5.0+1.1i
float r = object1.real_part();   // 7.6 is returned
object1 = object1 + object2;     // object1 ← object1.operator+(object2) = 12.6+4.1i
```

  - The **`public`** part is the interface of a class module, and the **`private`** part is the body. Therefore, the declarations in the public section are exported, and the variables **`r`** and **`i`** are not exported.
  - Crucial differences between classes and files in C++?
    - Different data objects can be created for each class.
    - Class names are part of the exported names.

      e.g.) **`object1.real_part(), object1.r`**

Modules in CLU

- A module in CLU is called a cluster

```
Complex = cluster is construct, real_part, imaginary_part, plus, minus,...
   representation = record [r, i : real]
   construct = proc(rl, im : real) return(Complex)
         return(representation${r : rl,i : im})
   end construct
   real_part = proc(num : Complex) returns(real)
         return(num.r)
   end real_part
   imaginary_part = proc(num : Complex) returns(real)
         return(num.i)
   end imaginary_part
   plus = proc(num1, num2 : Complex) returns(Complex)
         return (representation${r : num1.r+num2+r, i : num1.i+num2+i})
   end plus
         ...
end Complex
   ...
object1 : Complex := Complex$construct(7.6,3.0)
object2 : Complex := Complex$construct(5.0,1.1)
x : real := Complex$real_part(object1)
object1 := Complex$plus(object1,object2)
```

  - The interface of a cluster is defined as "**`cluster is`**".
  - The declarations in the interface are exported.
  - **`representation`** is a built-in cluster defined by the language.

Implementation of modules

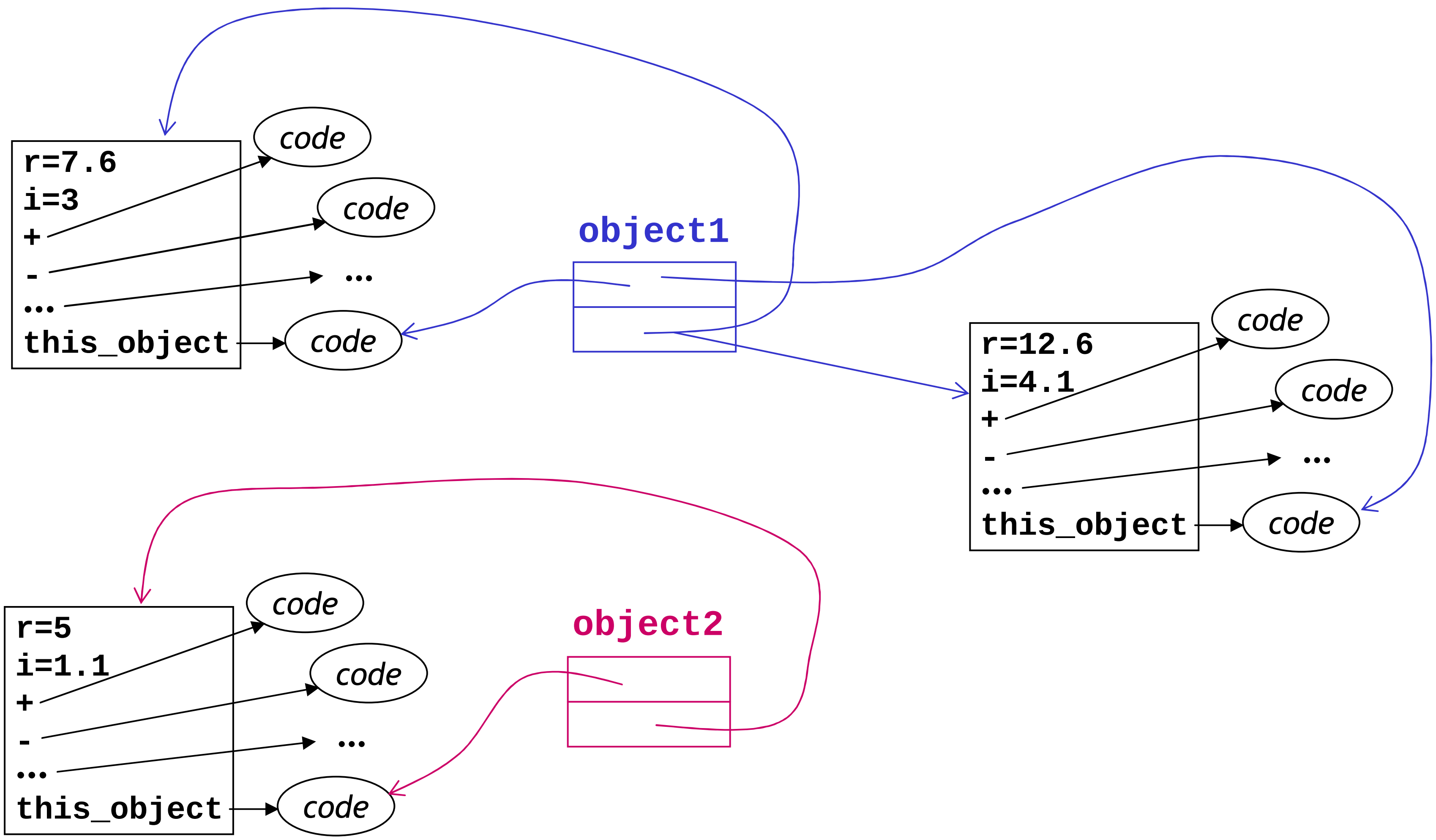
- Modules can be implemented in a language that does not provide them.
- Module/object = code + data
- Function/procedure = code
- A function itself is a passive entity
  - → It has no life when it is not invoked. (no activation record or any other data structures maintaining its status)
- A module is an active entity maintaining its data structures until it is explicitly destructed whether it is currently invoked or not.

Implementation of modules

- In Scheme, a module can be implemented with HOFs.

```
> (define complex (lambda (r i)
      (define + (lambda (a)
          (complex (+ r (a 'real_part)) (+ i (a 'imaginary_part)))))
      (define - (lambda (a)   ...   ))
          ...
      (define this_object (lambda (func)
          (cond ((eq? func 'real_part) r)
                ((eq? func 'imaginary_part) i)
                ((eq? func '+ +))     // returns a thunk + → not global addition +
                      ...      )))))
    this_object))
> (define object1 (complex 7.6 3))     // object1 is 7.6+3.0i
> (define object2 (complex 5 1.1))     // object2 is 5.0+1.1i
> (object1 'real_part)
  7.6                                  // return 7.6
> (define object1 ((object1 '+) object2))  // procedure as results
                                           // object1 is now 12.6+4.1i
```

Implementation of modules



Monitor

- A monitor is a *module* that is used to perform parallel programming by implementing critical sections (Modula, Concurrent Pascal)
- But, it is different from ordinary modules since it allows only one process to call one of its public procedures (*e.g.*: **`updates`** and **`read`** in monitor **`sync`**).
- Monitors have the same advantage of modules.
  - abstraction
  - information hiding
  - encapsulation.

→ With low level synchronization primitives such as test-and-set, semaphores and barriers, the protocols for implementing critical sections are exposed. This leads to error-prone and less programmable coding.

Example of a monitor

```
type sync = monitor          // for multiple readers and writers
var C, N : integer;
    Waiting : queue;
procedure update(D : integer) // call-by-value
  begin
    C := D;           // Now, one of the writers updates a new data
    N := R;            // assuming R is the number of readers
    wakeup(Waiting);  // Wake up all readers in the queue
  end;
procedure read(var M : integer) // call-by-reference
  begin
    if (N = 0) sleep(Waiting); // no new data is updated
    M := C;           // each reader reads the new data
    N := N-1;         // Mark that I have read this new data
  end;
begin                 // initialize private variables
  N := 0; Waiting :=ϕ;
end;
...
var S: sync;
parbegin
  begin               // for a writer 1
    ... /* compute some results */ ...
    S.update(result);
      ...
  end;
  ... /* code for other writers */
  begin   // for a reader 1
      ...
    S.read(X);        // X is private variable to each reader
    ... /* use X for its computation */ ...
  end;
   ... /* code for other readers */
parend.
```

regularly updated with new value by the writers (C)

number of readers that have read new value of C (N)

Definition of a monitor

Abstraction

- **Abstraction** of a process or object consists of
  1. its high-level and essential properties that are exposed
  2. the remaining low-level details that are hidden.
- The forms of abstraction in programming languages
  1. procedural abstraction
  2. data abstraction (type abstraction)
  3. object abstraction

Procedural abstraction

- Procedure **blocks** are procedural abstractions.
- *Task: "Prints the names of all employees living in L.A. in alphabetical order"*

```
struct ER { char* name; char* addr; ... ER* next; }
main() {
    ER* full_record = read_record_file("employ records");
    ER* nw_record = get_employees_living("L.A.", full_record);
    ER* sorted_record = sort_names(nw_record);
    print_records(sorted_record);
}
```

  - Local variables and algorithms used in a block are hidden within the block, and only parameters and name of the procedure are exposed.
    - → *For example, the procedure sort names can use any sorting algorithm (ex: quick/merge/radix sorting) and data structures or the algorithm without affecting the caller* ***main****.*
- Advantages of procedural abstractions are that they provide **program partitioning** and **information hiding**.
    - → *Why are they advantageous?*

Program partitioning

- allows the programmer to focus on one section of a program at a time without the overall detailed program continually intruding.
- abstracts away many of the details of each program section, facilitating the construction of comprehension of a large program.
- usually makes programs smaller.
  - ex) calls to the same subroutine
  - Advantages of smaller programs?

    → *easier to manage since difficulty of program writing and debugging increases more than linearly with the program size.*

Information hiding

- can be achieved by allowing a program to specify the *high-level description of a task* without providing *low-level design decisions* for how it is to be done.

  procedure name/type, parameters, module interface, …

  algorithms, local variables, control/data structures, …

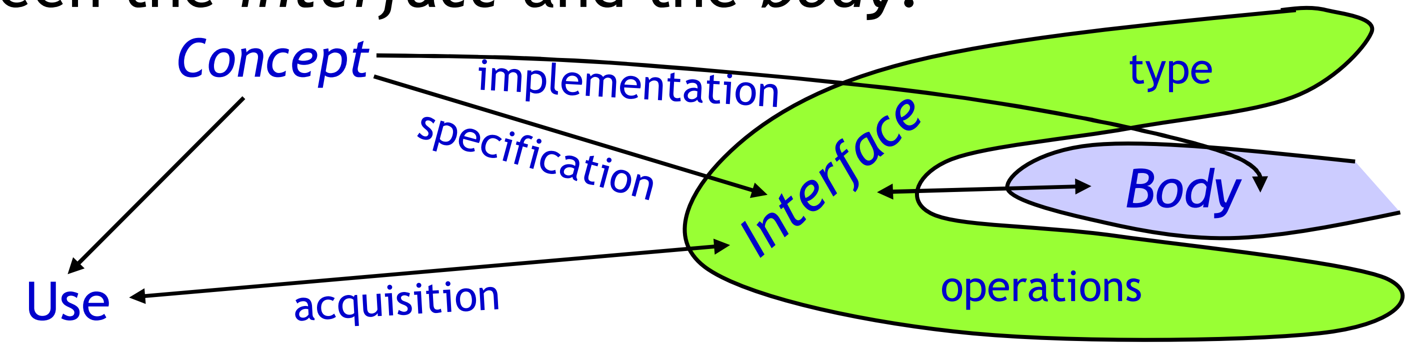
- can reduce program complexity.

  → *With information hiding, when a design decision is changed, only the block is affected, facilitating testing and refinement of the program.*

Data abstraction

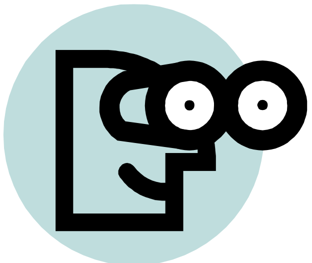
data objects + operations on the objects

- A data abstraction is a user-defined **abstract <u>data type</u>** which encompasses the *representation* of a data type and a set of *operations* for objects of that type.
  - → Like procedural abstractions, data abstractions provide ***program partitioning*** and ***information hiding***.
- A crucial ingredient of an abstract data type is separation between the *interface* and the *body*.



  - An interface is like a contract between the users and the designers.
  - An interface is a high-level and short specification of the data type and description of the operations provided.
  - The body implements the specification defined by the interface.

Data abstraction



integer

interface

representation: **…, -3, -2, -1, 0, 1, 2, 3, …**

operations: **+, -, *, /, &, |, <, >, ==, …**

implementation

representation: 16-bit binary

```
…
1111111111111111
0000000000000000
0000000000000001
0000000000000010
…
```

operations: binary add/subtract/multiply/…

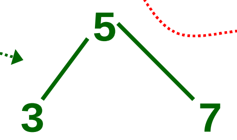
```
  0000001000100111
+ 0000101010010101
------------------
  0000110010111100
```

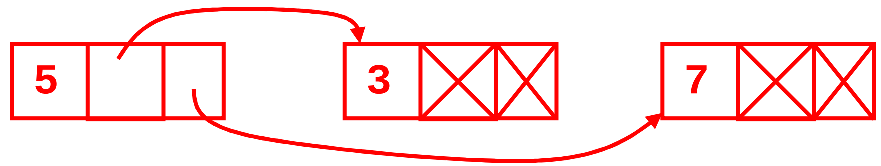
Examples of abstract data types

- Binary Tree

  abstract view: an object which can be queried for its label and for its left and right children associated with operations: *insert*, *delete*, *root*, *left*, *right* ...

  concrete view: a record containing a data field and pointers to its children records with operations: *allocation*, *deallocation*, *pointer assignments*



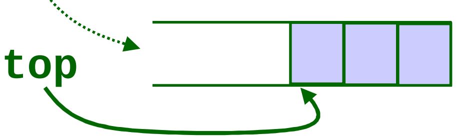


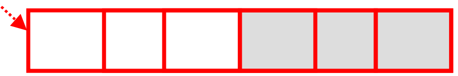
- Stack

  abstract view: an ordered list in which all insertions and deletions are made at one end, called the top (the opposite end is called the bottom), associated with operations: *push*, *pop*, *empty?*, *top_elem*, *clear* ...

  concrete view 1: an array with an additional integer that holds the index of the top. associated with operations: *array assignments*

  concrete view 2: a linked list with a pointer that points to the top element associated. with operations: *allocation*, *deallocation*, *pointer assignments*





Modules for data abstraction

- To provide program partitioning and information hiding, data abstractions are typically implemented with **modules**.

  Why? … →

  (Example: stack)

  - A data abstraction for a stack can be implemented with an abstract data type **`Stack`** with a module (*a class in C++*).
  - Since **`Stack`** is a data type, it can have objects of that type by declarations. *e.g.)* **`Stack stack1, stack2`**;
  - Programs use the public operations **`pop`**, **`push`** and **`is_empty`**, without being aware of the underlying design decisions such as whether a linked list or an array is used to implement **`Stack`**.
- Procedural abstractions are provided by languages with block structure. → *languages mostly before 80's*(Fortran, C, Pascal)
- Data abstractions are provided by languages that supports modules. → *languages in 80's or later*(Ada, Modula-2, CLU, C++)

Moving toward data abstraction

```
struct Element {
    ElemType data;
    Element* next;
};
struct Stack {
    Element* top;
    int num_of_elems;
};
main() {
    Element* d, e;
    Stack s;
    s.top = 0;
    s.num_of_elems = 0;
        . . .
    e = new Element;
    e->data = data;
    e->next = 0;
    s.top = e;
        . . .
    d = s.top;
    s.top = s.top->next;
    data = d->data;
        . . .
    if (s.num_of_elems > 0)
        . . .
}
```

Original code for stack operations

```
Element* pop(Stack* stack) {
    Element* t = stack->top;
    stack->top = t->next;
    return t;
}
void push(Stack* stack,
          Element* elem) {
    elem->next = stack->top;
    stack->top = elem;
}
main() {
    Element* d, e;
    Stack s;
    s.top = 0;
    s.num_of_elems = 0;
        . . .
    e = new Element;
    e->data = . . .;
        . . .
    push(&s, e);
        . . .
    d = pop(&s);
    data = d->data;
        . . .
    if (s.num_of_elems > 0)
        . . .
}
```

Procedural abstraction for stack operations

```
Class Stack {
  public:
    Stack() // constructor
      { initialize }
    void push(ElemType* data)
      { . . . }
    ElemType* pop()
      { . . . }
    Boolean is_empty()
      { . . . }
  private:
    Element* top;
    int num_of_elems;
};

main() {
    Stack s;  // automatically
              // initialized
      . . .   // by the constructor
    s.push(data);
      . . .
    data = s.pop();
      . . .
    if (s.is_empty())
      . . .
}
```

Data abstraction for stack operations

initialize

push

pop

check if it is empty

Type security with data abstraction

- **Subtypes:** improve *type security* by constraining the set of legal operations on a piece of data. → *But the facilities have limitations*.

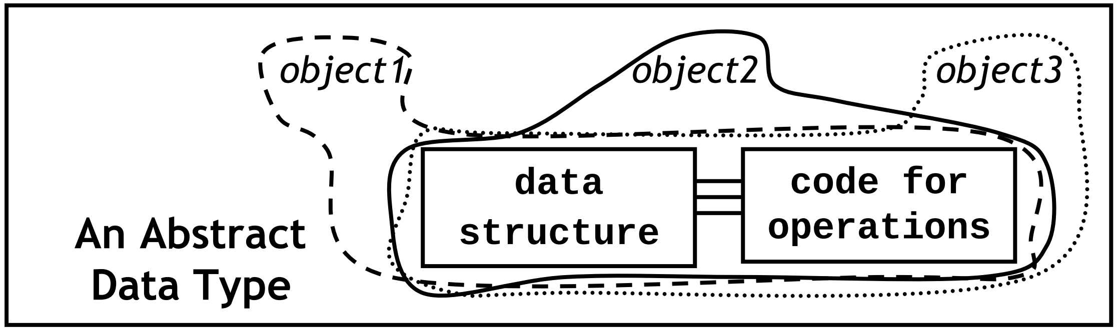
```
subtype day_type is integer range 1..31;
var d1, d2, d3 : day_type;
    i : integer;
   . . .
d1 := -11;          // Error detected
d2 := i;            // Possible error, but maybe undetectable at run-time.
d3 := d2 + 20;      // Possible error, but maybe undetectable at run-time.
```

- **Data abstraction:** offer better security by providing facilities that define a set of legal operations according to semantics of the data type.

```
class Day_Type {
  public: int operator=(int c) { 0<c<32 ? d = c : error; return *this; }
          int operator+(int c) { 0<c+d<32 ? return c+d : error; }
                                . . .
  private: int d;               // private variable for storing the value
}
  . . .
int i;
  . . .
Day_type day1 = i;              // Error detectable at run-time
Day_type day = day1 + 20;       // Error detectable at run-time
```

Limitations of data abstraction

- In data abstraction, all objects of the same abstract data type use the same **representation** (= *data structure* + *code*).



The code that implements the operations on the type

e.g.) Data type: **`Stack`**

- *data structure → an array*
- *code → array assignments to implement push, pop, and top operations*

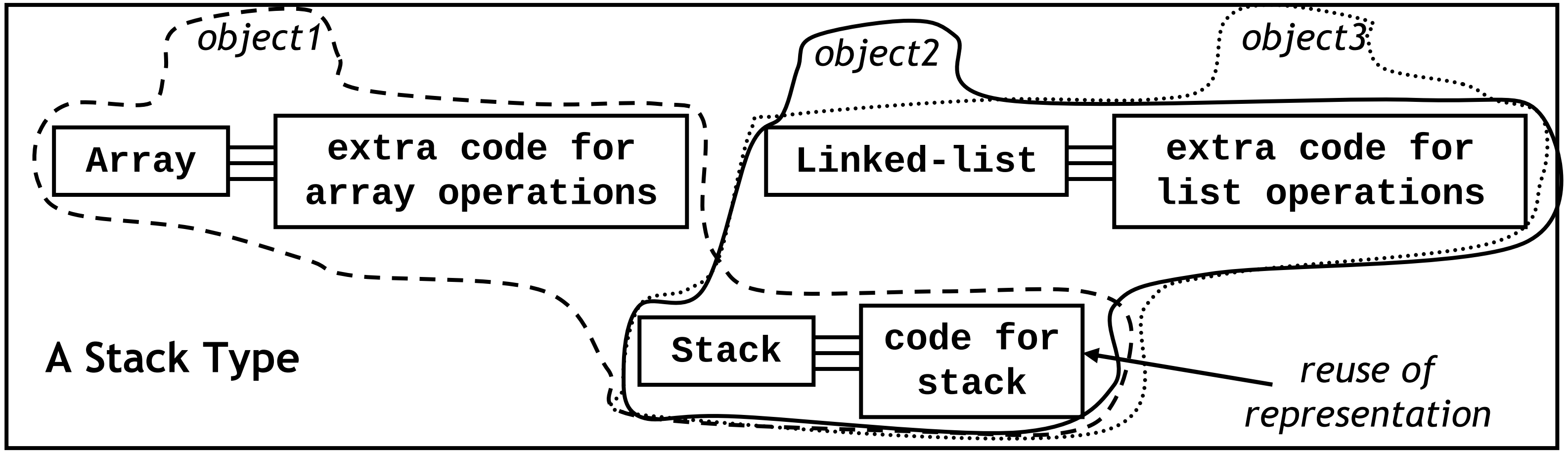
- In the development of large software, **reuse** of existing representations is essential to increase the productivity.
- However, there may not be a single representation that is the most efficient under all situations.
- Thus, an existing abstract data type usually requires some *modification* in its representation.

Object abstraction as a solution

- Different situations may prefer the autonomy to choose their own versions of representation **derived** from the same **base** representation that is common to them.

  Ex) *Someone may want the* **Stack** *type to be implemented with arrays while others want it to be implemented with linked lists*.

- In **object abstraction**, each object can have a representation different from what other objects of the same type have. $\rightarrow$ *multiple representations*



Incomplete object abstraction

- Ada83 supports data abstraction w/ modules, called **`package`**.

```
max: constant integer = 9999;                      // maximum possible stack size
   . . .
generic package Stack is
     procedure push(x: in real);                   // call-by-value
     procedure pop(x: out real);                   // call-by-result
     function top return real;                     // the top element
     function is_empty return boolean;
end Stack
package body Stack is
   stack: array (1..max) of real;
   top_ptr: integer range 0..max := 0;
   procedure push(x: in real) is
     begin
       if top = max then error("overflow");        // exception!
       else top := top+1; stack(top) := x;
       endif;
     end push;
   procedure pop(x: out real) is
          . . .
end Stack
   . . .
package stack1 is new Stack;             // Both stacks are implemented with
package stack2 is new Stack;             // arrays of the same size max. The
stack1.push(3.4);                        // size won't be changed at run-time.
if stack2.is_empty() then . . .
```

An abstract data type does not allow dynamically configurable data size or ***multiple representations*** for the type.

- But, all objects of an abstract data type in Ada83 like CLU has a single representation determined at compile-time.

Object-oriented programming

- The language that supports object abstraction is called a **object-oriented programming** language.
- OO programming languages
  - Simula 67 : Class concept was first introduced
  - Smalltalk : programming using window system
  - Objective C, **C++** : start from C language
  - Flavor, CLOs (Common List Objective System) : start from Lisp language
  - Turbo Pascal : start from Pascal language
  - Actor
  - Ada 95 : OO extension of the modular language Ada 83

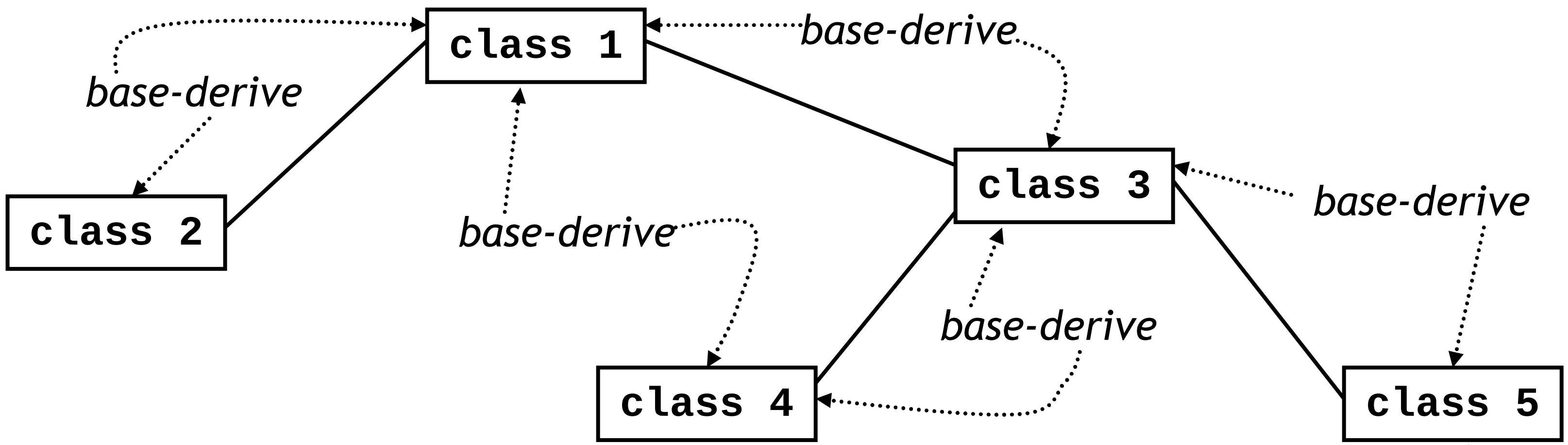
Object-oriented programming

- OO programming treats an overall system as a collection of interacting *objects*.
- Objects are instances of a *data type* (= a **`class`** in C++ or SmallTalk term).
- The objects interact by sending *messages* to each other.
- Each message is associated with a *method (*or *member function)* in C++ or SmallTalk term.
- Methods are defined by the code in the data type.
- To support object abstraction, a language should provide **data abstraction + <u>type inheritance</u>**.

  → *for multiple representations*

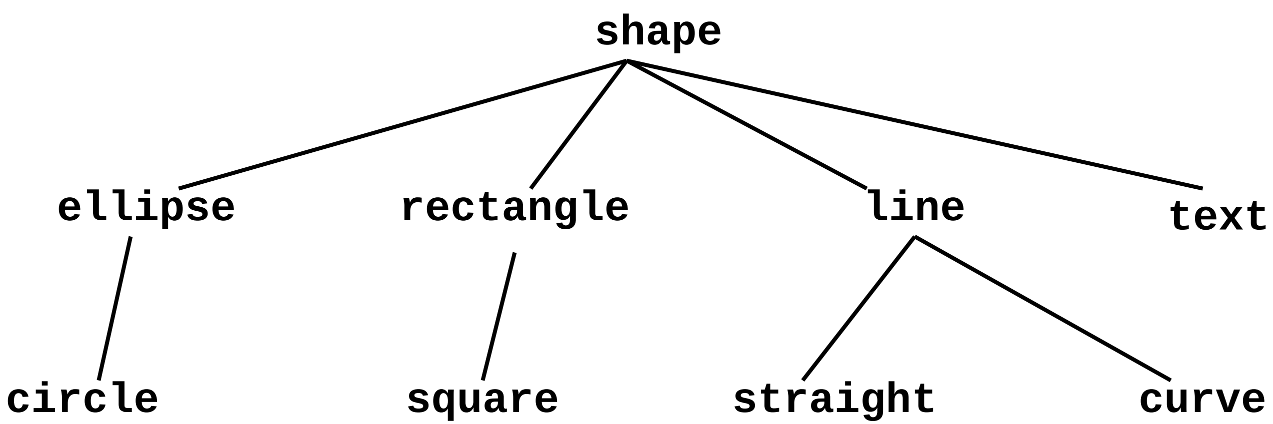
Type inheritance

- One data type D inherits the data and operations of other data types B_1 ~ B_n. Then, B_i's are called **base** types and D is their **derived** type.
  - → *Example of derived types: Subtypes in Pascal and Ada*
- In object abstraction, *abstract data types* (= **`classes`** in C++ terms) can be placed in a hierarchy.
- This hierarchy establishes a *base-derived* class relationship between the parent class and the child class.



Type inheritance

- Type inheritance in object abstraction
  → Objects in a child (derived) class can use the representation defined in its parent (base) class.
- Through the inheritance, a class can contain code that can be refined in different ways in different derived classes.
- This provides an effective way to **reuse** code.
- Ex: a hierarchy for graphic objects



An example of type inheritance

- We have two classes, each of which represents a record of an employee and that of a manager in a corporate.
- If they are represented in C++, then

```
class Employee {
  char* name;
  int salary;
  int position;                 // secretary, president, janitor. . .
        . . .
  Employee* next;               // points to the next coworker
};

class Manager {
  char* name;
  int salary;
        . . .
  char* department;             // managed by this manager
  Employee* men;                // under this manager
  Employee* next;
};
```

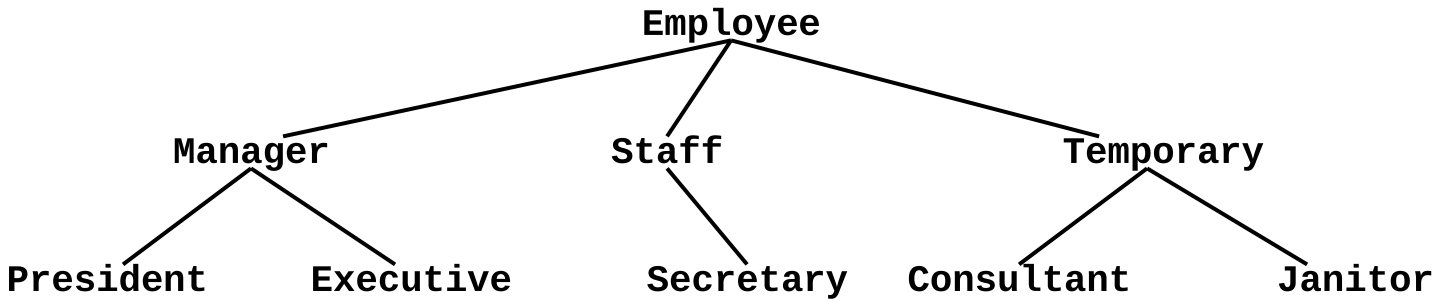
An example of type inheritance

- To the language, **`Employee`** objects and **`Manager`** objects are completely different.
- But, they have many fields in common.
- In fact, a manager is also an employee in real life.
- So, it would be ideal if a manager object is treated like an employee object with *extra fields*.
- This can be represented more efficiently in C++ as follows:

```
class Manager: public Employee {
  char* department;        // extra field
  Employee* men;           // extra field
};                         // The representation is greatly
                           // simplified with code reuse
```

A hierarchy of employees

- Using the base-derived class relationship, the language knows a manager object is derived from the base class **`Employee`**.
  - → *So, the data and code defined in* **`Employee`** *is reused in* **`Manager`**.
- We can build a hierarchy of employees in a corporate.

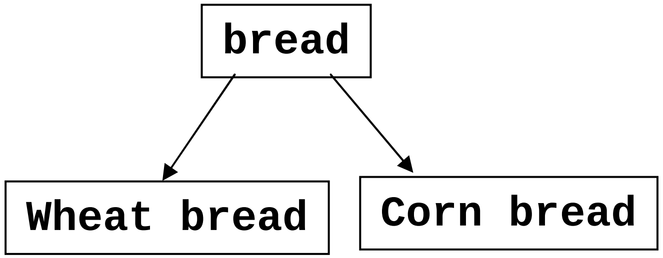


- The hierarchy can be represented in the language in terms of base-derived class relationships.

```
class Staff: public Employee { . . . };
class Temporary: public Employee { . . . };
class President: public Manager { . . . };
class Executive: public Manager { . . . };
class Secretary: public Staff { . . . };
class Consultant: public Temporary { . . . };
class Janitor: public Temporary { . . . };
```

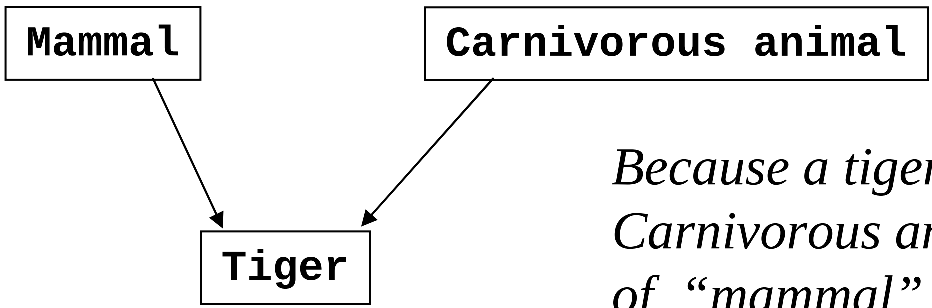
Inheritance types

- Single inheritance → *convenient to manage because of its level of tree formation, but it doesn't often reflect real world as it is*



Wheat bread and corn bread are kind of bread so they inherits and uses class of "bread"

- Multiple inheritance → *more flexible in terms of reflection of real world, but it needs very much cautions because of occurrence of problems like collision between inherited forms*



Because a tiger is not only mammal and but also Carnivorous animal, it inherits and uses classes of "mammal" & "carnivorous animal"

Dynamic binding in OO programming

- A derived object can be assigned to its base object.
  - → That is, a reference variable of a class can point to objects of any class derived from that class.
  - → By doing so, a reference variable of a type (base class) is used for different types (derived class) at run-time. → *dynamic binding*

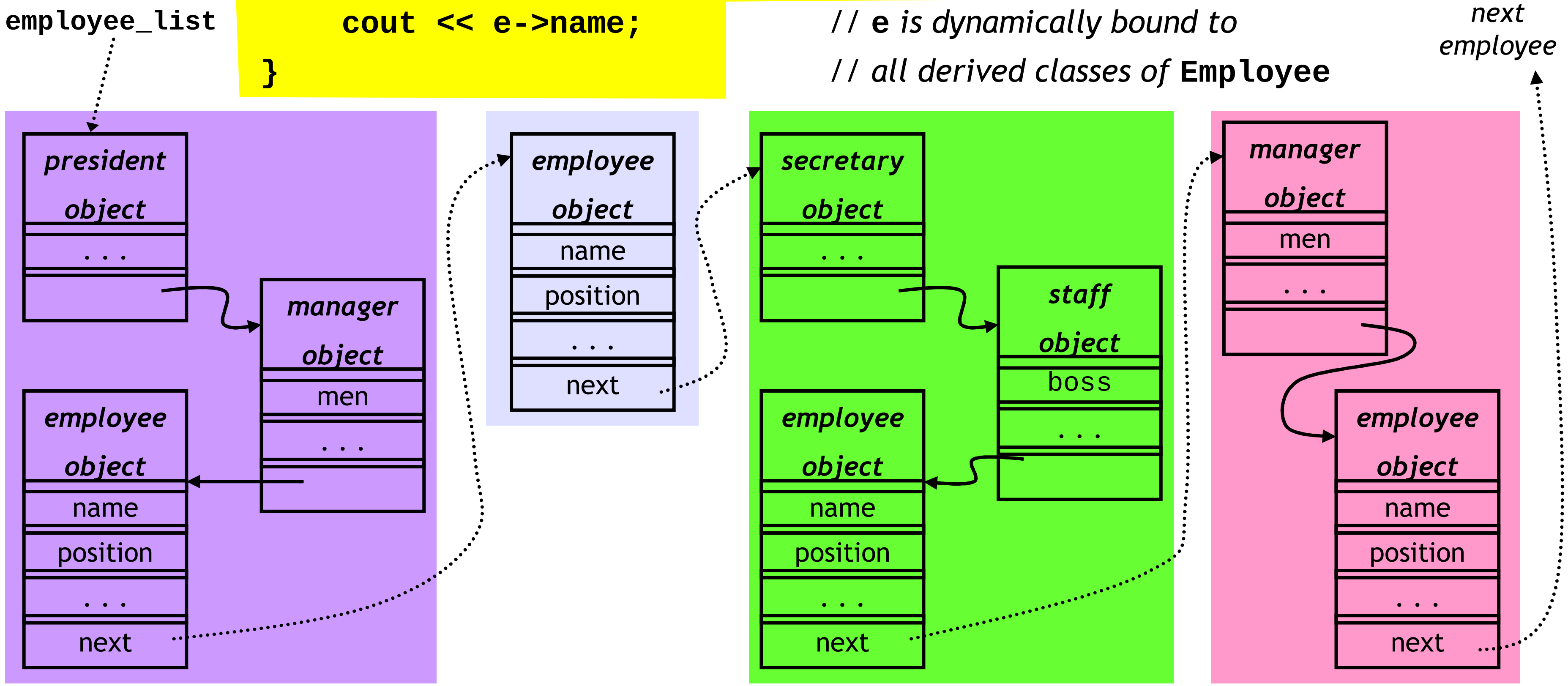
```
void insert_employees() {
  Employee e1, e2, e3, e4, *eptr;
  Manager m1, m2, m3, *mptr;
  Employee* employee_list = 0;      // The list is initially empty
        . . .
  eptr = &m1;             // dynamic binding - simply copy the reference of m1
  mptr = &e1;             // illegal - due to e1's lack of the extra field in m1
  mptr = (Manager*) &e2;  // forced to be legal, but dangerous
  e2 = m1;                // both are illegal because member-wise copy
  m3 = e4;                // is impossible due to their different sizes
        . . .
  e3.next = employee_list;          // insert the employee e3 to the list
  employee_list = &e3;
  m1.next = employee_list;          // insert the manager m1 to the list
  employee_list = &m1;    // dynamic binding!
        . . .
}
```

  - → *Note that all other variables in C++ are statically bound.*

Why dynamic binding?

- Using dynamic binding, managers and all other people in a corporate can be treated as employees in the language.

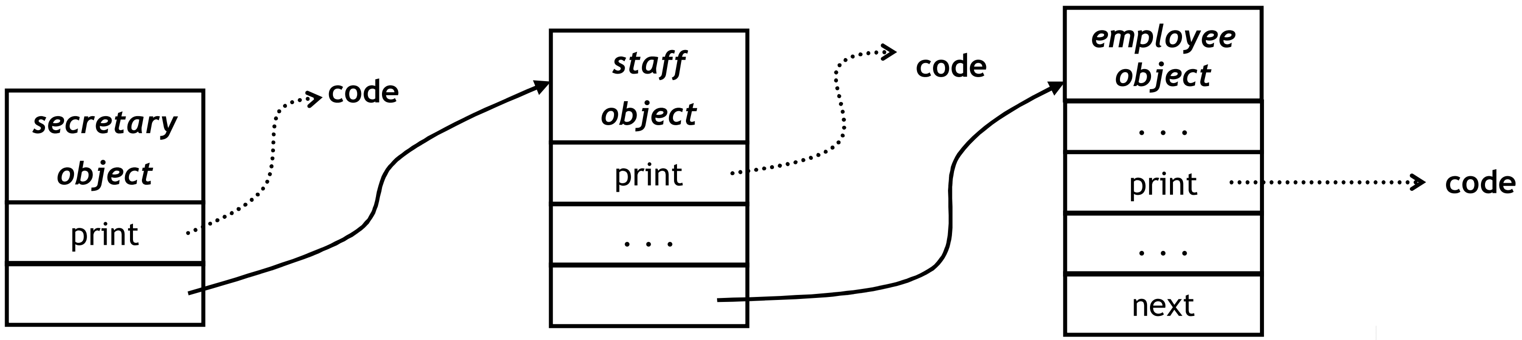
```
void list_names(Employee* employee_list) {
  for (Employee* e = employee_list; e != 0; e = e->next)
    cout << e->name;     // e is dynamically bound to
}                        // all derived classes of Employee
```



Need more for dynamic binding

- Suppose all objects have the **`print`** function to print the specific information for each object.

```
class Employee  {
   . . .
   void print() {  /* print name, salary, position,  . . . */  }
   . . .
};
class Manager: public Employee {
   . . .
   void print() {  /* print  name, salary, . . . , department, men */  }
   . . .
};
class Staff: public Employee {
   . . .
   void print() {  /* print name, salary, . . . , boss */  }
   . . .
};
 . . .
void print_employees(Employee*  employee_list) {
   Employee* e = employee_list;
   for (; e != 0; e = e->next)
     e->print();    // ambiguous! → Which print will be invoked for each object?
}     //  also tedious to define the code for all base prints if the secretary print is only needed
```



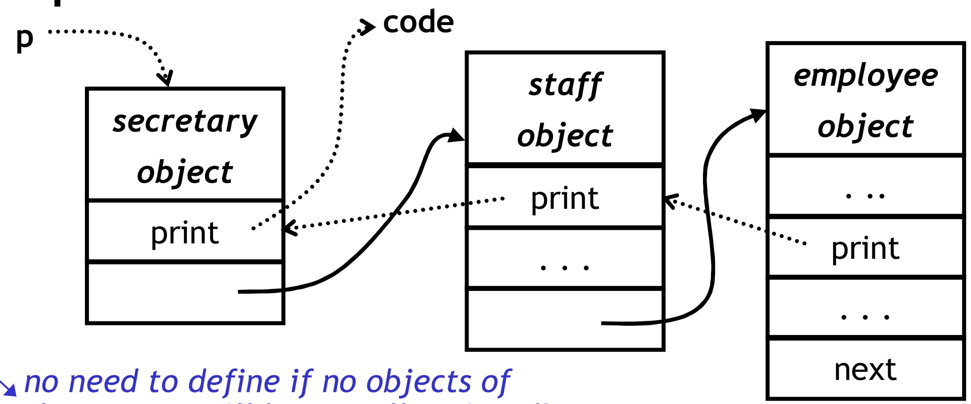
Dynamic binding of methods

- To choose the right *member function* (or called *method*) **`print`** for each object, **`print_employees`** should check the type of the object before it is printed. → *This is awkward!*

```
for (; e != 0; e = e->next)
     switch (e->position) {
        case MANAGER: ((Manager*) e)->print(); break;
        case STAFF: ((Staff*) e)->print(); break;
         . . .
}
```

- To solve the problem of dynamically choosing the specialized *methods* of each object, C++ provides **virtual functions.**

```
class Employee {
     . . .
   virtual void print() = 0;
};
class Staff: public Employee {
     . . .
   virtual void print() = 0;
};
class Secretary: public Staff {
     . . .
   virtual void print() { . . . }
};
  . . .
Employee* p = new Secretary;
p->print();
```



no need to define if no objects of these types will be actually printed!

// Which print is to be used is determined at run-time

Multiple representations

- Type inheritance and dynamic binding enable an abstract data type to have multiple representations.

```
class Stack {
  public:
    Stack();
    virtual void push(Element* data);
    virtual Element* pop();
  private: . . .
};
```

```
class Array_Stack: public Stack {
  public:
    Array_Stack(int size);
    void push(Element* data);
    Element* pop();
  private: . . .
};
```

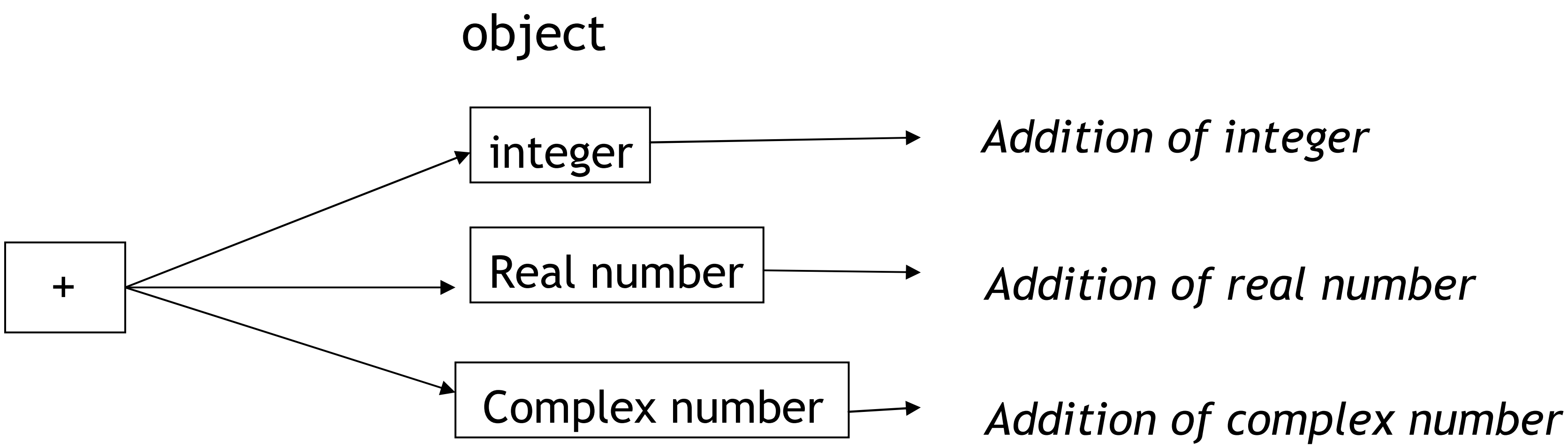
```
class List_Stack: public Stack {
  public:
    List_Stack();
    void push(Element* data);
    Element* pop();
  private: . . .
};
```

.
.
.

```
main() {
  Element* x, y, z;
  // cf: Stack in Ada
  Stack* st1 = new Array_Stack(99);
  Stack* st2 = new List_Stack;
    . . .
  st1->push(x);     // insert x to the array
  st2->push(y);     // insert y to the linked list
  z = st1->pop();
```

Polymorphic objects in OO languages

- Ad-hoc polymorphism
  - Although Object-Oriented programs are different to each other, they send the same messages to the related objects so as to provide the functionality (called *polymorphism* ← read the **type** system) of performing the same operation.
  - Overloaded operators



Polymorphic objects in OO languages

- Universal polymorphism
  - **inclusion** polymorphism → type inheritance (*subtypes*, *derived classes*)

    Ex) **`Manager`** class objects in C++ ← *derived (sub) type objects*

    → *Type expression for* **`Manager`** *objects* **=** { **`Manager`**, **`Employee`** }

    Ex) **`Employee::print()`** work on objects of all its derived classes
  - **parametric** polymorphism → **`template`**
- Recall …
  - unlike ad hoc polymorphic functions, universal polymorphic functions typically allow the *same code* to be used regardless of the types of the parameters, and
  - they exploit a *common structure* among different types.

  Ex) **`Employee::print()`** assumes all objects have **`Employee`** structure

Parametric polymorphism in C++

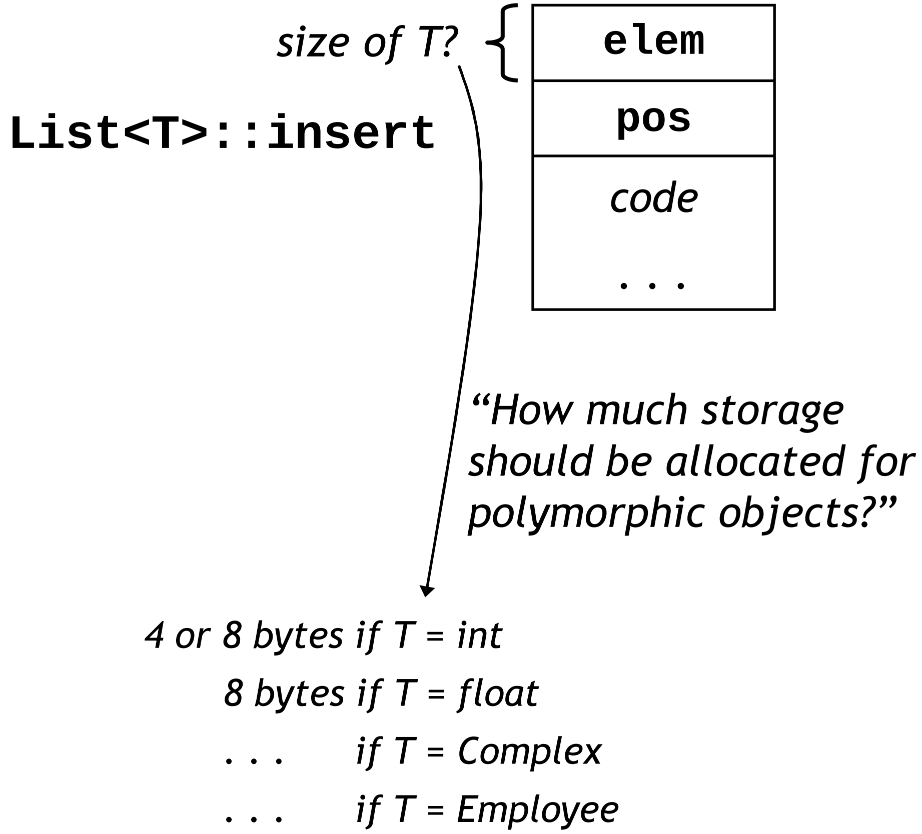
```
template<class T> class List {        // T is a type variable
    T* list;
    int size;
public:
    List() { list = 0; }              // 0 is polymorphic that can be applied to the unknown type T
    ~List() { delete [] list; }       // delete is polymorphic
    create(int new_size) { list = new T[new_size]; size = new_size; }
    int size() { return size; }
    T& operator[](int i) { return list[i]; }
    void insert(T elem, int pos) { list[pos] = elem; }
         . . .
};
   . . .
main() {
    List<float> flist;                flist.create(100);
    List<Complex> clist;              clist.create(9);
    List<int> ilist1;                 ilist.create(200);
    List<int> ilist2;                 ilist.create(130);
    List<List<int>> list_ilist;       // a list of lists of integers
         . . .
    flist[29] = 3.43e+20;
    clist1[0] = Complex(3.1, 4.2);   // create a complex object and copy it to the list of complex type
    clist1.insert(1, Complex(2.1,9.0)+clist1[0]);
    for (int j = 0; j < 200; j++)
          ilist1[j] = j * 10;
    list ilist[0] = ilist1;
    list ilist[1] = ilist2;
}
```

Parametric polymorphism in C++

```
template<class S> List<S>& merge(List<S>& l1, List<S>& l2) {
        // merge the two lists of type S(type variable), and return the merged list
   List<S>* Slist = new Slist;
   Slist->create(l1.size()+l2.size());
        int i;
   for (i = 0; i < l1.size(); i++)
        (*Slist)[i] = l1[i];
   for (int j = i; j < Slist→size(); j++)
        (*Slist)[j] = l2.[j-i];
   return *Slist;
}  . . .
main() {
   List<char> charlist1;  charlist1.create(50);
   List<char> charlist2;  charlist2.create(70);
   List<Employee> elist1; elist1.create(33);
   List<Employee> elist2; elist2.create(26);
        . . .
   List<char> clist3 = merge(clist1, clist2);
   List<Employee> elist3 = merge(elist1, elist2);  // merge two employee records
        ...
}
```

Implementing parametric polymorphism

- In many languages (C++, Ada), different instantiations of code are to be generated.



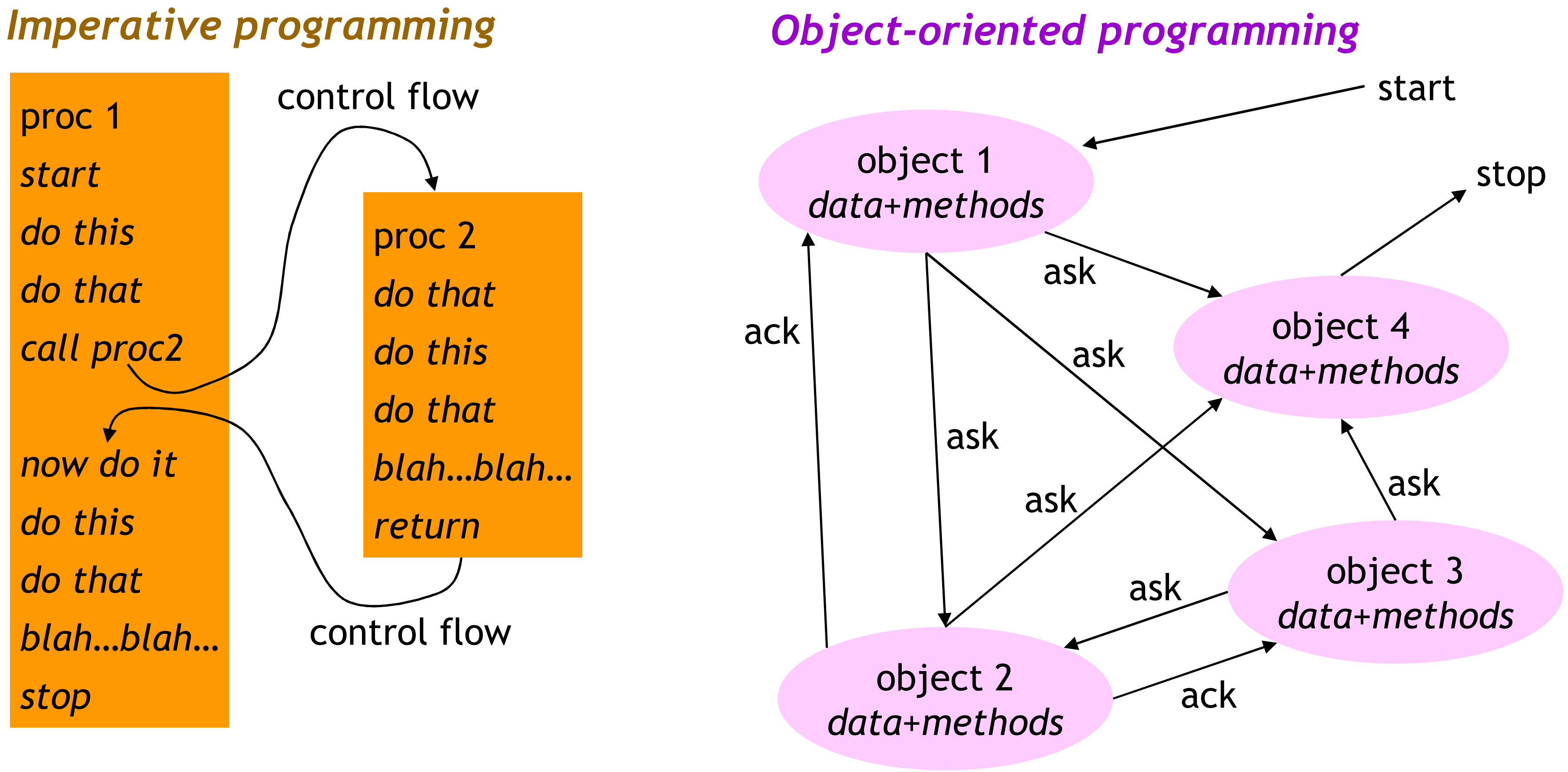
In short…

- Object-oriented programming associates the object-oriented design concept in software engineering with the programming language.
- It is used in software system design and implementation.
- Its primary goal is to improve programmers' productivity and reduce software complexity and management cost as increasing software extensibility and reusability.
- Key concepts of OO programming
  - Module (class, package, cluster)
    - Abstract data types and operations
    - Information hiding
  - Inheritance
  - Polymorphism

Imperative vs. Object-Oriented

- a procedure
  - a collection of *imperative* orders/instructions with data
  - not first-class valued
  - operations are performed by procedures in imperative programs
  - data is merely the storage where the result of computation is stored
- an object
  - a variable with its own data and methods
  - data represents the current state of the object
  - methods are the operations on the data defined for the object
  - objects in object-oriented programs interact with other objects by exchanging messages
- mapping problem space to program space
  - imperative/procedural programming: bottom-up
  - object-oriented programming: generally top-down

Imperative vs. Object-Oriented



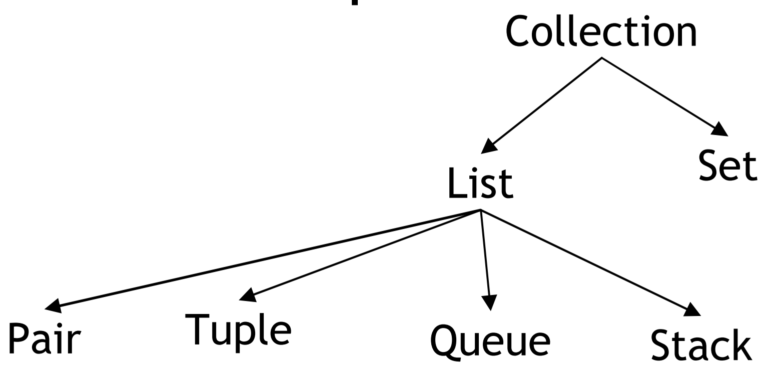
OO programming regards all in problem area as individual object, and regards system operation for problem area as object operation by message transmission among the objects

Problem solving

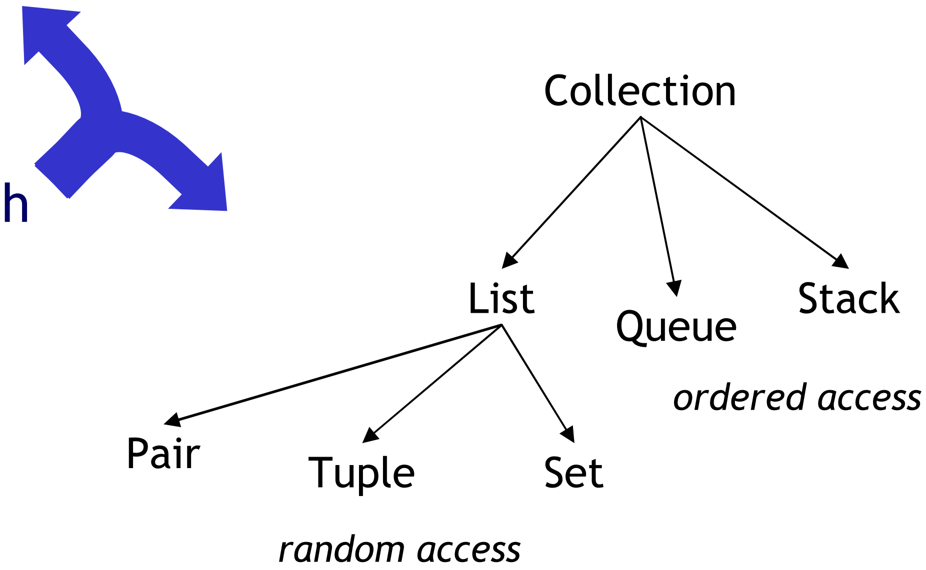
- Mapping problem space to program space
- imperative programming: bottom-up problem solving
  1. design and implement low-level structures: small blocks, loops, data structures, …
  2. weave together the low-level structures into high-level structures: large blocks, subroutines, …
- O-O programming: generally top-down problem solving
  1. partition a component in the problem space into several subcomponents
  2. each subcomponent is implemented with a object or a set of objects

Object-oriented problem solving

- Top level: partition a component in the problem space into several components



Depending on the user's approach to the problem, the way to partition a component may vary.



Object-oriented problem solving

- Lower level: associate a component with characteristics that are common to all of its subcomponents, and define methods for it
  - collection - a collection of elements, # of elements, empty?, print
  - list - insert, delete, list-print
  - stack - top, push, pop, print-top
  - queue - front, rear, insert, delete, print-front
  - set - insert, delete, union, difference, intersection
  - tuple - order, element-of-*n*th
  - pair - left-insert, right-insert, left-delete, right-delete, print-pair
- The original partitioning of a component determined at the top level will guide the relationship between data and methods and their implementation at lower (bottom) level.

Imperative programming example

Problem: “Design a database that maintains the information of employees!”

- Fortran

```
integer ages(n), salaries(n), …
character names(n), addresses(n),
   …

do I = 1, n , 1
   names(i) = …
   ages(i) = …
   …
enddo
…
get the index idx of “David”
   from names
print *, ages(idx)
```

- C

```
struct {
   int age, salary, …;
   char* name, address, …;
}database[n];
for (i = 0; I < n; i++) {
   database[i].name = …
   database[i].age = …
   …
}
// Print the age of an employee “Peter”
idx = 1;
while (!strcmp(“Peter”,
   database[idx].name)
   idx++;
printf(“%d”, database[idx].age);
// easier and less error-prone than Fortran
// due to the composite data type struct
// but basically the approach is still the
// same: imperative programming
```

O-O programming example

- C++

```
class{
   private:        ← information hiding
        int ages[n], salaries[n], …;
        char* names[n], addresses[n], …;
   public:
        void insert(char* name, char* address, …);
        int age_of(char* name);
        …
}database;
for(i = 0; I < n; i++)
   database.insert(…);
…
cout << database.age_of("David");
```

Conclusions about OO programming

- In OO programming paradigm, each object has some *state*. For computation, objects exchange *messages*.
  - → The state of an object is mutated in response to incoming messages.
- OO programming provides programmers with a paradigm to build their programs in a *modular* pattern.
- A good modulation mechanism facilitates …
  - work partitioning that helps avoid too much interaction bet'n users.
  - maintenance/debugging/refinement of existing programs.
- OO programming is an appropriate programming tool to model many real-world systems because
  - OO programming provides a natural mechanism to break down a program into separate objects.
  - A system in the real world usually comprises a set of physical objects.

OO is everywhere!

- It comes into the spotlight in a various field as computer science and business science.
- Object oriented programming language, that represents the object oriented concept well, is used.
- Object oriented operating systems regard resource and process as independent objects.
- Objected oriented database systems regard data as an independent object and process.
- Object oriented user interface simulation, etc