Implementation Aspects of OO-Languages

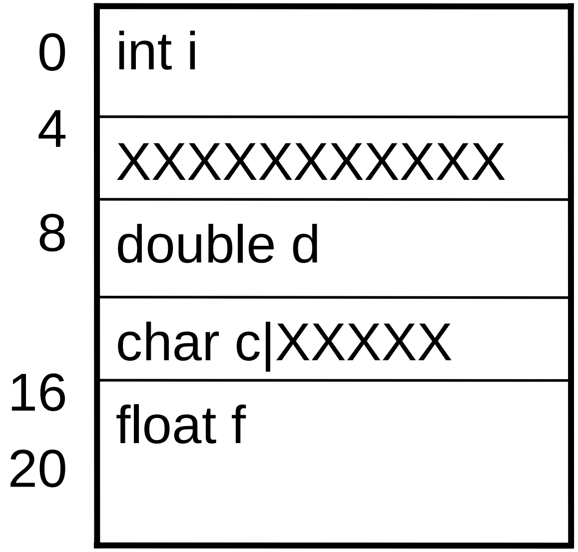
- Allocation of space for data members: The space for data members is laid out the same way it is done for structures in C or other languages. Specifically:
  - The data members are allocated next to each other.
  - Some padding may be required in between fields, if the underlying machine architecture requires primitive types to be aligned at certain addresses.
  - At runtime, there is no need to look up the name of a field and identify the corresponding offset into a structure; instead, we can statically translate field names into relative addresses, with respect to the beginning of the object.
  - Data members for a derived class immediately follow the data members of the base class
  - Multiple inheritance requires more complicated handling, we will not discuss it here

Implementation Aspects of OO-Languages

class B {

int i; double d;

char c; float f; }



// Integer requires 4 bytes

// pad,

// Double requires 8 bytes

// char needs 1 byte, 3 are padded

// float to be aligned on 4-byte

// require 4-bytes of space

Implementation Aspects of OO-Languages

```
class C {
   int k, l; B b;
}
```

0	int k
4	int l
8	int i
12	XXXXXXXXXXX
16	double d
24	char c|XXXXX
28	float f

Implementation Aspects of OO-Languages

```
class D: public C {
   double x;
}
```

0	int k
4	int l
8	int i
12	XXXXXXXXXXX
16	double d
24	char c|XXXXX
28	float f
32	double x

Implementation of Virtual Functions

- Approach 1:
  - Lookup type info at runtime, and then call the function defined by that type.
  - Problem: very expensive, require type info to be maintained at runtime.

Implementation of Virtual Functions(Contd.)

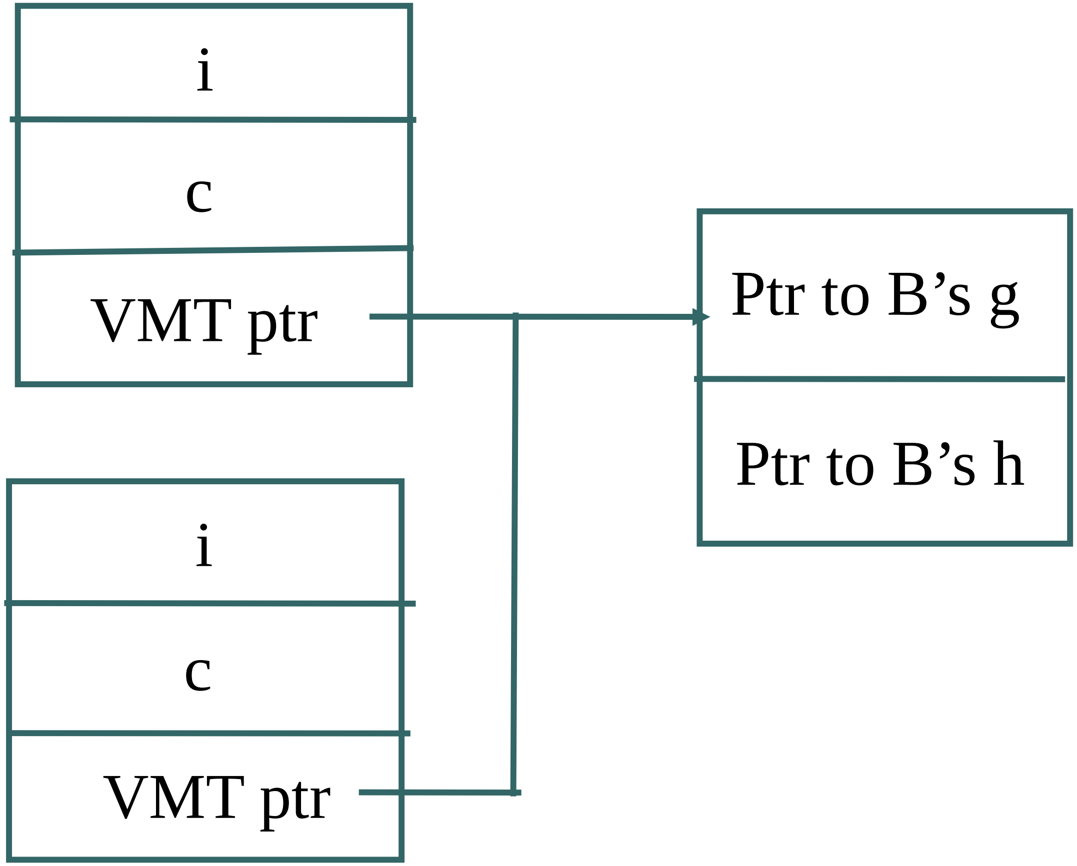
- Approach 2:
  - Treat function members like data members:
    - Allocate storage for them within the object.
    - Put a pointer to the function in this location, and translate calls to the function to make an indirection through this field.
  - Benefit:
    - No need to maintain type info at runtime.
    - Implementation of virtual methods is fast.
  - Problem:
    - Potentially lot of space is wasted for each object.
    - Even though all objects of the same class have identical values for the table.

Implementation of Virtual Functions(Contd.)

- Approach 3:
  - Introduce additional indirection into approach 2.
  - Store a pointer to a table in the object, and this table holds the actual pointers to virtual functions.
  - Now we use only one word of storage in each object.

Implementation of Virtual Functions(Contd.)

```
class B {
    int i ;
    char c ;
    virtual void g();
    virtual void h();
  }
B b1, b2;
```



Impact of subtype principle on Implementation

- The subtype principle requires that any piece of code that operates on an object of type B can work "as is" when given an object belonging to a subclass of B.
- This implies that runtime representation used for objects of a subtype A must be compatible with those for objects of the base type B.
- Note that the way the fields of an object are accessed at runtime is using an offset from the start address for the object.
  - For instance, b1.i will be accessed using an expression of the form *(&b1+0), where 0 is the offset corresponding to the field i.
  - Similarly, the field b1.c will be accessed using the expression *(&b1+1)

Impact of subtype principle on Implementation (Contd.)

- an invocation of the virtual member function b1.h() will be implemented at runtime using an instruction of the form:

  call *(*(&b1+2)+1)

  - &b1+2 gives the location where the VMT ptr is located
  - *(&b1+2) gives the value of the VMT ptr, which corresponds to the location of the VMT table
  - *(&b1+2) + 1 yields the location within the VMT table where the pointer to virtual function h is stored.

Impact of subtype principle on Implementation (Contd.)

- The subtype principle imposes the following constraint:
  - Any field of an object of type B must be stored at the same offset from the base of any object that belongs to a subtype of B.
  - The VMT ptr must be present at the same offset from the base of any object of type B or one of its subclasses.
  - The location of virtual function pointers within the VMT should remain the same for all virtual functions of B across all subclasses of B.

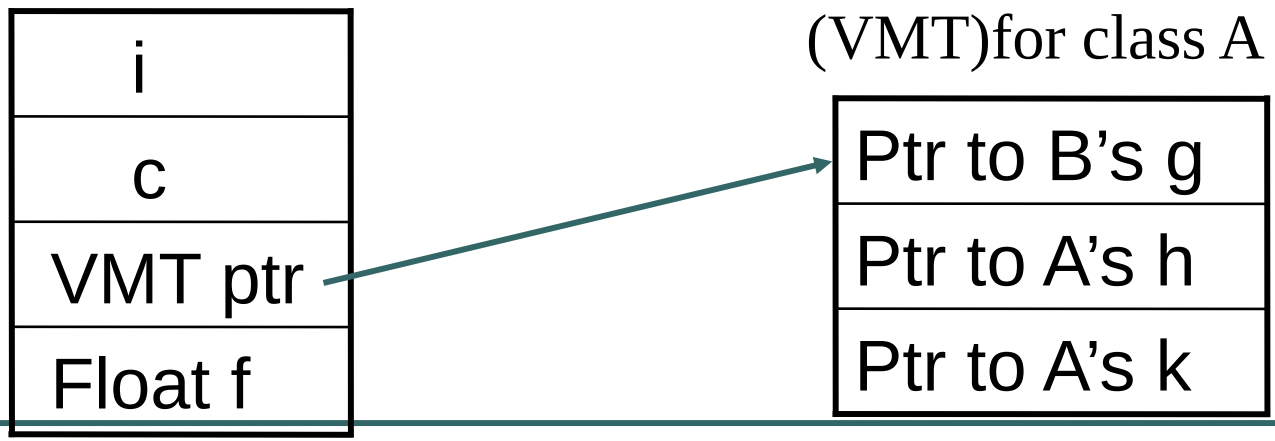
Impact of subtype principle on Implementation (Contd.)

- We must use the following layout for an object of type A defined as follows:

```
class A: public B {
    float f;
    void h(); // reuses implementation of G from B;
    virtual void k();}
 A a;
```

a's layout

Virtual Method Table (VMT)for class A



Impact of subtype principle on Implementation (Contd.)

- In order to satisfy the constraint that VMT ptr appear at the same position in objects of type A and B, it is necessary for the data field f in A to appear after the VMT field.
- A couple of other points:
  - a) non-virtual functions are statically dispatched, so they do not appear in the VMT table
  - b) when a virtual function f is NOT redefined in a subclass, the VMT table for that class is initialized with an entry to the function f defined its superclass.