Compiling Object Oriented Programs

Mooly Sagiv

Chapter 6.2.9

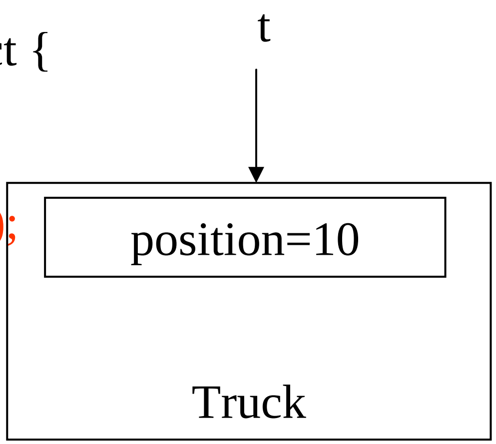
Object Oriented Programs

- Objects (usually of type called class)
  - Code
  - Data
- Naturally supports Abstract Data Type implementations
- Information hiding
- Evolution & reusability
- Examples: C++, Eifel, Java, Modula 3, Smalltalk, Cool

A Simple Example

```
class Vehicle extends object {

   int position = 10;

   void move(int x)

     {

       position = position + x ;

     }


class Car extends Vehicle {
  int passengers = 0 ;
  void await(vehicle v) {
         if  (v.position < position)
               v.move(position-v.position);
         else this.move(10);
}
```

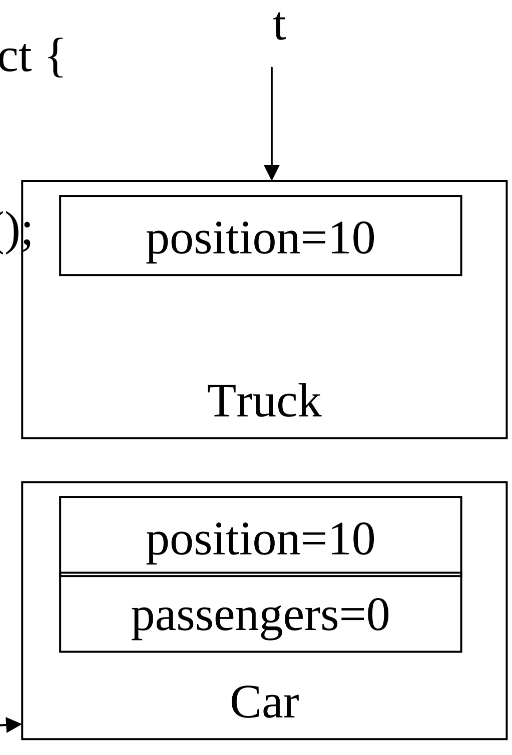
```
class Truck extends Vehicle {
  void move(int x)
   {
    if (x < 55)
       position = position+x;
   }
class main extends object {

   void main() {

    Truck t = new Truck();

    Car c = new Car();

    Vehicle v = c;

     c. move(60);

     v.move(70);

     c.await(t);}

}
```



A Simple Example

```
class Vehicle extends object {
   int position = 10;
   void move(int x)
     {
       position = position + x ;
 }

class Car extends Vehicle {
  int passengers = 0 ;
  void await(vehicle v) {
          if  (v.position < position)
                v.move(position-v.position);
         else this.move(10);
}
```

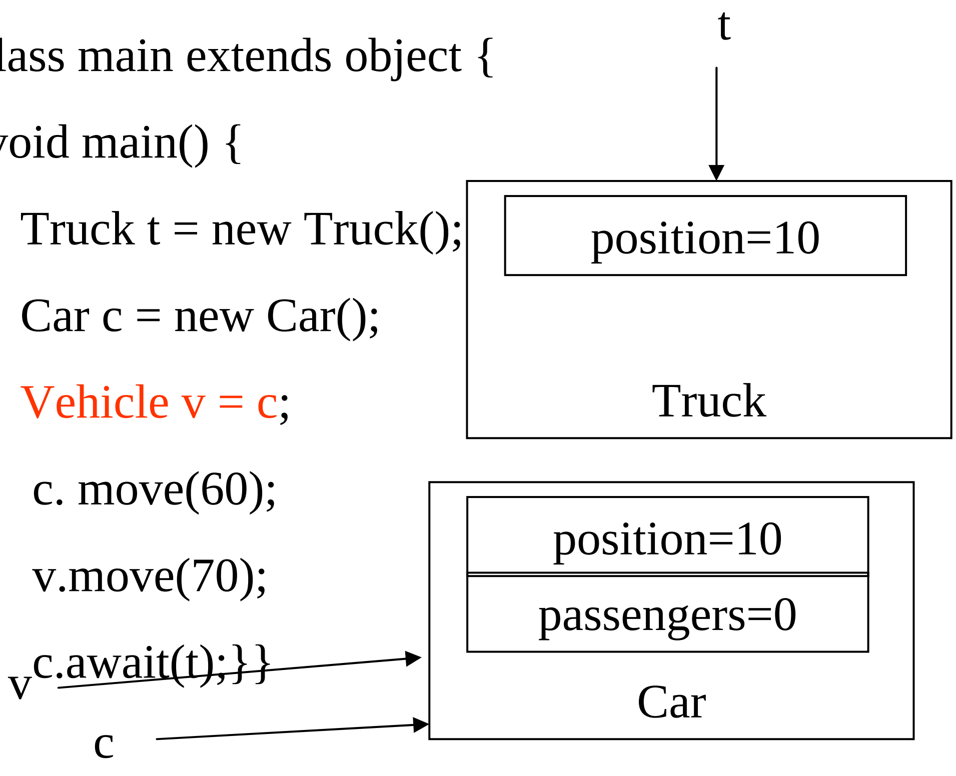
```
class Truck extends Vehicle {
  void move(int x)
   {
    if (x < 55)
       position = position+x;
   }

class main extends object {
 void main() {
    Truck t = new Truck();
    Car c = new Car
    Vehicle v = c;
     c. move(60);
     v.move(70);
     c.await(t); }}
```



A Simple Example

```
class Vehicle extends object {
   int position = 10;
   void move(int x)
     {
       position = position + x ;
     }

class Car extends Vehicle {
  int passengers = 0 ;
  void await(vehicle v) {
          if  (v.position < position)
                v.move(position-v.position);
         else this.move(10);
}
```

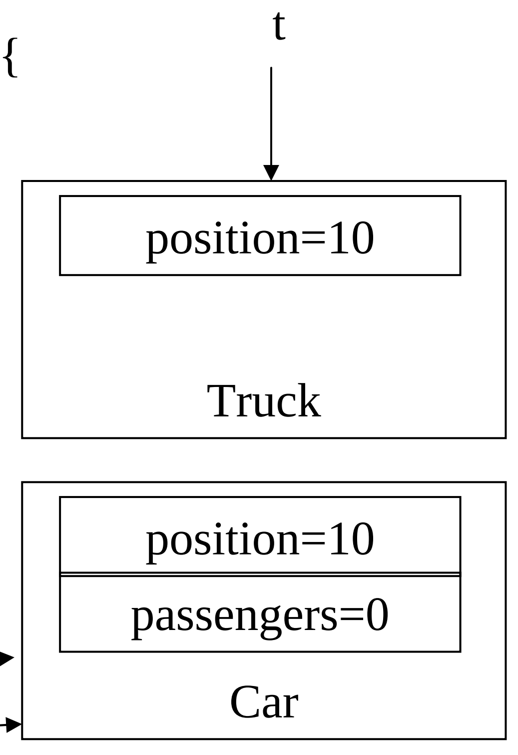
```
class Truck extends Vehicle {
  void move(int x)
   {
    if (x < 55)
       position = position+x;
   }

class main extends object {
 void main() {
    Truck t = new Truck();
    Car c = new Car();
    Vehicle v = c;
     c. move(60);
     v.move(70);
     c.await(t);}}
```



A Simple Example

```
class Vehicle extends object {

   int position = 10;

   void move(int x)

     {

       position = position + x ;

     }

class Car extends Vehicle {
  int passengers = 0 ;
  void await(vehicle v) {
          if  (v.position < position)
                v.move(position-v.position);
         else this.move(10);
}
```

```
class Truck extends Vehicle {
  void move(int x)
   {
    if (x < 55)
       position = position+x;
   }

class main extends object {

 void main() {

    Truck t = new Truck();

    Car c = new Car();

    Vehicle v = c;

     c. move(60);

     v.move(70);

     c.await(t);}}
```

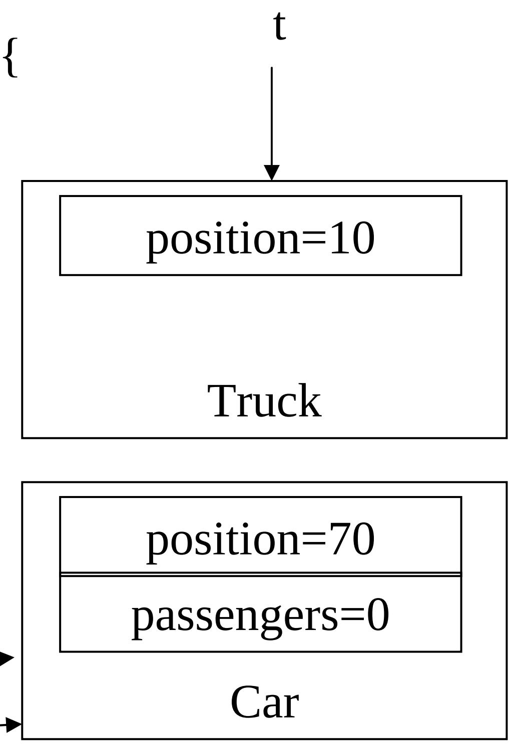


A Simple Example

```
class Vehicle extends object {

   int position = 10;

   void move(int x)

     {

       position = position + x ;

     }


class Car extends Vehicle {
  int passengers = 0 ;
  void await(vehicle v) {
          if  (v.position < position)
                v.move(position-v.position);
          else this.move(10);
}
```

```
class Truck extends Vehicle {
  void move(int x)
   {
    if (x < 55)
       position = position+x;
   }
```

```
class main extends object {

 void main() {

    Truck t = new Truck();

    Car c = new Car();

    Vehicle v = c;

     c. move(60);

     v.move(70);

     c.await(t);}}
```



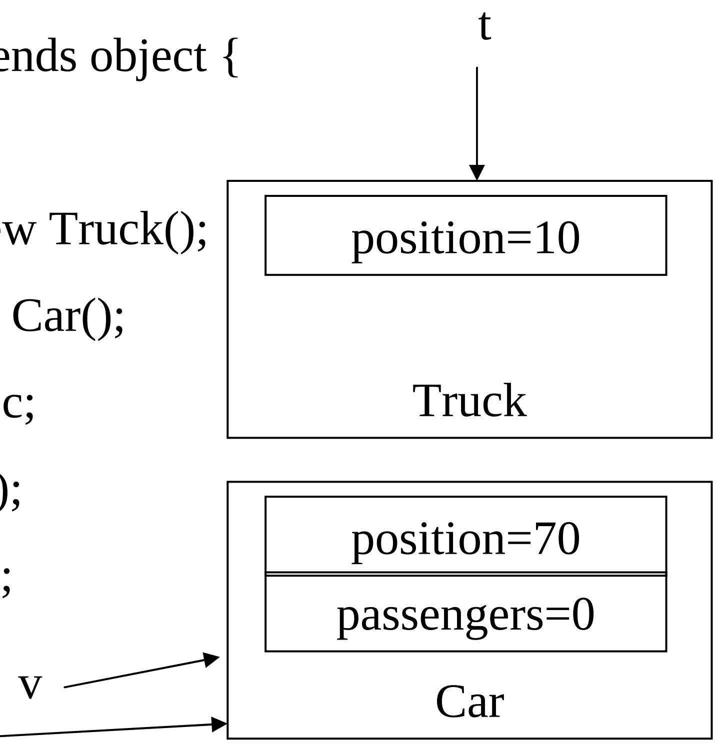
A Simple Example

```
class Vehicle extends object {

   int position = 10;

   void move(int x)

     {

       position = position + x ;

     }
```

```
class Car extends Vehicle {
  int passengers = 0 ;
  void await(vehicle v) {
          if  (v.position < position)
                v.move(position-v.position);
         else this.move(10);
}
```

```
class Truck extends Vehicle {
  void move(int x)
   {
    if (x < 55)
       position = position+x;
   }
```

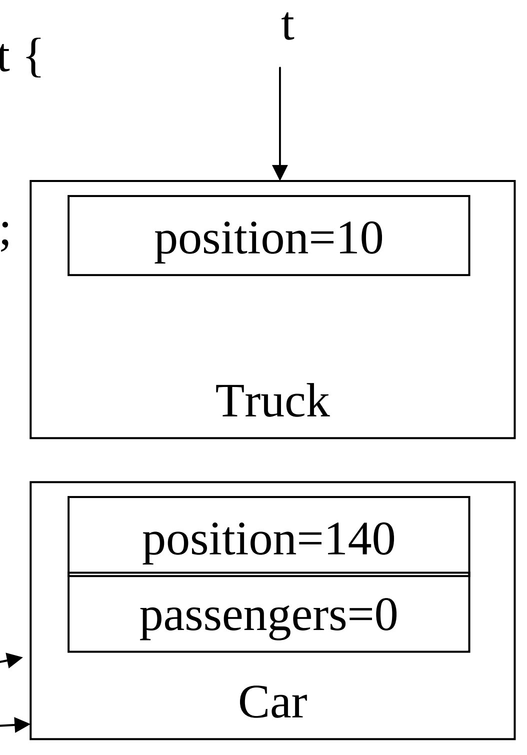
```
class main extends object {

 void main() {

    Truck t = new Truck();

    Car c = new Car();

    Vehicle v = c;

    c. move(60);

    v.move(70);

    c.await(t);

}}
```



A Simple Example

```
class Vehicle extends object {

   int position = 10;

   void move(int x)

     {

       position = position + x ;

     }


class Car extends Vehicle {
  int passengers = 0 ;
  void await(vehicle v) {
          if  (v.position < position)
                v.move(position-v.position);
         else this.move(10);
}
```

```
class Truck extends Vehicle {
  void move(int x)
   {
    if (x < 55)
       position = position+x;
   }

class main extends object {

 void main() {

    Truck t = new Truck();

    Car c = new Car();

    Vehicle v = c;

     c. move(60);

     v.move(70);

     c.await(t);

}}
```



Translation into C (Vehicle)

```
class Vehicle extends object {
  int position = 10;
  void move(int x)
   {
     position = position + x ;
   }
```

```
struct  Vehicle {
  int position ;
       }
  void New_V(struct Vehicle *this)
  {
     this→position = 10;
  }
  void move_V(struct Vehicle *this, int x)
 {
    this→position=this→position + x;
  }
```

Translation into C(Truck)

```
class Truck extends Vehicle {
  void move(int x)
   {
    if (x < 55)
       position = position+x;
   }
```

```
struct  Truck {
   int position ;
          }
   void New_T(struct Truck *this)
   {
       this→position = 10;
    }
   void move_T(struct Truck *this, int x)
     {
     if (x <55)
          this→position=this→position + x;
     }
```

Naïve Translation into C(Car)

```
class Car extends Vehicle {
  int passengers = 0 ;
  void await(vehicle v) {
         if  (v.position < position)
              v.move(position-v.position);
        else this.move(10);
}
```

```
struct  Car {
   int position ;
   int passengers;     }
   void New_C(struct Car *this)
   {  this→position = 10;
       this →passengers = 0;    }
 void await_C(struct Car *this, struct Vehicle *v)
     {  if (v→position < this →position )
              move_V(this →position - v→position )
          else Move_C(this, 10) ;}
```

Naïve Translation into C(Main)

```
class main extends object {
  void main(){
    Truck t = new Truck();
    Car c = new Car();
    Vehicle v = c;
     c. move(60);
     v.move(70);
     c.await(t);}}
```

```
void main_M()
 {
    struct Truck *t = malloc(1, sizeof(struct Truck));
    struct Car *c= malloc(1, sizeof(struct Car));
    struct Vehicle *v = (struct Vehicle*) c;
     move_V((struct Vehicle*) c, 60);
     move_V(v, 70);
     await_C(c,(struct Vehicle *) t);
}
```

Compiling Simple Classes

- Fields are handled as records
- Methods have unique names

```
class A {
    field a1;
    field a2;
    method m1() {…}
    method m2(int i) {…}
}
```

```
a.m2(5)
```

Runtime object

a1
a2

Compile-Time Table

m1_A
m2_A

```
void m2_A(class_A  *this, int i)
{
   Body of m2 with any object field x as this →x
}
```

```
m2_A(&a, 5)
```

Features of OO languages

- Inheritance
- Method overriding
- Polymorphism
- Dynamic binding

Handling Single Inheritance

- Simple type extension
- Type checking module checks consistency
- Use prefixing to assign fields in a consistent way

```
class A {
    field a1;
    field a2;
    method m1() {…}
    method m2() {…}
}
```

Runtime object

a1
a2

Compile-Time Table

m1_A
m2_A

```
class B extends A {
    field a3;
    method m3() {…}
}
```

Runtime object

a1
a2
a3

Compile-Time Table

m1_A
m2_A
m3_B

Method Overriding

- Redefines functionality

```
class A {
    field a1;
    field a2;
    method m1() {…}
    method m2() {…}
}
```

m2 is declared and defined

```
class B extends A {
    field a3;
    method m2() {…}
    method m3() {…}
}
```

m2 is redefined

Method Overriding

- Redefines functionality
- Affects semantic analysis

```
class A {
    field a1;
    field a2;
    method m1() {…}
    method m2() {…}
}
```

Runtime object

a1
a2

Compile-Time Table

m1_A_A
m2_A_A

```
class B extends A {
    field a3;
    method m2() {…}
    method m3() {…}
}
```

Runtime object

a1
a2
a3

Compile-Time Table

m1_A_A
m2_A_B
m3_B_B

Method Overriding

```
class A {
    field a1;
    field a2;
    method m1() {…}
    method m2() {…}
}
```

Runtime object

a1
a2

Compile-Time Table

m1_A_A
m2_A_A

a.m2 () // class(a)=A

⇓

m2_A_A (&a)

```
class B extends A {
    field a3;
    method m2() {…}
    method m3() {…}
}
```

Runtime object

a1
a2
a3

Compile-Time Table

m1_A_A
m2_A_B
m3_B_B

a.m2 () // class(a)=B

⇓

m2_A_B (&a)

Method Overriding (C)

struct class_A {

field a1;

field a2;

}

void m1_A_A(class_A *this) {…}

void m2_A_A(class_A *this, int x)) {…}

struct class_B {

field a1;

field a2;

field a3;

}

void m2_A_B(class_B *this, int x) {…}

void m3_B_B(class B *this) {…}

}

Runtime object

a1
a2

Compile-Time Table

m1_A_A
m2_A_A

a.m2 (5) // class(a)=A

⇓

m2_A_A (&a, 5)

Runtime object

a1
a2
a3

Compile-Time Table

m1_A_A
m2_A_B
m3_B_B

a.m2 (5) // class(a)=B

⇓

m2_A_B (&a, 5)

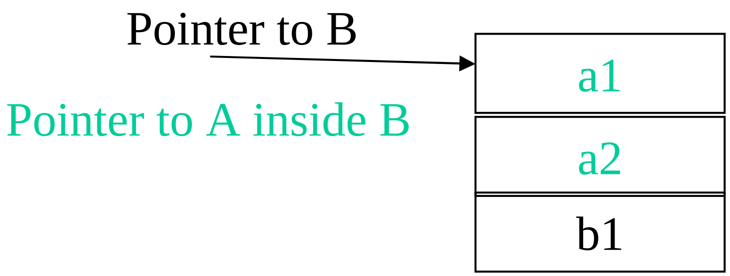
Abstract Methods

- Declared separately
  - Defined in child classes
- Java abstract classes
- Handled similarly
- Textbook uses “Virtual” for abstract

Handling Polymorphism

- When a class B extends a class A
  - variable of type pointer to A may actually refer to object of type B
- Upcasting from a subclass to a superclass
- Prefixing guarantees validity

```
class B *b = …;

class A *a = b ;        ⇒    class A *a=convert_ptr_to_B_to_ptr_A(b) ;
```



Dynamic Binding

- An object o of class A can refer to a class B
- What does ‘o.m()’ mean?
  - Static binding
  - Dynamic binding
- Depends on the programming language rules
- How to implement dynamic binding?
- The invoked function is not known at compile time
- Need to operate on data of the B and A in consistent way

Conceptual Implementation of Dynamic Binding

```
struct class_A {
   field a1;
   field a2;
}
  void m1_A_A(class_A *this) {…}
  void m2_A_A(class_A *this, int x) ) {…}
```

Runtime object

a1
a2

Compile-Time Table

m1_A_A
m2_A_A

```
struct class_B  {
   field a1;
   field a2;
   field a3;
}
  void m2_A_B(class_B *this, int x) {…}
  void m3_B_B(class B *this) {…}
}
```

Runtime object

a1
a2
a3

Compile-Time Table

m1_A_A
m2_A_B
m3_B_B

```
p.m2(3);      switch(dynamic_type(p) {
                case Dynamic_class_A: m2_A_A(p, 3);
                case Dynamic_class_B:m2_A_B(convert_ptr_to_A_to_ptr_B(p), 3);
              }
```

More efficient implementation

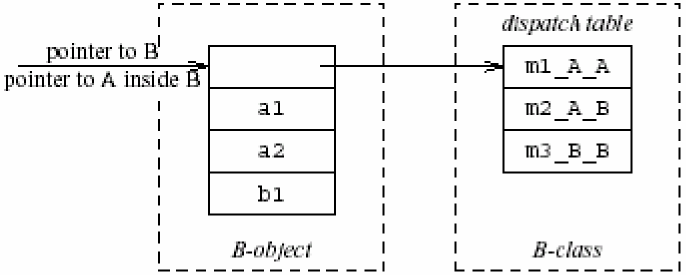
- Apply pointer conversion in sublasses

```
void m2_A_B(class A *this_A, int x) {
    Class_B *this = convert_ptr_to_A_ptr_to_A_B(this_A);
   …
  }
```

- Use dispatch table to invoke functions
- Similar to table implementation of case

```
struct class_A {
    field a1;
    field a2;
}
  void m1_A_A(class_A *this) {…}
  void m2_A_A(class_A *this, int x) )
{…}
```

```
struct class_B  {
    field a1;
    field a2;
    field a3;
}
  void m2_A_B(class_A *this_A, int x) {
      Class_B *this =
convert_ptr_to_A_to_ptr_to_B(this_A);
   …}
  void m3_B_B(class A *this_A) {…}
}
```

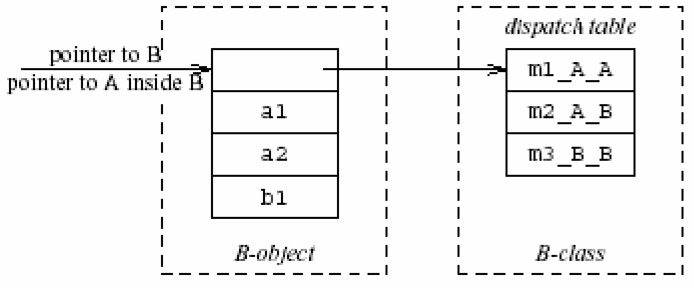



```
p.m2(3);
```

```
p→dispatch_table→m2_A(p, 3);
```

```
struct class_A {
    field a1;
    field a2;
}
  void m1_A_A(class_A *this) {…}
  void m2_A_A(class_A *this, int x) )
{…}
```

```
struct class_B  {
    field a1;
    field a2;
    field a3;
}
   void m2_A_B(class_A *this_A, int x) {
       Class_B *this =
convert_ptr_to_A_to_ptr_to_B(this_A);
   …}
   void m3_B_B(class A *this_A) {…}
}
```




```
p.m2(3); // p is a pointer to B          m2_A_B(convert_ptr_to_B_to_ptr_to_A(p), 3);
```

Multiple Inheritance

```
class C {
    field c1;
    field c2;
    method m1();
    method m2();
};

class D {
    field d1;
    method m3();
    method m4();
};

class E extends C, D {
    field e1;
    method m2();
    method m4();
    method m5();
};
```

Multiple Inheritance

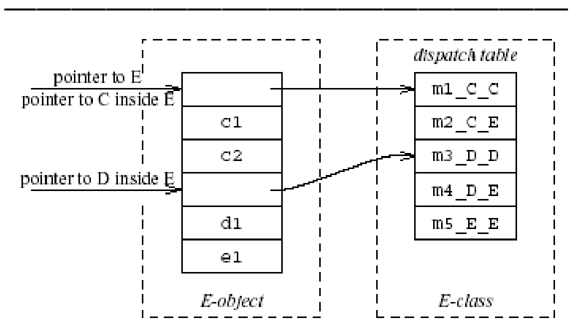
- Allows unifying behaviors
- But raises semantic difficulties
  - Ambiguity of classes
  - Repeated inheritance
- Hard to implement
  - Semantic analysis
  - Code generation
    - Prefixing no longer work
    - Need to generate code for downcasts
- Hard to use

A simple implementation

- Merge dispatch tables of superclases
- Generate code for upcasts and downcasts

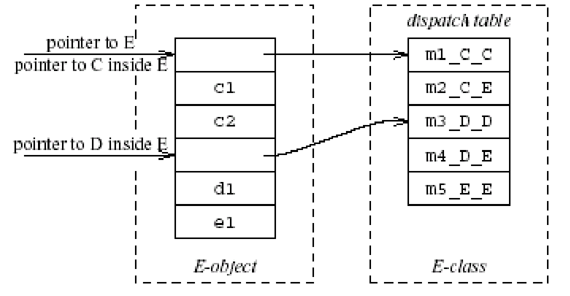
A simple implementation

```
class C {
    field c1;
    field c2;
    method m1();
    method m2();
};
class D {
    field d1;
    method m3();
    method m4();
};
class E extends C, D {
    field e1;
    method m2();
    method m4();
    method m5();
};
```



A simple implementation (downcasting)

```
class C {
    field c1;
    field c2;
    method m1();
    method m2();
};
class D {
    field d1;
    method m3();
    method m4();
};
class E extends C, D {
    field e1;
    method m2();
    method m4();
    method m5();
};
```

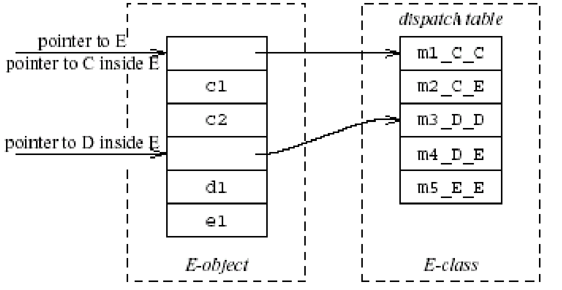


convert_ptr_to_E_to_ptr_to_C(e) = e;

convert_ptr_to_E_to_ptr_to_D(e) = e + sizeof(C);

A simple implementation (upcasting)

```
class C {
    field c1;
    field c2;
    method m1();
    method m2();
};

class D {
    field d1;
    method m3();
    method m4();
};

class E extends C, D {
    field e1;
    method m2();
    method m4();
    method m5();
};
```



convert_ptr_to_C_to_ptr_to_E(c) = c;

convert_ptr_to_D_to_ptr_to_E(d) = d - sizeof(C);

Dependent Multiple Inheritance

```
class A {
    field a1;
    field a2;
    method m1();
    method m3();
};

class C extends A {
    field c1;
    field c2;
    method m1();
    method m2();
};

class D extends A {
    field d1;
    method m3();
    method m4();
};

class E extends C, D {
    field e1;
    method m2();
    method m4();
    method m5();
};
```

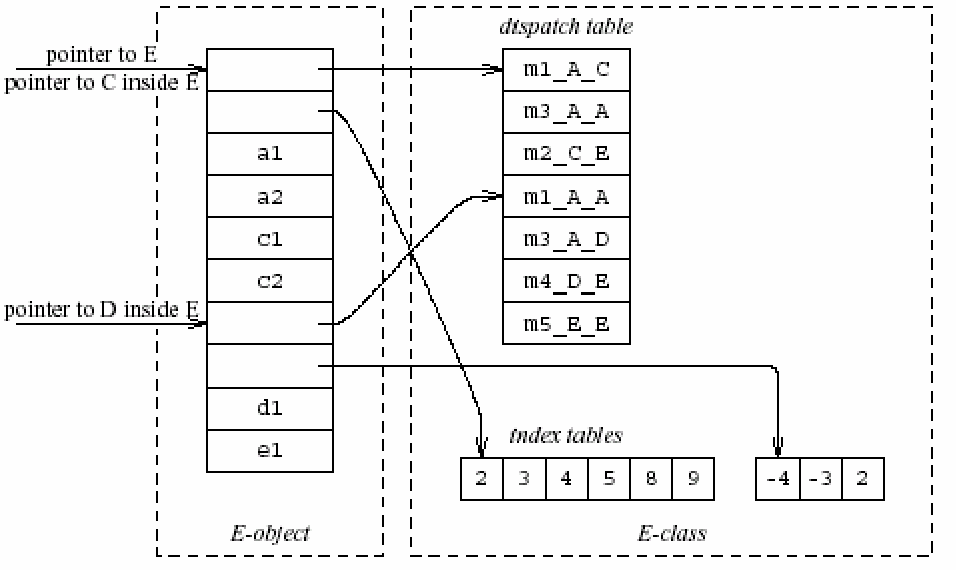
Dependent Inheritance

- The simple solution does not work
- The positions of nested fields do not agree

Implementation

- Use an index table to access fields
- Access offsets indirectly
- Some compilers avoid index table and uses register allocation techniques to globally assign offsets

```
class A {
    field a1;
    field a2;
    method m1();
    method m3();
};
class C extends A {
    field c1;
    field c2;
    method m1();
    method m2();
};
class D extends A {
    field d1;
    method m3();
    method m4();
};
class E extends C, D {
    field e1;
    method m2();
    method m4();
    method m5();
};
```



Class Descriptors

- Runtime information associated with instances
- Dispatch tables
  - Invoked methods
- Index tables
- Shared between instances of the same class

Interface Types

- Java supports limited form of multiple inheritance
- Interface consists of several methods but no fields
- A class can implement multiple interfaces

```
public interface Comparable {
  public int compare(Comparable o);
}
```

- Simpler to implement/understand/use
- A separate dispatch table per interface specification which refers to the implemented method

Dynamic Class Loading

- Supported by some OO languages (Java)
- At compile time
  - the actual class of a given object at a given program point may not be known
- Some addresses have to be resolved at runtime
- Compiling c.f() when f is dynamic:
  - Fetch the class descriptor d at offset 0 from c
  - Fetch p the address of the method-instance f from (constant) f offset at d
  - Jump to the routine at address p (saving return address)

Other OO Features

- Information hiding
  - private/public/protected fields
  - Semantic analysis (context handling)
- Testing class membership

Optimizing OO languages

- Hide additional costs
- Replace dynamic by static binding when possible
- Eliminate runtime checks
- Eliminate dead fields
- Simultaneously generate code for multiple classes
- Code space is an issue

Summary

- OO features complicates compilation
  - Semantic analysis
  - Code generation
  - Runtime
  - Memory management (optional class)
- Understanding compilation of OO can be useful for programmers