Compilation

0368-3133 2015/16a

Lecture 10

Compiling Object-Oriented Programs

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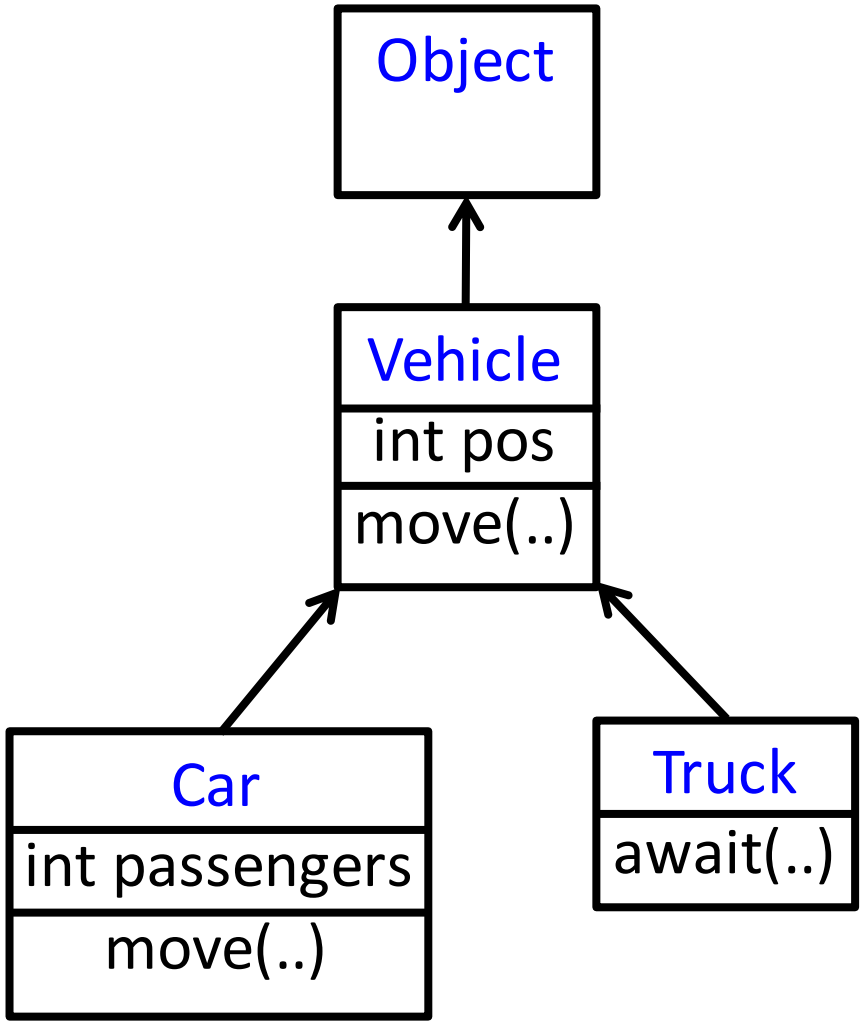
Object Oriented Programs

- C++, Java, C#, Python, …
- Main abstraction: **Objects** (usually of type called class)
  - Code
  - Data
- Naturally supports **A**bstract **D**ata **T**ype implementations
- Information hiding
- Evolution & reusability
- Important characteristic: Extension/Inheritance

A Simple Example



A Simple Example

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

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

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

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

A Simple Example

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  void move(int x) {
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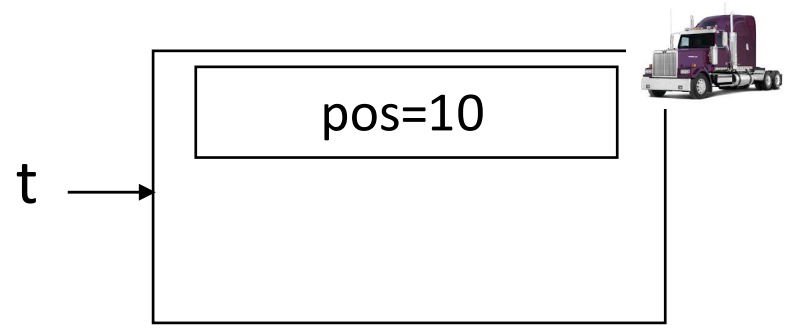

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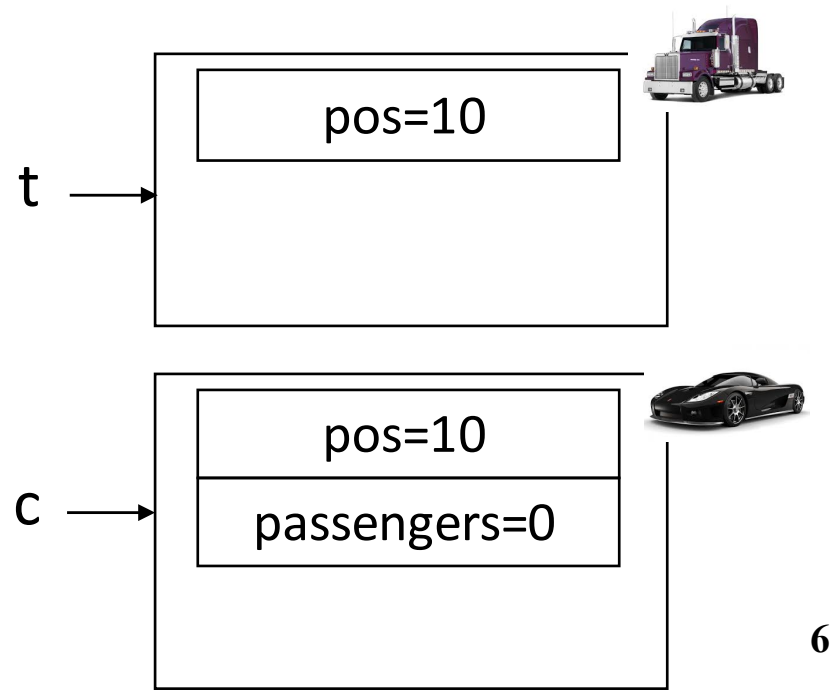
}
```



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    c.await(t);
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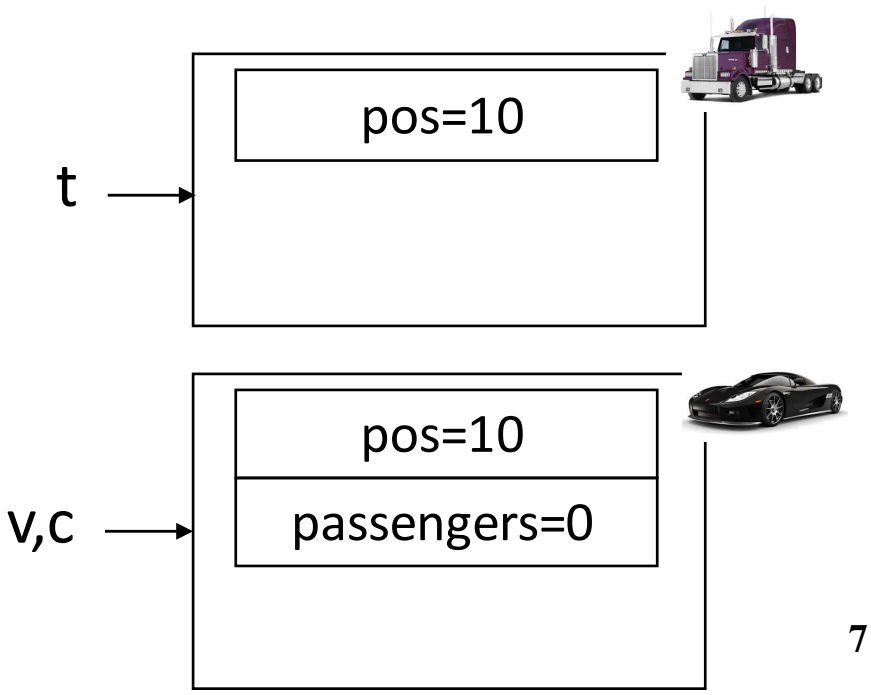
```



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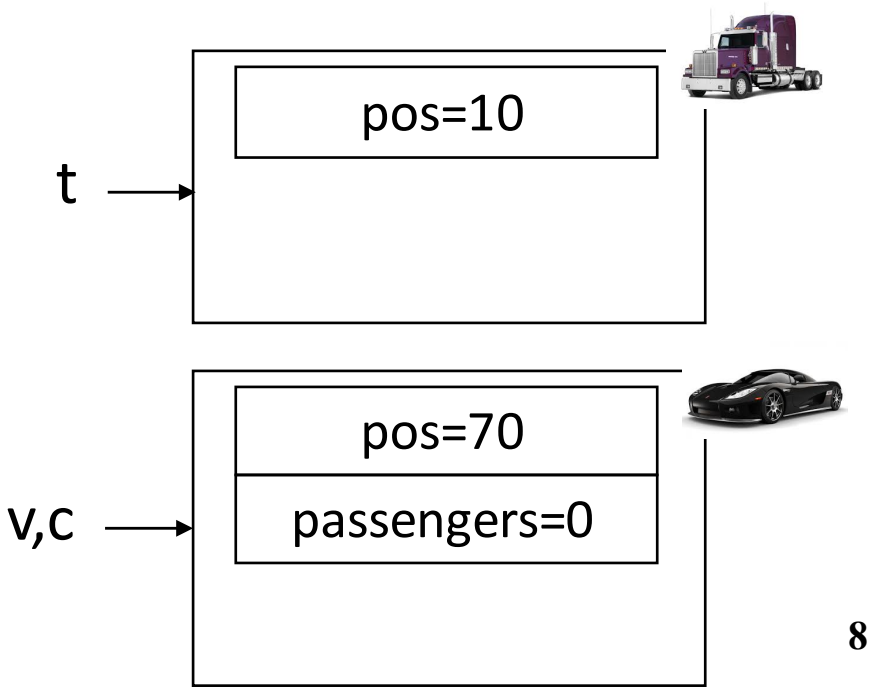

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    else
      this.move(10);
  }
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    t.move(70);
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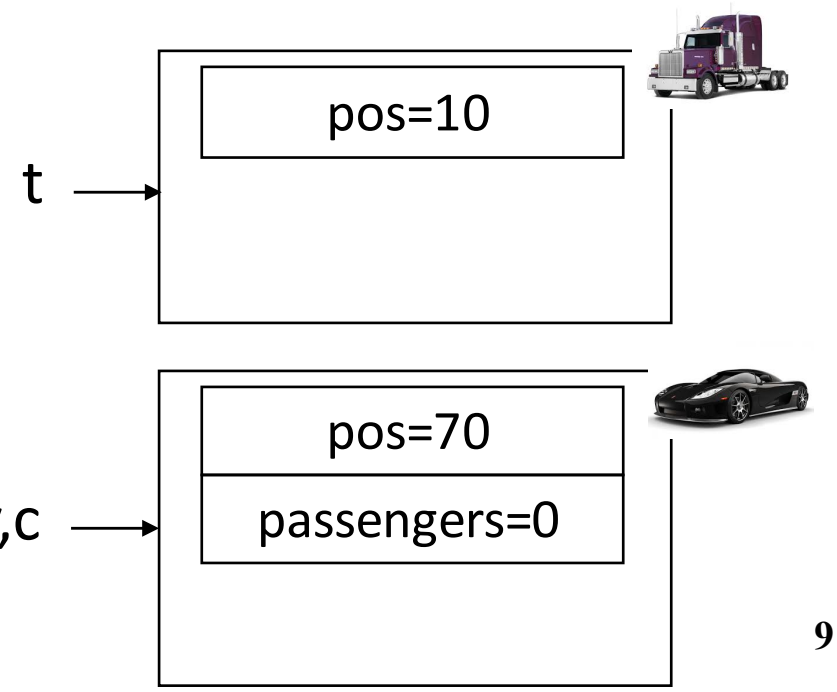
}
```



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    v.move(60);
    t.move(70);
    c.await(t);
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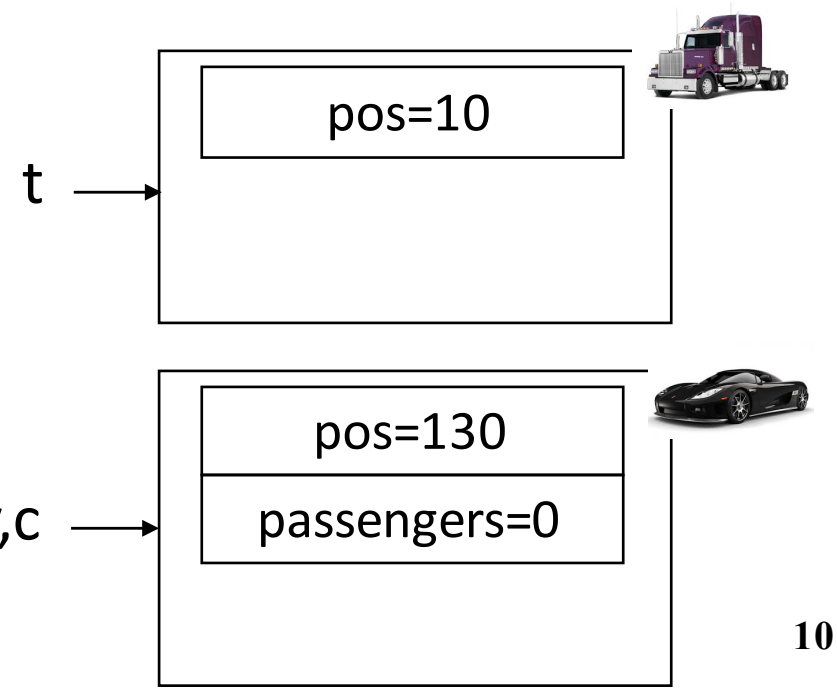
}
```



Translation into C

Translation into C (Vehicle)

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

```
typedef struct Vehicle {
  int pos;
} Ve;
```

Translation into C (Vehicle)

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

```
typedef struct Vehicle {
  int pos;
} Ve;

void NewVe(Ve *this){
  this→pos = 10;
}

void moveVe(Ve *this, int x){
  this→pos = this→pos + x;
}
```

Translation into C (Truck)

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

```
typedef struct Truck {
  int pos;
} Tr;

void NewTr(Tr *this){
  this→pos = 10;
}

void moveTr(Ve *this, int x){
  if (x<55)
    this→pos = this→pos + x;
}
```

Naïve Translation into C (Car)

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

```
typedef struct Car{
  int pos;
  int passengers;
} Ca;

void NewCa (Ca *this){
  this→pos = 10;
  this→passengers = 0;
}

void awaitCa(Ca *this, Ve *v){
  if (v→pos < this→pos)
    moveVe(this→pos – v→pos)
  else
    MoveCa(this, 10)
}
```

Naïve Translation into C (Main)

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

```
void mainMa(){
  Tr *t = malloc(sizeof(Tr));
  Ca *c = malloc(sizeof(Ca));
  Ve *v = (Ve*) c;
  moveVe(v, 60);
  moveVe(t, 70);
  awaitCa(c,(Ve*) t);
}
```

Naïve Translation into C (Main)

```
class main extends object {
  void main() {
    Truck t = new Truck();
    Car c = new Car();
    Vehicle v = c;
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}
```

```
void moveCa() ?
```

Naïve Translation into C (Main)

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  void main() {
    Truck t = new Truck();
    Car c = new Car();
    Vehicle v = c;
    v.move(60);
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```
void mainMa(){
  Tr *t = malloc(sizeof(Tr));
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}
```

```
void moveCa() ?
```

```
void moveVe(Ve *this, int x){
  this→pos = this→pos + x;
}
```

Naïve Translation into C (Main)

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

```
typedef struct Vehicle {
  int pos;
} Ve;
```

```
typedef struct Car{
  int pos;
  int passengers;
} Ca;
```

```
void mainMa(){
  Tr *t = malloc(sizeof(Tr));
  Ca *c = malloc(sizeof(Ca));
  Ve *v = (Ve*) c;
  moveVe(v, 60);
  moveVe(t, 70);
  awaitCa(c,(Ve*) t);
}
```

```
void moveCa() ?
```

```
void moveVe(Ve *this, int x){
  this→pos = this→pos + x;
}
```

Naïve Translation into C (Main)

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class main extends object {
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    v.move(60);
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void mainMa(){
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  Ve *v = (Ve*) c;
  moveVe(v, 60);
  moveVe(t, 70);
  awaitCa(c,(Ve*) t);
}
```

```
Vehicle x = t;
x.move(20);
```

```
Ve *x = t;
moveTr((Tr*)x, 20);
```

Naïve Translation into C (Main)

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

```
Vehicle x = t;
x.move(20);
```

```
Ve *x = t;
moveTr((Tr*)x, 20);
```

```
void moveVe(Ve *this, int x){…}
```

```
void moveTr(Ve *this, int x){…}
```

Translation into C

Compiling Simple Classes

- Fields are handled as records
- Methods have unique names

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

Runtime object

a1
a2

Compile-Time Table

m1A
m2A

```
void m2A(classA  *this, int i) {
   // Body of m2 with any object
   // field f as this    f
  …
}
```

Compiling Simple Classes

- Fields are handled as records
- Methods have unique names

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

Runtime object

a1
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Compile-Time Table

m1A
m2A

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

```
m2A(a,5)
```

```
void m2A(classA  *this, int i) {
   // Body of m2 with any
   // object-field f as this    f
   …
}
```

Features of OO languages

- **Inheritance**
  - Subclass gets (inherits) properties of superclass
- **Method overriding**
  - Multiple methods with the same name with different signatures
- **Abstract** (aka **virtual**) **methods**
- **Polymorphism**
  - Multiple methods with the same name and different signatures but with different implementations
- **Dynamic dispatch**
  - Lookup methods by (runtime) type of target object

Compiling OO languages

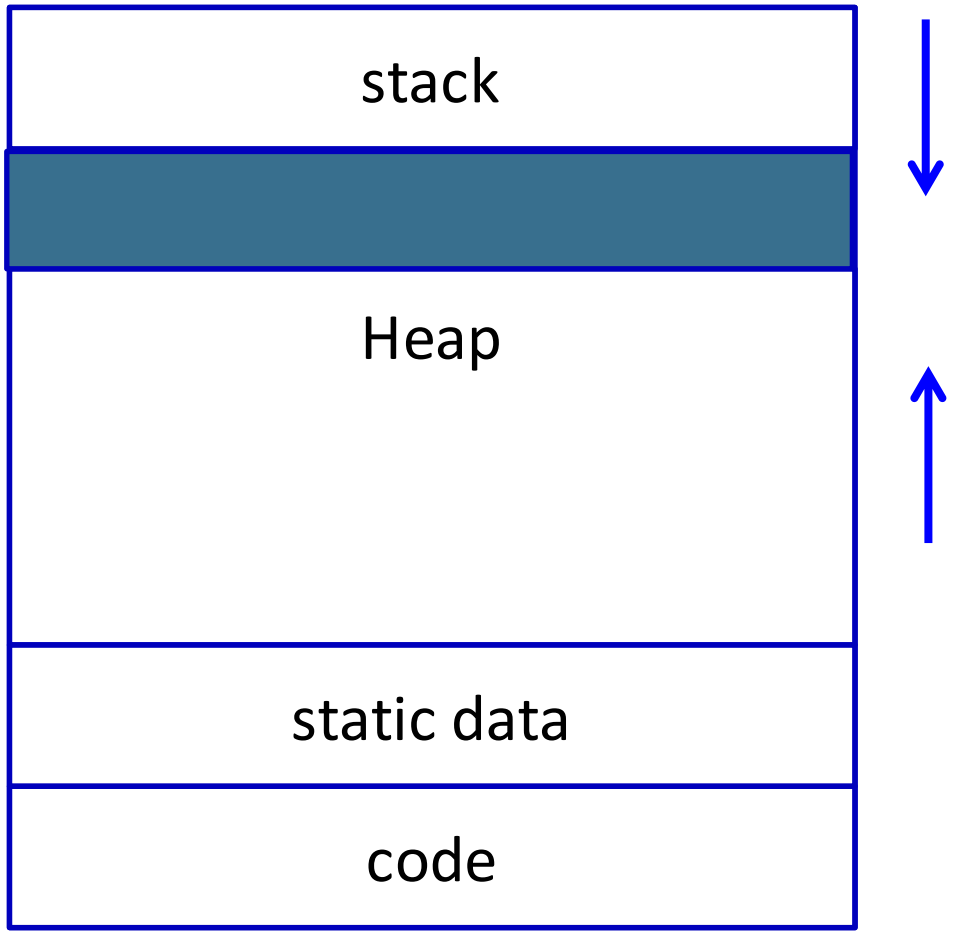
- “Translation into C”
- Powerful runtime environment

- Adding “gluing” code

Runtime Environment

- Mediates between the OS and the programming language
- Hides details of the machine from the programmer
  - Ranges from simple support functions all the way to a full-fledged virtual machine
- Handles common tasks
  - Runtime stack (activation records)
  - Memory management
- **Runtime type information**
  - **Method invocation**
  - **Type conversions**

Memory Layout



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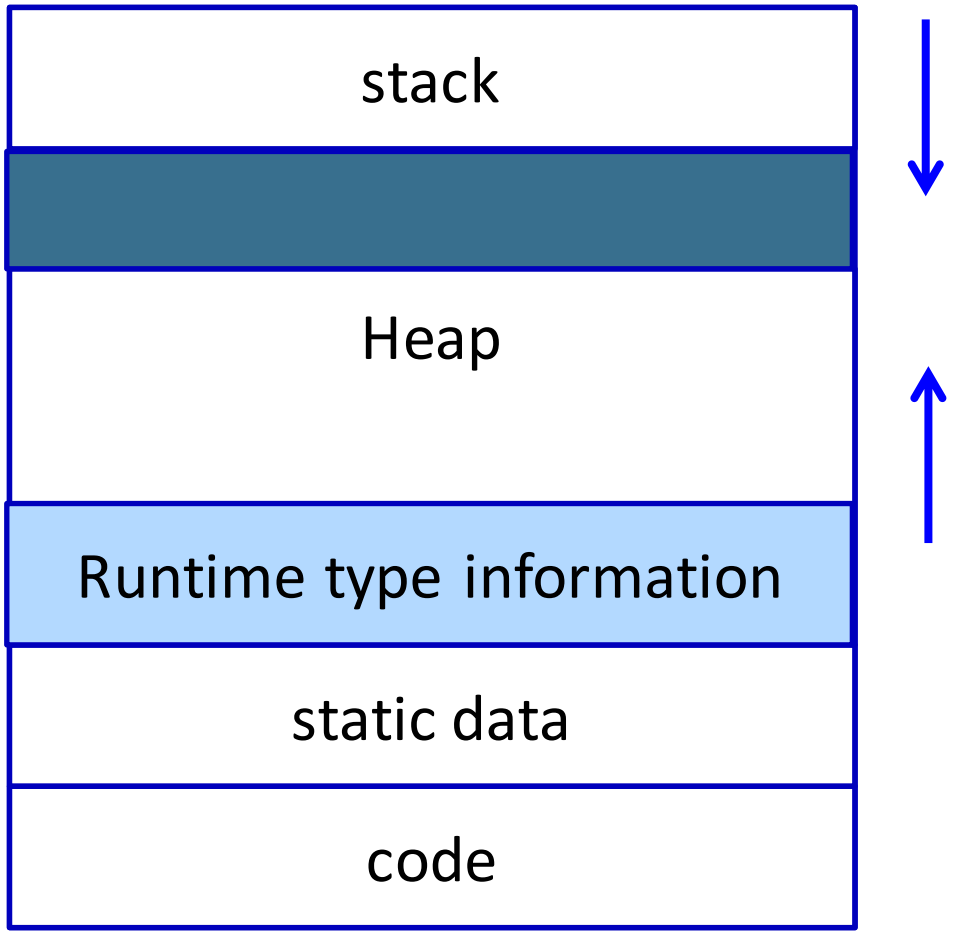

Handling Single Inheritance

- Simple type extension

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

```
class B extends A {
    field b1;
    method m3() {…}
}
```

Adding fields

Fields aka Data members, instance variables

- Adds more information to the inherited class
  - "Prefixing" fields ensures consistency

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

```
class B extends A {
    field b1;
    method m2() {…}
    method m3() {…}
}
```

```
typedef struct  {
    field a1;
    field a2;
} A;

void m1A_A(A* this){…}
void m2A_A(A* this){…}
```

```
typedef struct  {
    field a1;
    field a2;
    field b1;
} B;

void m2A_B(B* this) {…}
void m3B_B(B* this) {…}
```

Method Overriding

- Redefines functionality
  - More specific
  - Can access additional fields

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

```
class B extends A {
    field b1;
    method m2() {
        … b1 …
    }
    method m3() {…}
}
```

Method Overriding

- Redefines functionality
  - More specific
  - Can access additional fields

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

m2 is declared and defined

```
class B extends A {
    field b1;
    method m2() {
        … b1 …
    }
    method m3() {…}
}
```

m2 is redefined

Method Overriding

- Redefines functionality
- Affects semantic analysis

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

```
class B extends A {
    field b1;
    method m2() {
        … b1 …
    }
    method m3() {…}
}
```

Runtime object

a1
a2

Compile-Time Table

m1A_A
m2A_A

Runtime object

a1
a2
b1

Compile-Time Table

m1A_A
m2A_B
m3B_B

Method Overriding

- Redefines functionality
- Affects semantic analysis

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class A {
    field a1;
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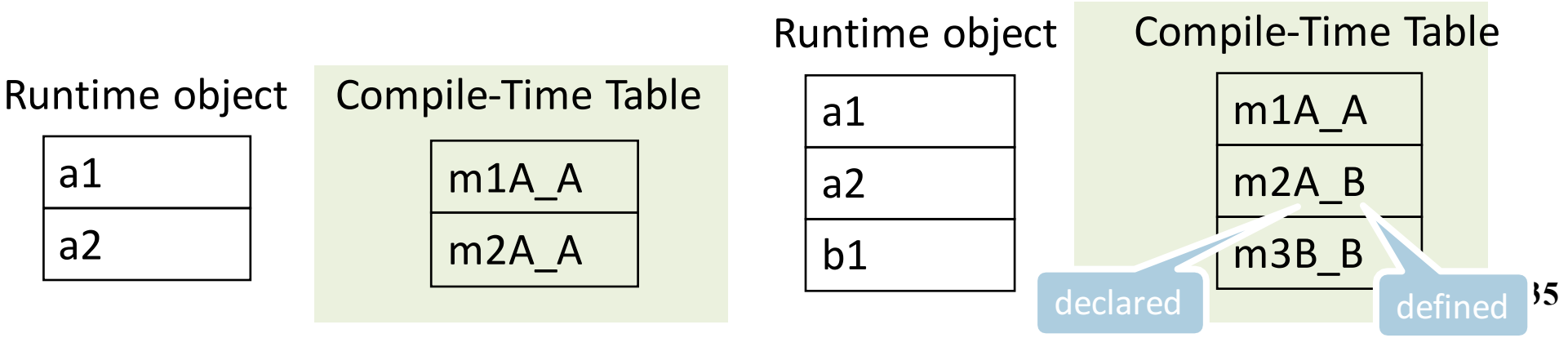

Method Overriding

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

```
m2A_A(a, 5)
```

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

```
b.m2(5)   // class(b) = B
```

```
m2A_B(b, 5)
```

```
class B extends A {
    field b1;
    method m2() {
        … b1 …
    }
    method m3() {…}
}
```

Runtime object

a1
a2

Compile-Time Table

m1A_A
m2A_A

Runtime object

a1
a2
b1

Compile-Time Table

m1A_A
m2A_B
m3B_B

Method Overriding

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```
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void m1A_A(A* this){…}
void m2A_A(A* this){…}
```

Runtime object

a1
a2

Compile-Time Table

m1A_A
m2A_A

```
class B extends A {
    field b1;
    method m2() {
     … b1 …
    }
    method m3() {…}
}
```

```
typedef struct  {
    field a1;
    field a2;
    field b1;
} B;

void m2A_B(B* this) {…}
void m3B_B(B* this) {…}
```

Runtime object

a1
a2
b1

Compile-Time Table

m1A_A
m2A_B
m3B_B

Method Overriding

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

m2A_A(a, 5)

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

m2A_B(b, 5)

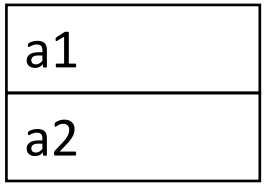
```
typedef struct  {
    field a1;
    field a2;
} A;

void m1A_A(A* this){…}
void m2A_A(A* this){…}
```

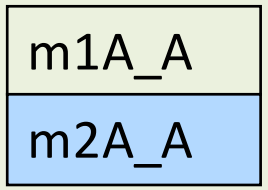
```
typedef struct  {
    field a1;
    field a2;
    field b1;
} B;

void m2A_B(B* this) {…}
void m3B_B(B* this) {…}
```

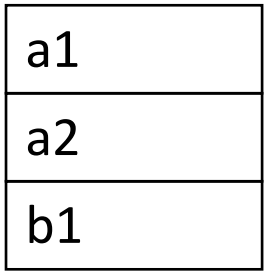
Runtime object



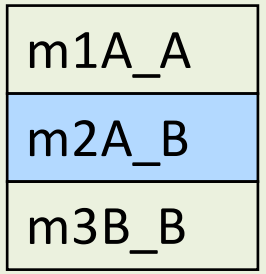
Compile-Time Table



Runtime object



Compile-Time Table



Abstract methods & classes

- Abstract methods
  - Declared separately, defined in child classes
  - E.g., C++ pure virtual methods, abstract methods in Java
- Abstract classes = class may have abstract methods
  - E.G., Java/C++ abstract classes
  - Abstract classes cannot be instantiated
- Abstract aka "virtual"
- Inheriting abstract class handled like regular inheritance
  - Compiler checks abstract classes are not allocated

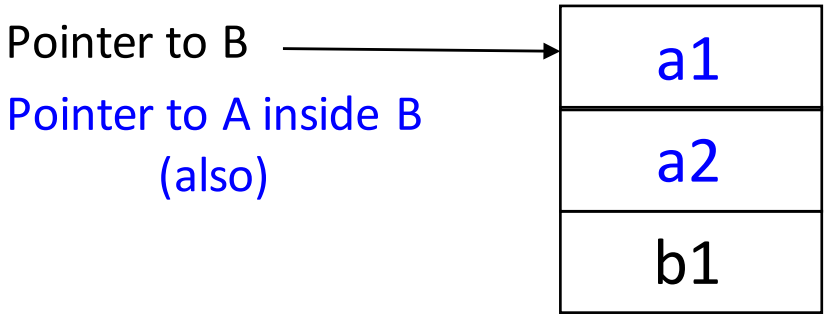
Handling Polymorphism

- 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 fields guarantees validity

```
class B *b = …;

class A *a = b ;
```

```
classA *a = convert_ptr_to_B_to_ptr_A(b) ;
```



Dynamic Binding

- An object ("pointer") o declared to be of class A can actually be ("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 Impl. of Dynamic Binding

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

```
typedef struct  {
    field a1;
    field a2;
} A;

void m1A_A(A* this){…}
void m2A_A(A* this){…}
```

```
class B extends A {
    field b1;
    method m2() {
     … a3 …
    }
    method m3() {…}
}
```

```
typedef struct  {
    field a1;
    field a2;
    field b1;
} B;

void m2A_B(B* this) {…}
void m3B_B(B* this) {…}
```

Runtime object

a1
a2

Compile-Time Table

m1A_A
m2A_A

Runtime object

a1
a2
b1

Compile-Time Table

m1A_A
m2A_B
m3B_B

Conceptual Impl. of Dynamic Binding

”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);
}
```

```
typedef struct  {
    field a1;
    field a2;
} A;

void m1A_A(A* this){…}
void m2A_A(A* this){…}
```

```
typedef struct  {
    field a1;
    field a2;
    field b1;
} B;

void m2A_B(B* this) {…}
void m3B_B(B* this) {…}
```

Runtime object

a1
a2

Compile-Time Table

m1A_A
m2A_A

Runtime object

a1
a2
b1

Compile-Time Table

m1A_A
m2A_B
m3B_B

Conceptual Impl. of Dynamic Binding

”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);
}
```

```
typedef struct  {
    field a1;
    field a2;
} A;

void m1A_A(A* this){…}
void m2A_A(A* this){…}
```

```
typedef struct  {
    field a1;
    field a2;
    field b1;
} B;

void m2A_B(B* this) {…}
void m3B_B(B* this) {…}
```

Runtime object

a1
a2

Compile-Time Table

m1A_A
m2A_A

Runtime object

a1
a2
b1

Compile-Time Table

m1A_A
m2A_B
m3B_B

More efficient implementation

- Apply pointer conversion in sublasses
  - Use dispatch table to invoke functions
  - Similar to table implementation of case

```
void m2A_B(classA *this_A) {
    Class_B *this = convert_ptr_to_A_ptr_to_A_B(this_A);
    …
}
```

More efficient implementation

```
typedef struct  {
    field a1;
    field a2;
} A;

void m1A_A(A* this){…}
void m2A_A(A* this, int x){…}
```

```
typedef struct  {
    field a1;
    field a2;
    field b1;
} B;

void m2A_B(A* thisA, int x){
  Class_B *this =
    convert_ptr_to_A_to_ptr_to_B(thisA);
    …
  }

void m3B_B(B* this){…}
```

More efficient implementation

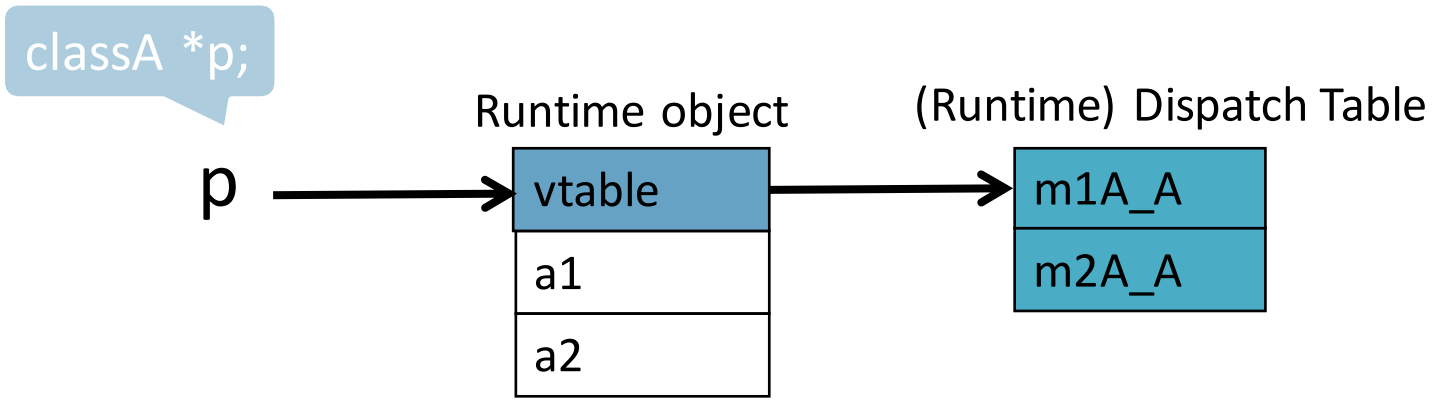
```
typedef struct  {
    field a1;
    field a2;
} A;

void m1A_A(A* this){…}
void m2A_A(A* this, int x){…}
```

```
typedef struct  {
    field a1;
    field a2;
    field b1;
} B;

void m2A_B(A* thisA, int x){
  Class_B *this =
    convert_ptr_to_A_to_ptr_to_B(thisA);
    …
  }

void m3B_B(B* this){…}
```



More efficient implementation

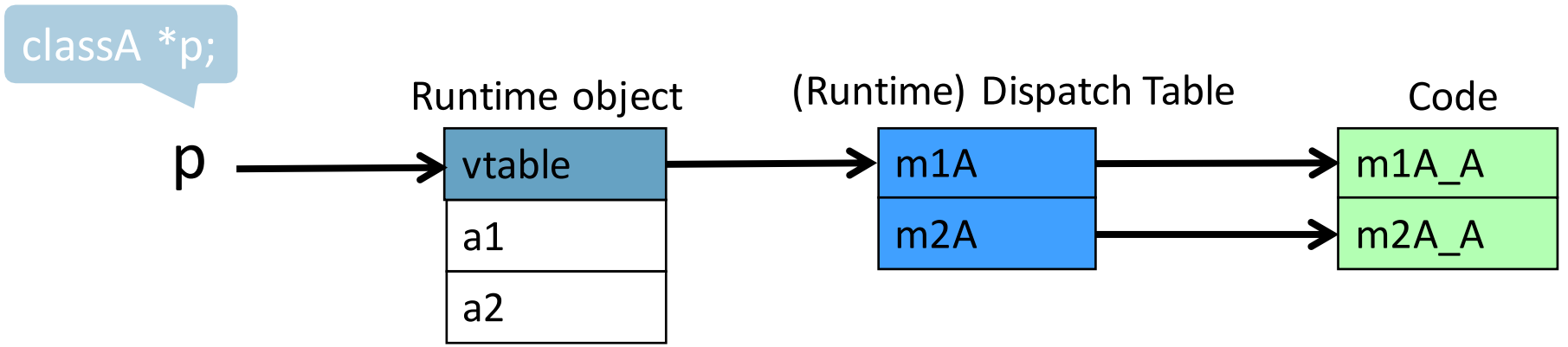
```
typedef struct  {
    field a1;
    field a2;
} A;

void m1A_A(A* this){…}
void m2A_A(A* this, int x){…}
```

```
typedef struct  {
    field a1;
    field a2;
    field b1;
} B;

void m2A_B(A* thisA, int x){
  Class_B *this =
    convert_ptr_to_A_to_ptr_to_B(thisA);
    …
  }

void m3B_B(B* this){…}
```



More efficient implementation

```
typedef struct  {
    field a1;
    field a2;
} A;

void m1A_A(A* this){…}
void m2A_A(A* this, int x){…}
```

```
typedef struct  {
    field a1;
    field a2;
    field b1;
} B;

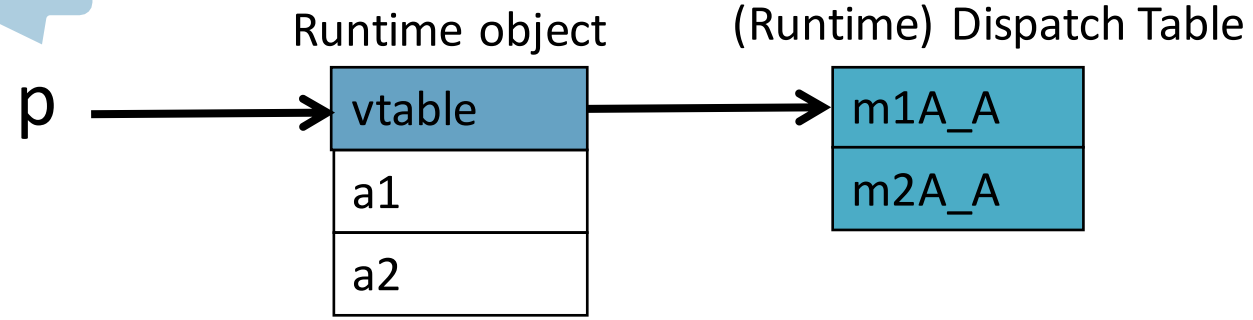
void m2A_B(A* thisA, int x){
  Class_B *this =
    convert_ptr_to_A_to_ptr_to_B(thisA);
    …
  }

void m3B_B(B* this){…}
```

classA *p;

p.m2(3);

p→dispatch_table→m2A(p, 3);



More efficient implementation

```
typedef struct  {
    field a1;
    field a2;
} A;

void m1A_A(A* this){…}
void m2A_A(A* this, int x){…}
```

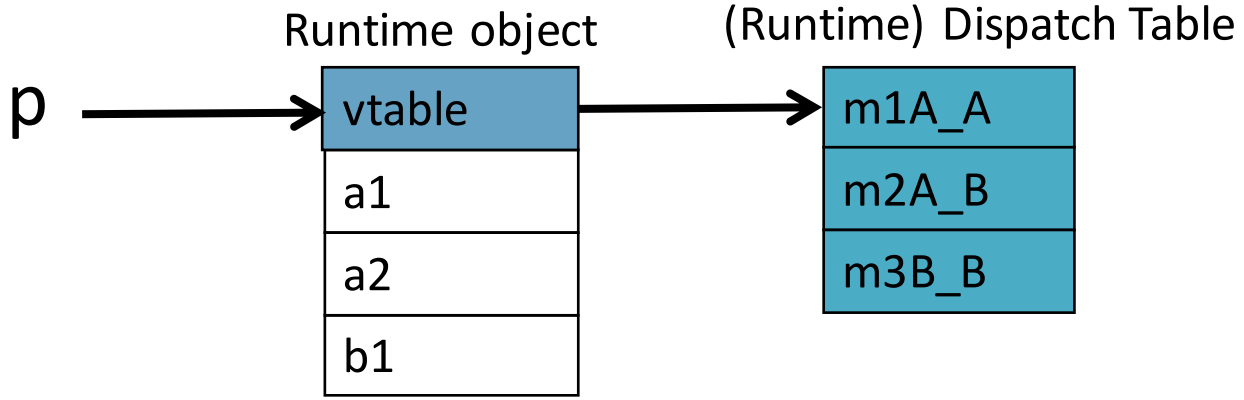
```
typedef struct  {
    field a1;
    field a2;
    field b1;
} B;

void m2A_B(A* thisA, int x){
  Class_B *this =
    convert_ptr_to_A_to_ptr_to_B(thisA);
    …
  }

void m3B_B(B* this){…}
```

p.m2(3);

p→dispatch_table→m2A(p, 3);



More efficient implementation

```
typedef struct  {
    field a1;
    field a2;
} A;

void m1A_A(A* this){…}
void m2A_A(A* this, int x){…}
```

```
typedef struct  {
    field a1;
    field a2;
    field b1;
} B;

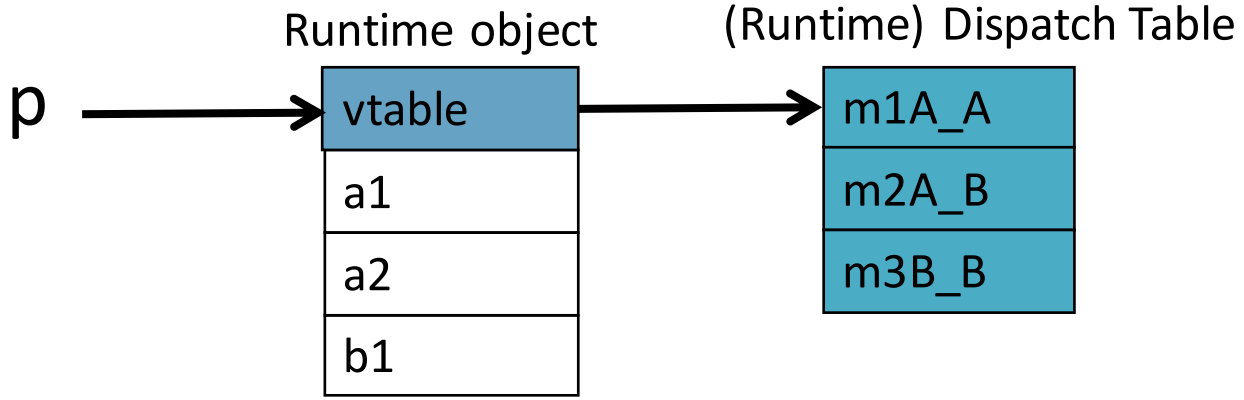
void m2A_B(A* thisA, int x){
  Class_B *this =
    convert_ptr_to_A_to_ptr_to_B(thisA);
    …
  }

void m3B_B(B* this){…}
```

convert_ptr_to_B_to_ptr_to_A(p)

```
p→dispatch_table→m2A( , 3);
```

p.m2(3);



Allocating objects (runtime)

- x = new A()

- Allocate memory for A's fields + pointer to vtable
- Initialize vtable to point to A's vtable
- initialize A's fields (call constructor)
- return object

Executing a.m2(5)

- Fetch the class descriptor at offset 0 from a
- Fetch the method-instance pointer p from the constant m2 offset of a
- call m2 (jump to address p)

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

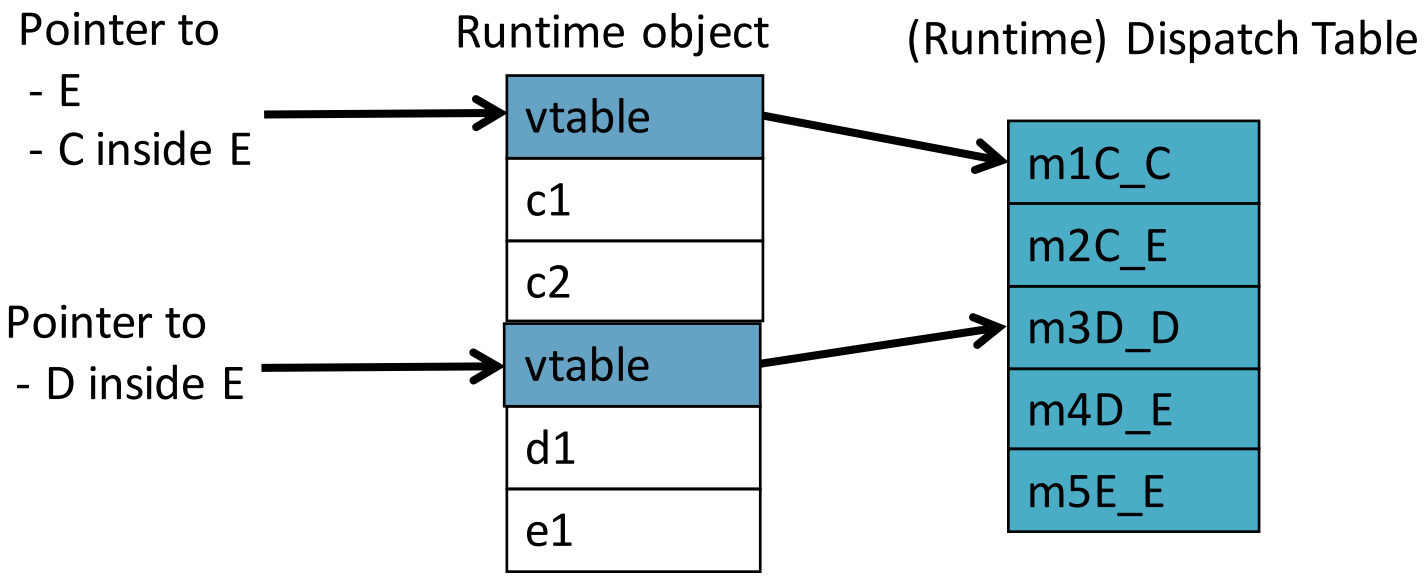
```
class C {
    field c1;
    field c2;
    method m1(){…}
    method m2(){…}
}
```

```
class D {
    field d1;

    method m3() {…}
    method m4(){…}
}
```

```
class E extends C, D {
    field e1;

    method m2() {…}
    method m4() {…}
    method m5(){…}
}
```



Downcasting (E→C,D)

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

```
class D {
    field d1;

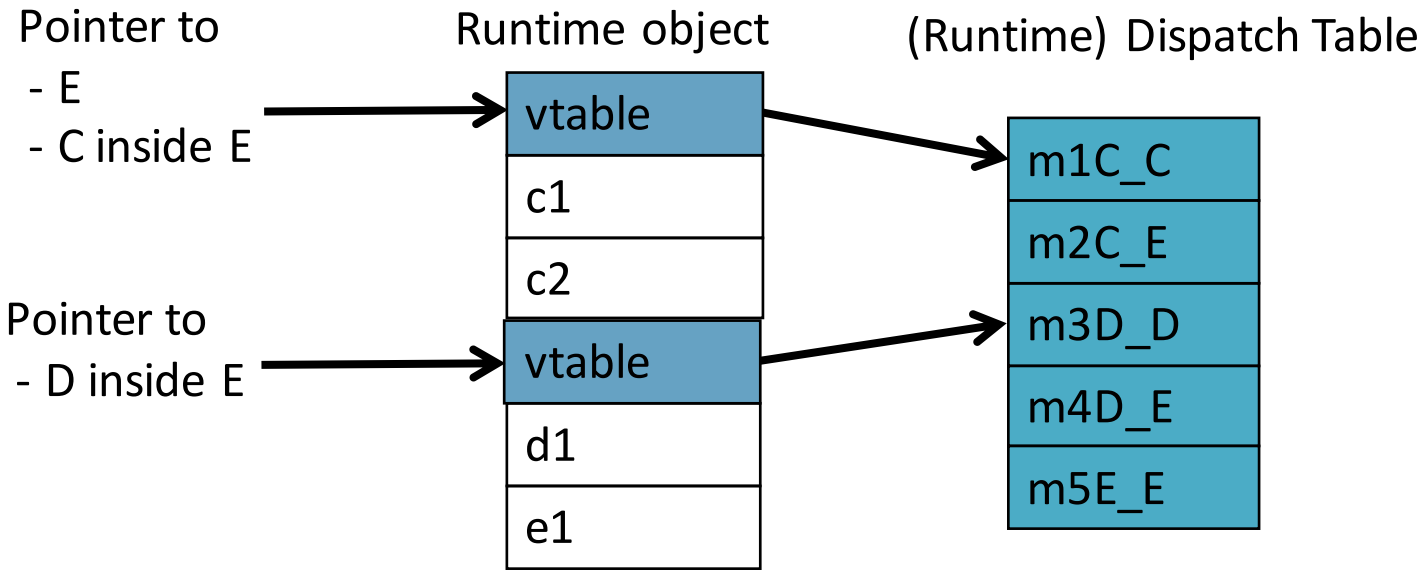
    method m3() {…}
    method m4(){…}
}
```

```
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);



Upcasting (C,D→E)

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

```
class D {
    field d1;

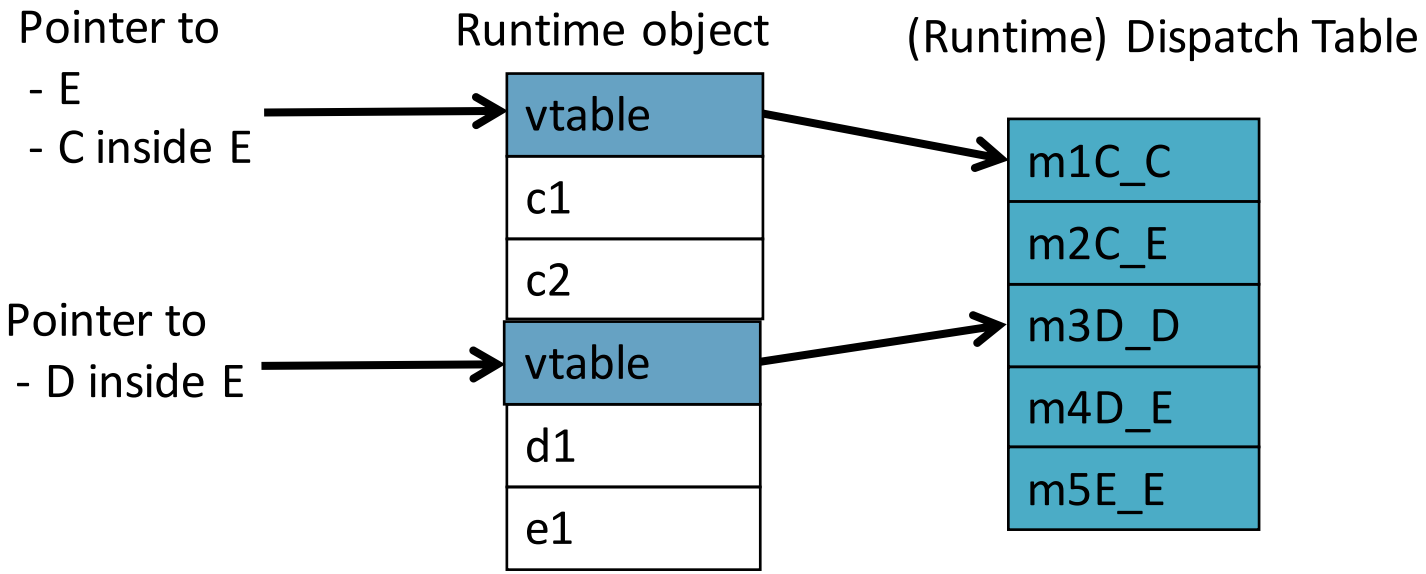
    method m3() {…}
    method m4(){…}
}
```

```
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);



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

```
class D extends A {
    field d1;

    method m3(){…}
    method m4(){…}
}
```

```
class E extends C, D {
    field e1;

    method m2() {…}
    method m4() {…}
    method m5(){…}
}
```

Independent multiple Inheritance

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

```
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(){…}
}
```

Independent multiple Inheritance

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

```
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(){…}
}
```

Independent multiple Inheritance

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

```
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 m3(){…}  //alt explicit qualification
    method m2() {…}
    method m4() {…}
    method m5(){…}
}
```

Independent Inheritance

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

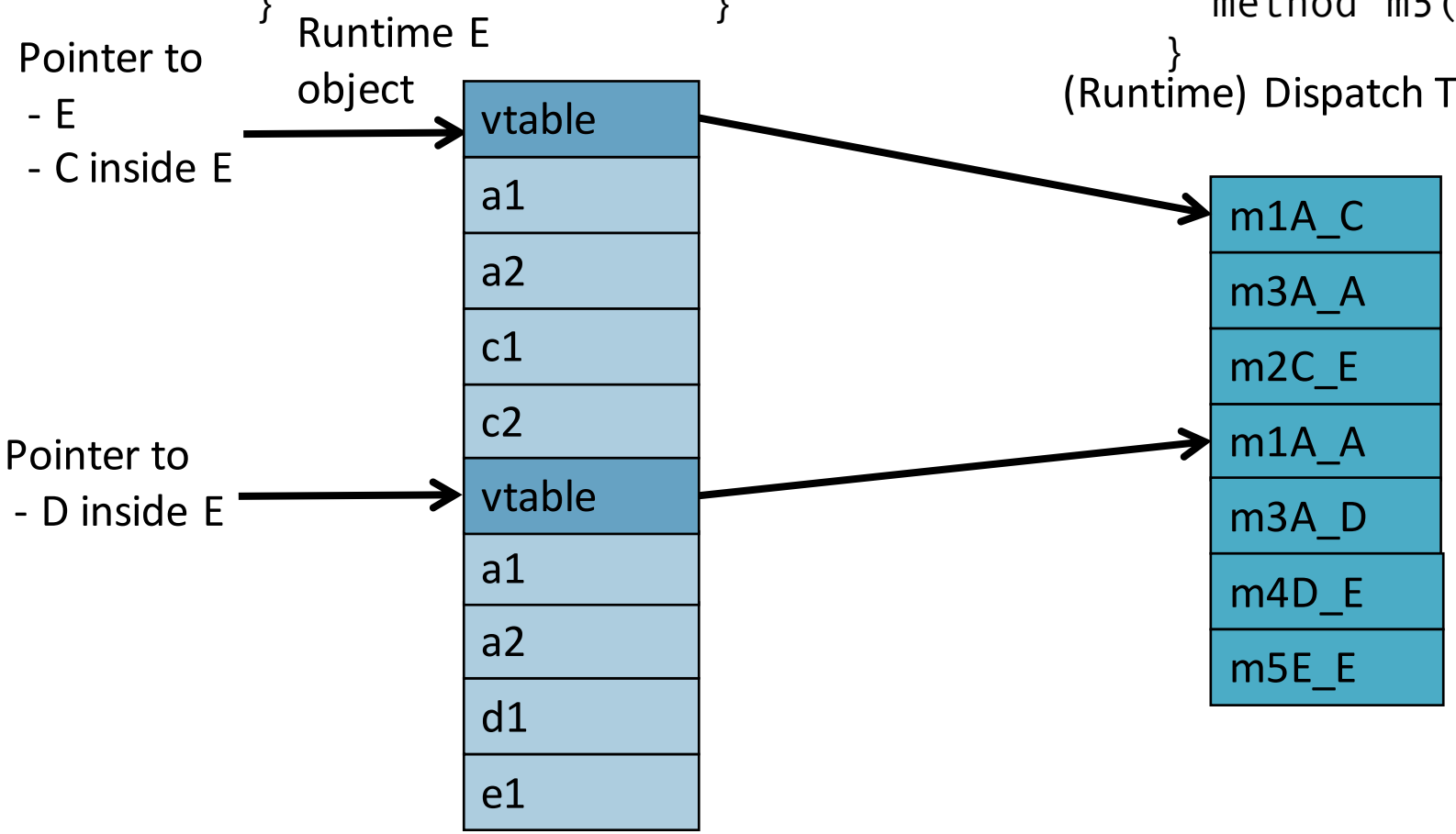
```
class C
    extends A{
  field c1;
  field c2;
  method m1(){…}
  method m2(){…}
}
```

```
class D
    extends A{
  field d1;

  method m3(){…}
  method m4(){…}
}
```

```
class E
    extends C,D{
  field e1;

  method m2() {…}
  method m4() {…}
  method m5(){…}
}
```



Dependent multiple inheritance

- Superclasses share their own superclass

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

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 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 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

- Superclasses share their own superclass

- 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

Implementation

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

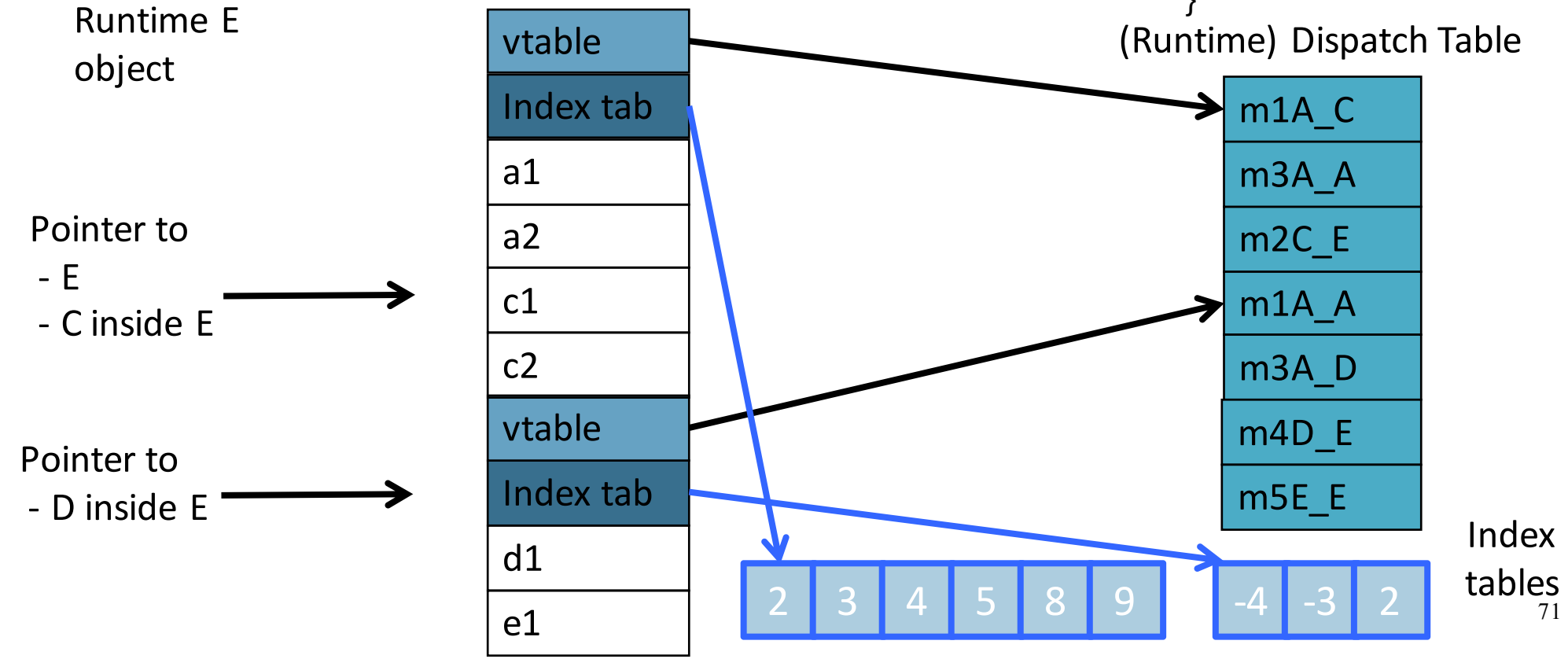
```
class C
    extends A{
  field c1;
  field c2;
  method m1(){…}
  method m2(){…}
}
```

```
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

- Can have more (reflection)

Interface Types

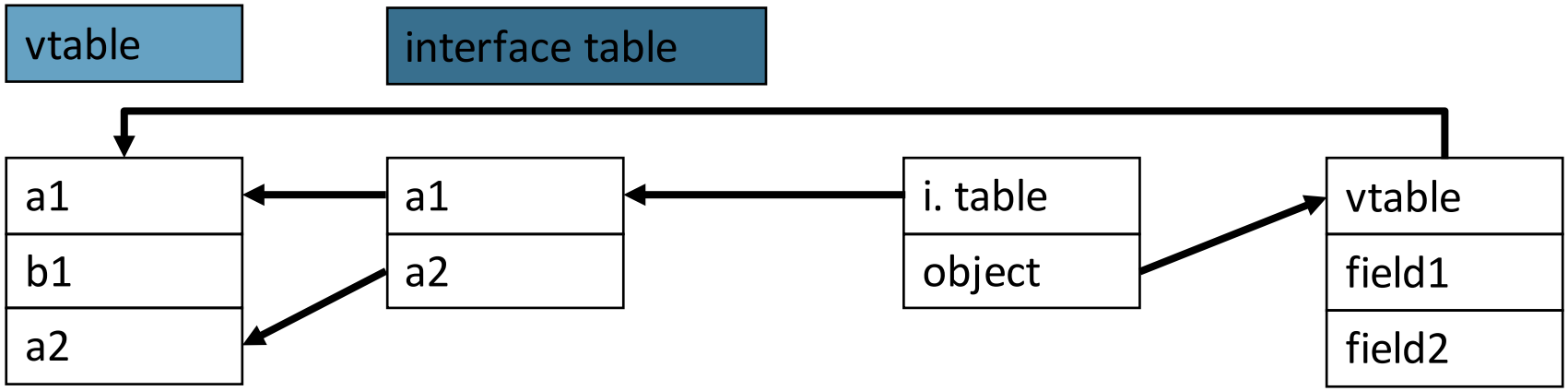
- Java supports limited form of multiple inheritance
- Interface consists of several methods but no fields

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

- A class can implement multiple interfaces
  Simpler to implement/understand/use

Interface Types

- Implementation: record with 2 pointers:
  - A separate dispatch table per interface
  - A pointer to the object



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
  - problem when multiple inheritance is allowed
    - Can use hash table to map fields name to pointers to functions

Other OO Features

- Information hiding
  - private/public/protected fields
  - Semantic analysis (context handling)
- Testing class membership
  - Single inheritance: look up the chain of “supers”
  - If inheritance is bounded
    - Allocate parent array at every class descriptors
    - look up at “depth-of-inheritance” index
- Up casting: (Possibly) runtime checks
  - B x = (B)a // B extends A

Optimizing OO languages

- Hide additional costs
  - Eliminate runtime checks

    A x = new B() // B extends A

    B y = (B) x
  - Eliminate dead fields

  - Replace dynamic by static binding when possible

    x = new B() // B extends A and overrides f

    x.f() // invoke B_f(x)
    - Type propagation analysis ~ reaching definitions

Optimizing OO languages

- Simultaneously generate code for multiple classes

```
class A {
  g() { }
  f() { g() }
}
```

```
class B extends A {
  g() {}
}
```

```
class B extends A {
  g()
}
```

- Generate code B_f() and C_f()
- Code space is an issue

Summary

- OO is a programming/design paradigm
- OO features complicates compilation
  - Semantic analysis
  - Code generation
  - Runtime
  - Memory management
- Understanding compilation of OO can be useful for programmers