Lecture 13 – Compiling Object-Oriented Programs

THEORY OF COMPILATION

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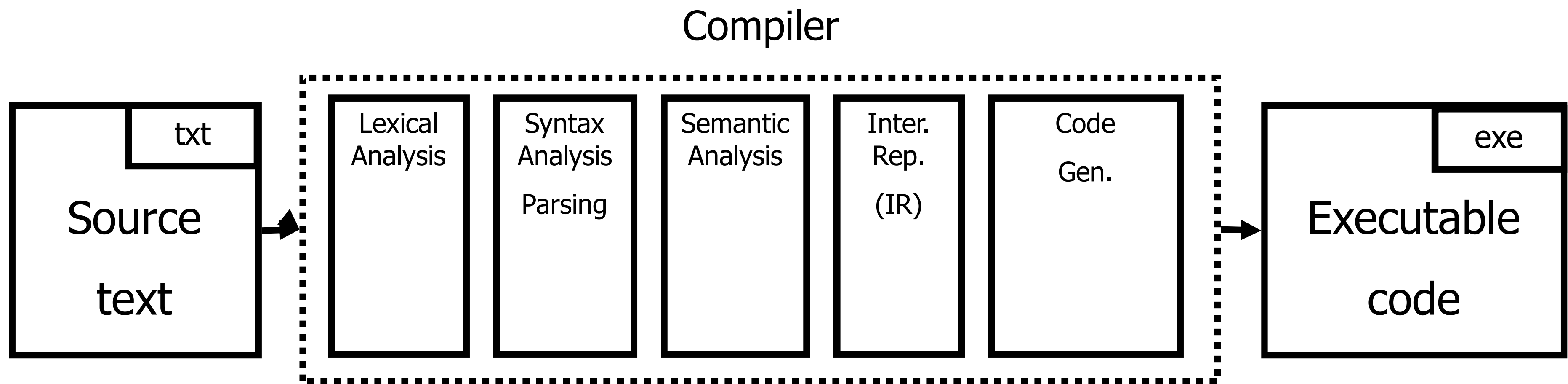
www.cs.technion.ac.il/~yahave/tocs2011/compilers-lec13.pptx

Reference: MCD 6.2.9

You are here



Representing Data at Runtime

- Source language types
  - int, boolean, string, object types
- Target language types
  - Single bytes, integers, address representation
- Compiler should map source types to some combination of target types
  - Implement source types using target types

Basic Types

- int, boolean, string, void
- Arithmetic operations
  - Addition, subtraction, multiplication, division, remainder
- Could be mapped directly to target language types and operations

Pointer Types

- Represent addresses of source language data structures
- Usually implemented as an unsigned integer
- Pointer dereferencing – retrieves pointed value

- May produce an error
  - Null pointer dereference
  - when is this error triggered?
  - how is this error produced?

Object Types

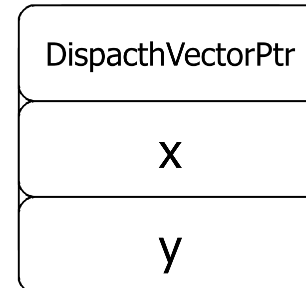
- Basic operations
  - Field selection
    - computing address of field, dereferencing address
  - Copying
    - copy block or field-by-field copying
  - Method invocation
    - Identifying method to be called, calling it

- How does it look at runtime?

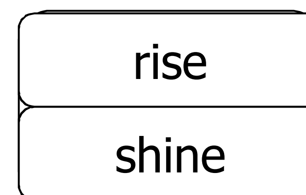
Object Types

```
class Foo {
  int x;
  int y;

  void rise() {…}
  void shine() {…}
}
```



Runtime memory layout for object of class Foo



Compile time information

Field Selection

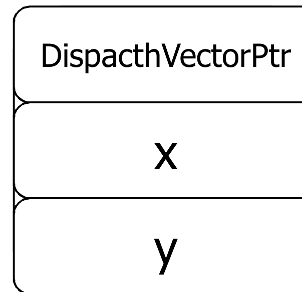
```
Foo f;
int q;

q = f.x;
```

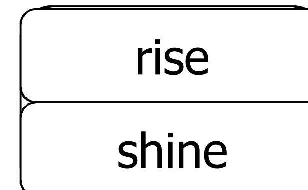
```
MOV f, %EBX
MOV 4(%EBX), %EAX
MOV %EAX, q
```

base pointer

field offset from base pointer



Runtime memory layout for object of class Foo



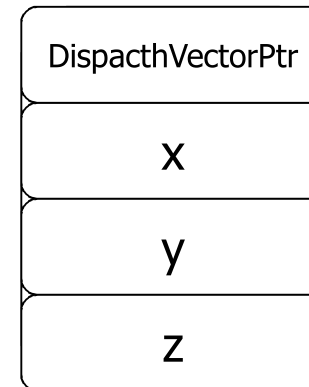
Compile time information

Object Types - Inheritance

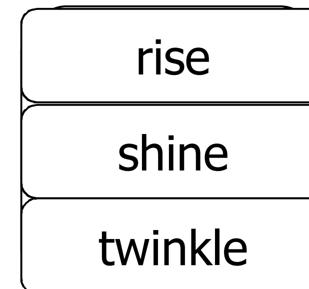
```
class Foo {
  int x;
  int y;

  void rise() {…}
  void shine() {…}
}

class Bar extends Foo{
  int z;
  void twinkle() {…}
}
```



Runtime memory layout for object of class Bar



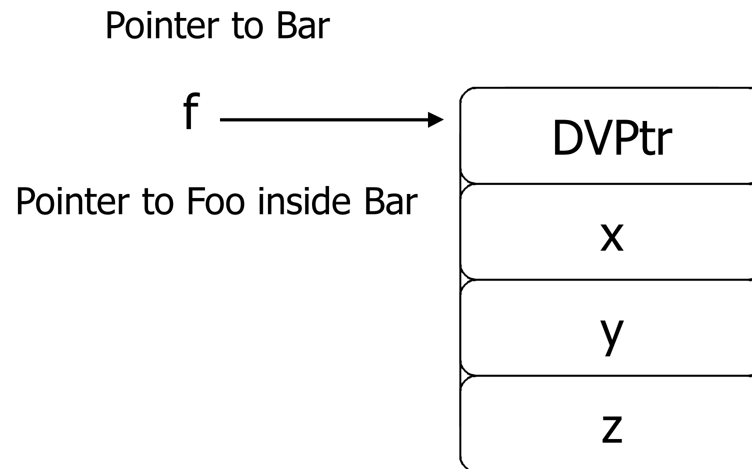
Compile time information

Object Types - Polymorphism

```
class Foo {
  …
  void rise() {…}
  void shine() {…}
}

class Bar extends Foo{
  …
}

class Main {
  void main() {
    Foo f = new Bar();
    f.rise();
}
```



Runtime memory layout for object of class Bar

Dynamic Binding

```
class Foo {
  …
  void rise() {…}
  void shine() {…}
}
```

```
class Main {
  void main() {
    Foo f = new Bar();
    f.rise();
}
```

```
class Bar extends Foo{
  void rise() {…}
}
```

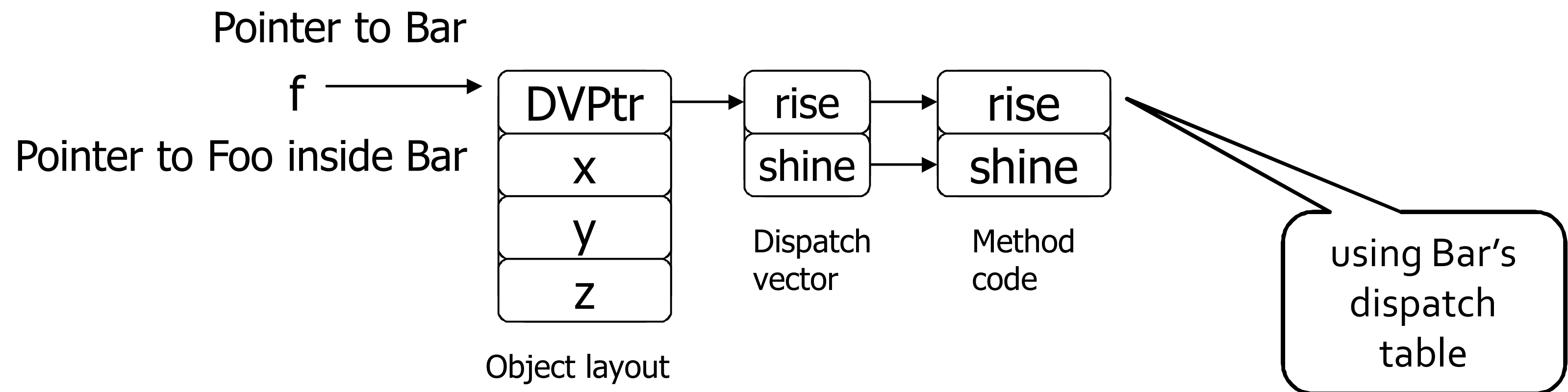
- Finding the right method implementation
- Done at runtime according to object type
- Using the Dispatch Vector (a.k.a. Dispatch Table)

Dispatch Vectors in Depth

```
class Foo {
  …
  void rise() {…}  0
  void shine() {…}  1
}
```

```
class Bar extends Foo{
  void rise() {…} 0
}
```

```
class Main {
  void main() {
    Foo f = new Bar();
    f.rise();
}
```



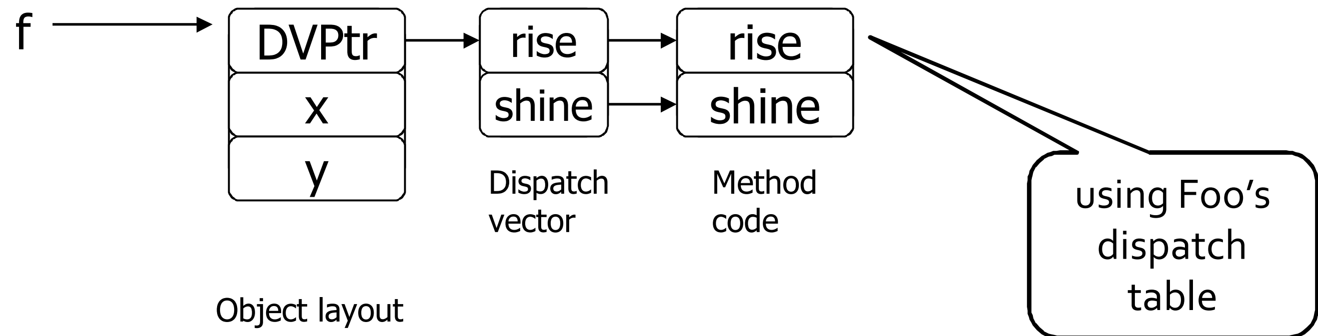
- Vector contains addresses of methods
- Indexed by method-id number
- A method signature has the same id number for all subclasses

Dispatch Vectors in Depth

```
class Foo {
  …
  void rise() {…}  0
  void shine() {…}  1
}
```

```
class Bar extends Foo{
  void rise() {…} 0
}
```

```
class Main {
  void main() {
    Foo f = new Foo();
    f.rise();
}
```



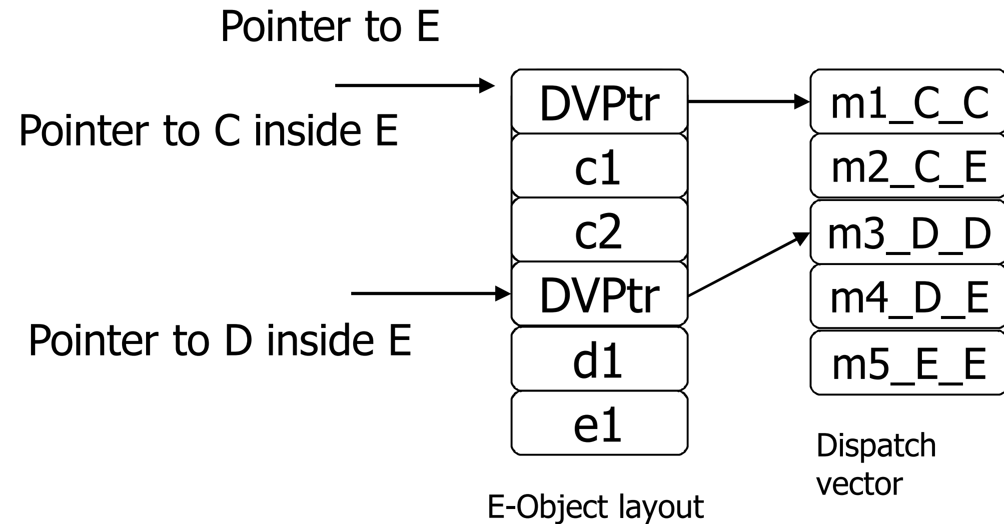
Representing dispatch tables

```
class A {
  void rise() {…}
  void shine() {…}
  static void foo()
{…}
}
class B extends A {
  void rise() {…}
  void shine() {…}
  void twinkle() {…}
}
```

```
# data section
.data
  .align 4
_DV_A:
  .long _A_rise
  .long _A_shine
_DV_B:
  .long _B_rise
  .long _B_shine
  .long _B_twinkle
```

Multiple Inheritance

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



supertyping
convert_ptr_to_E_to_ptr_to_C(e) = e
convert_ptr_to_E_to_ptr_to_D(e) = e + sizeof (class C)

subtyping
convert_ptr_to_C_to_ptr_to_E(e) = c
convert_ptr_to_D_to_ptr_to_E(e) = e - sizeof (class C)

Runtime checks

- generate code for checking attempted illegal operations
  - Null pointer check
    - MoveField, MoveArray, ArrayLength, VirtualCall
    - Reference arguments to library functions should not be null
  - Array bounds check
  - Array allocation size check
  - Division by zero
  - …

- If check fails jump to error handler code that prints a message and gracefully exists program

Null pointer check

```
# null pointer check
cmp $0,%eax
je labelNPE
```

Single generated handler for entire program

```
labelNPE:
   push $strNPE      # error message
   call __println
   push $1           # error code
   call __exit
```

Array bounds check

```
# array bounds check
mov -4(%eax),%ebx   # ebx = length
mov $0,%ecx         # ecx = index
cmp %ecx,%ebx
jle labelABE        # ebx <= ecx ?
cmp $0,%ecx
jl  labelABE        # ecx < 0 ?
```

Single generated handler for entire program

```
labelABE:
    push $strABE    # error message
    call __println
    push $1         # error code
    call __exit
```

Array allocation size check

```
# array size check
 cmp $0,%eax        # eax == array size
 jle labelASE       # eax <= 0 ?
```

Single generated handler for entire program

```
 labelASE:
     push $strASE  # error message
     call __println
     push $1       # error code
     call __exit
```

Automatic Memory Management

- automatically free memory when it is no longer needed
- not limited to OO programs, we show it here because it is prevalent in OO languages such as Java
  - also in functional languages
- approximate reasoning about object liveness
- use reachability to approximate liveness
- assume reachable objects are live
  - non-reachable objects are dead

- Three classical garbage collection techniques
  - reference counting
  - mark and sweep
  - copying

GC using Reference Counting

- add a reference-count field to every object
  - how many references point to it
- when (rc==0) the object is non reachable
  - non reachable => dead
  - can be collected (deallocated)

Managing Reference Counts

- Each object has a reference count o.RC
- A newly allocated object o gets o.RC = 1
  - why?

- write-barrier for reference updates

```
update(x,old,new) {
  old.RC--;
  new.RC++;
  if (old.RC == 0) collect(old);
}
```

- collect(old) will decrement RC for all children and recursively collect objects whose RC reached 0.

Cycles!

- cannot identify non-reachable cycles
  - reference counts for nodes on the cycle will never decrement to 0
- several approaches for dealing with cycles
  - ignore
  - periodically invoke a tracing algorithm to collect cycles
  - specialized algorithms for collecting cycles

GC Using Mark & Sweep

- Marking phase
  - mark roots
  - trace all objects transitively reachable from roots
  - mark every traversed object

- Sweep phase
  - scan all objects in the heap
  - collect all unmarked objects

GC Using Mark & Sweep

```
mark_sweep() {
  for Ptr in Roots mark(Ptr)
  sweep()
}
```

```
mark(Obj) {
  if mark_bit(Obj) == unmarked {
    mark_bit(Obj)=marked
    for C in Children(Obj) mark(C)
  }
}
```

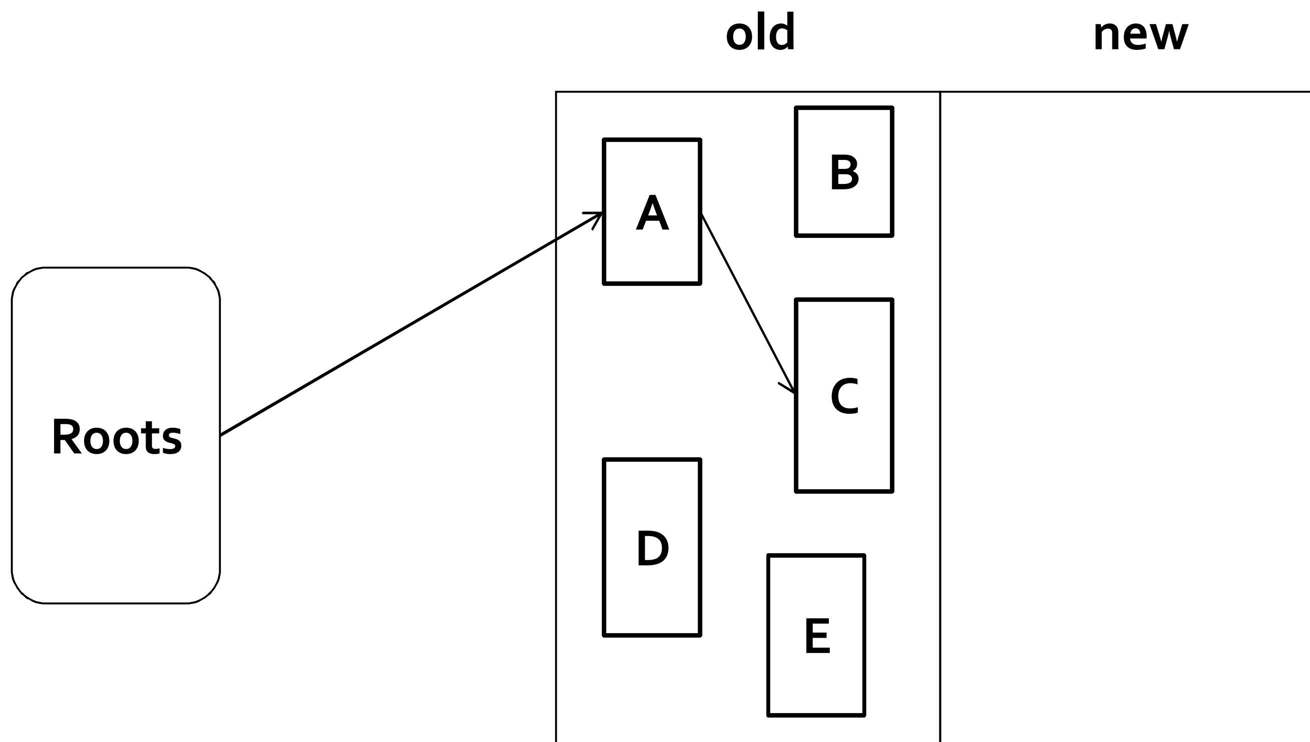
```
Sweep() {
  p = Heap_bottom
  while (p < Heap_top)
    if (mark_bit(p) == unmarked) then free(p)
      else mark_bit(p) = unmarked;
    p=p+size(p)
}
```

Copying GC

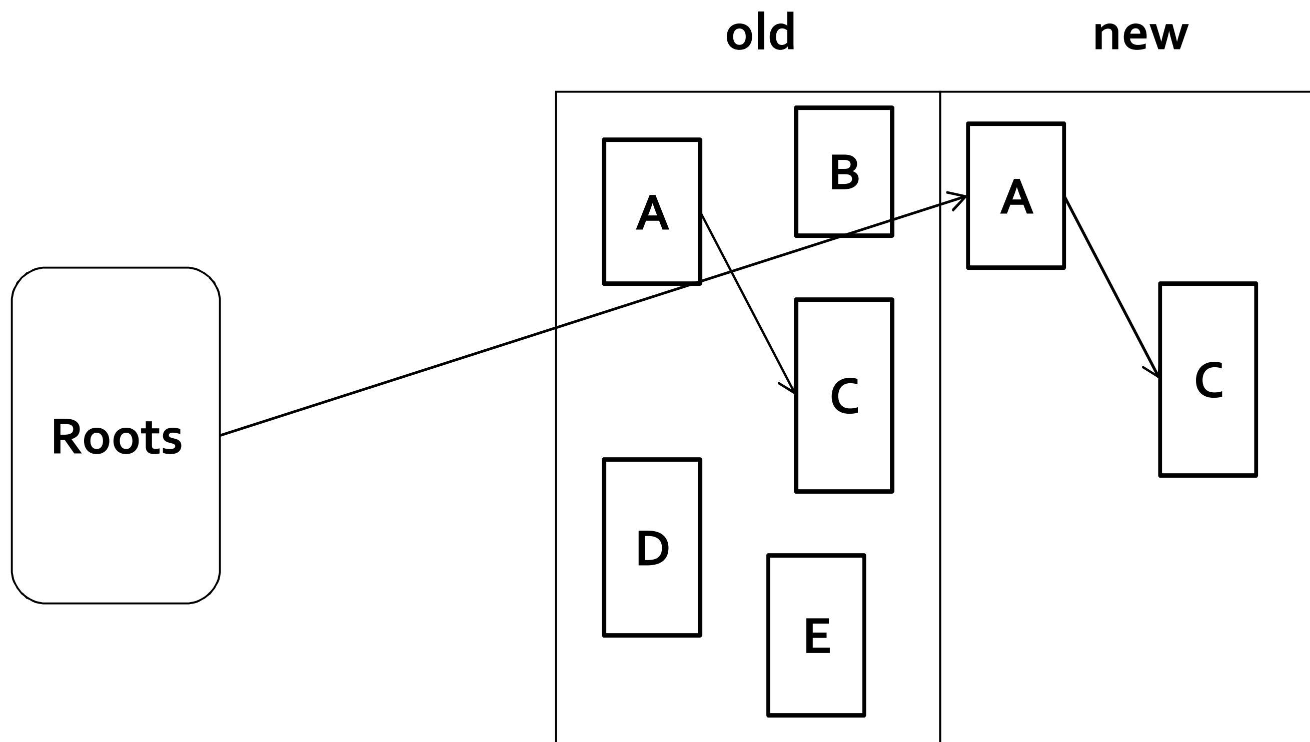
- partition the heap into two parts: old space, new space

- GC
  - copy all reachable objects from old space to new space
  - swap roles of old/new space

Example



Example



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