Tracing sharing and immutability in OO languages

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joint work with Tim Richter (Univ. Potsdam), Marco Servetto (Victoria Univ. of Wellington) and Elena Zucca (Univ. Genova)

HVL, Bergen, 16 August 2018

Outline

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- Design of imperative (object oriented) programming languages[1]

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- particularly important in the concurrent/multithreaded case in which the "heap" containing objects is shared by threads
- hence: interest in type systems which statically detect (and control) sharing and mutation

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Simplified Java syntax

e	$::=$		expression
		x	variable
		$\mid e.f$	field access
		$\mid e.m(e_1, \ldots, e_n)$	method call
		$\mid e.f{=}e'$	field assignment
		$\mid$ **new** $C(e_1, \ldots, e_n)$	object creation
		$\mid \{T_1\ x_1{=}e_1; \ldots\ T_n\ x_n{=}e_n;\ e\}$	block
T	$::=$	$C \mid$ **int** $\mid \ldots$	type
md	$::=$	$T\ m(T'_1\ y_1, \ldots, T'_k\ y_k)\{T_1\ x_1{=}e_1; \ldots\ T_n\ x_n{=}e_n;\ e\}$	method definition
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We assume classes have a constructor initialising all their fields:

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in the examples we sometimes omit the outermost block.

Sharing between variables

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class B { C f; }
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C y = new C(0);
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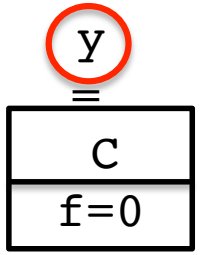

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class B { C f; }     class C { int f;}
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C y = new C(0); B x= new B(y);
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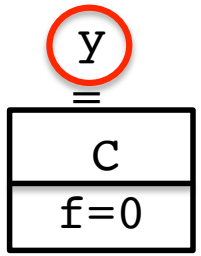

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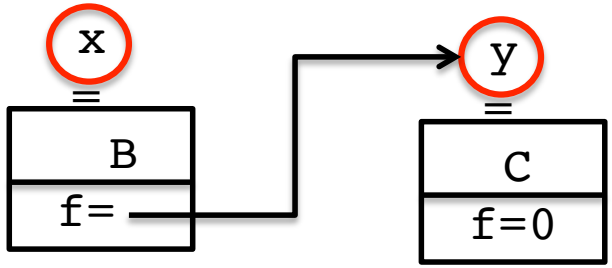

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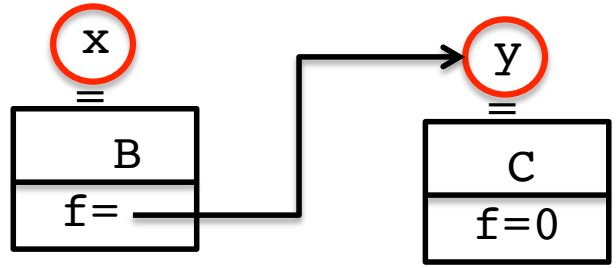


```
y.f = 5; // modifies also x.f.f
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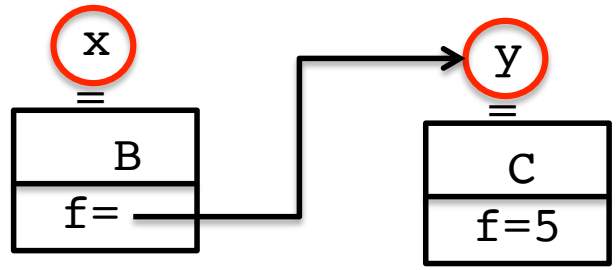

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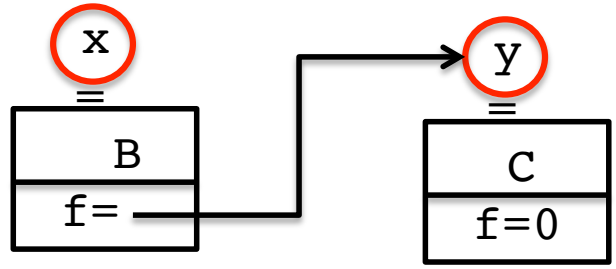


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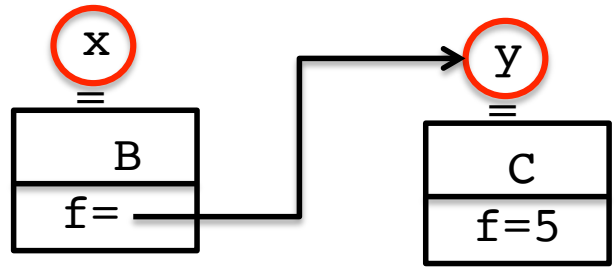


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x.f.f = 3; // modifies also y.f
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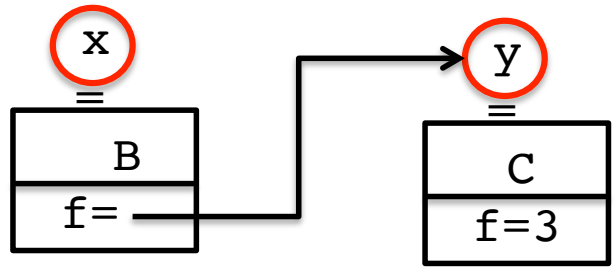

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In the following nodes in red refer to mutable references in green to immmutable references and in blu to unique/capsule references.

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 D m(C z1){C x = new C(1); C y = new C(2);  new D(x,y,z1);}
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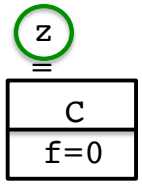

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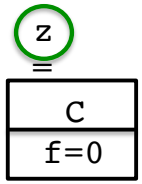

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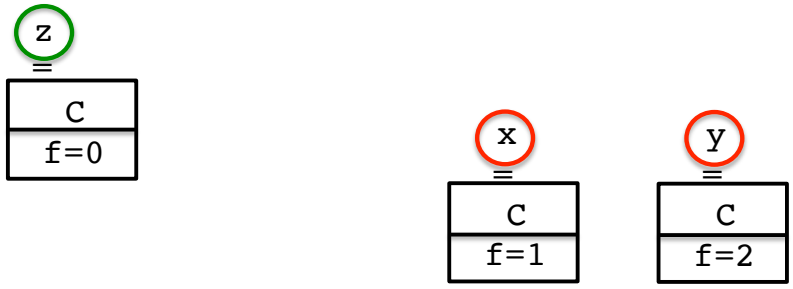

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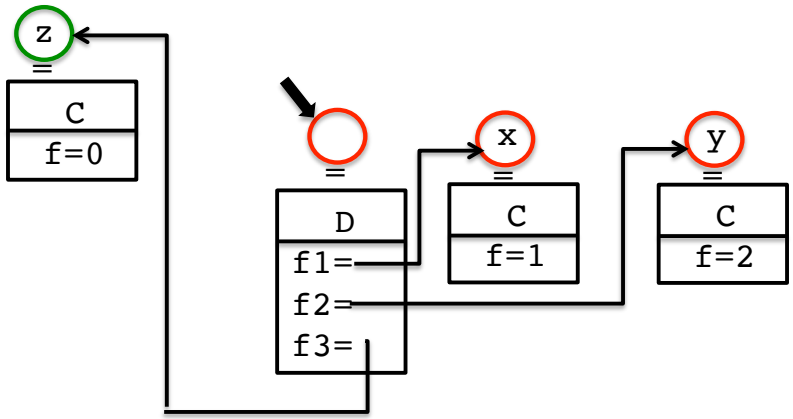

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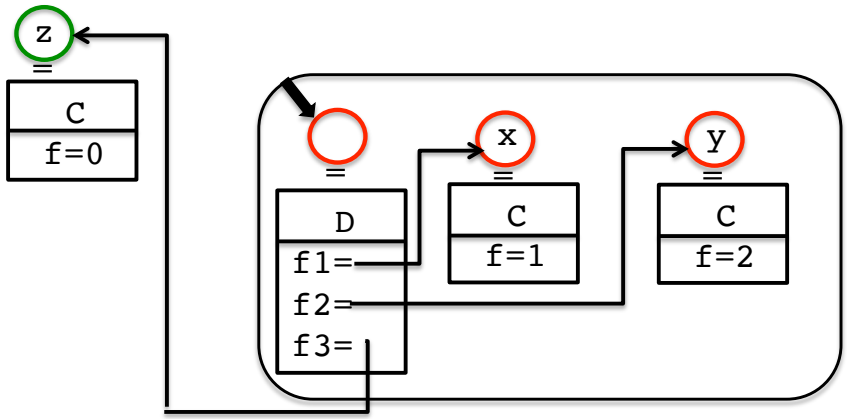

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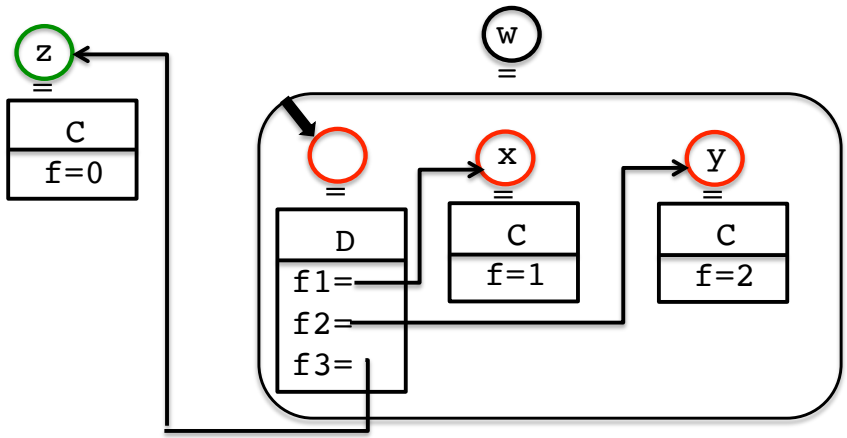

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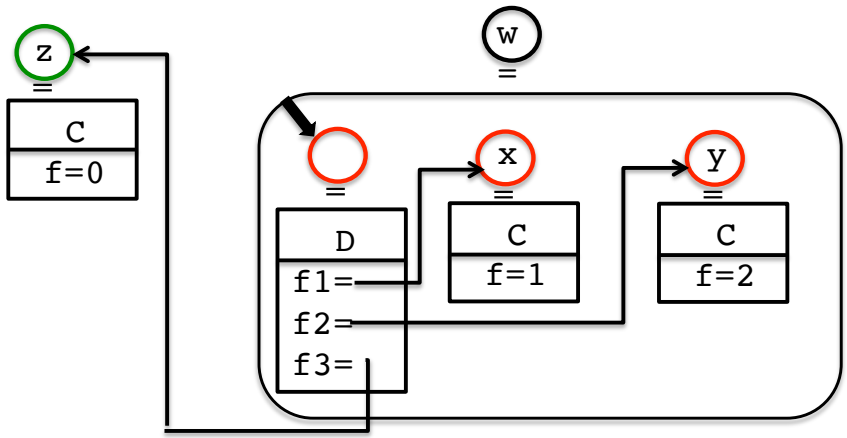

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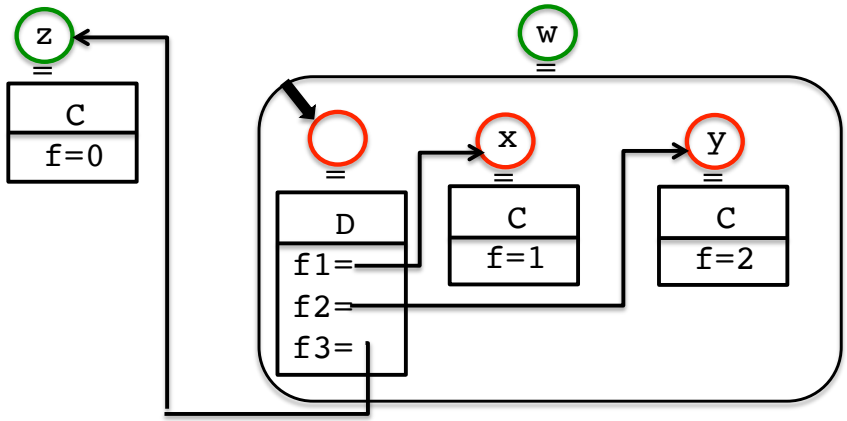

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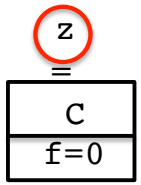

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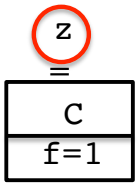

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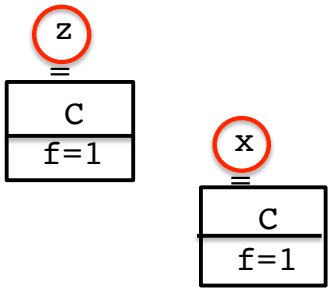

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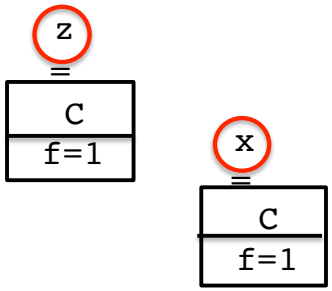

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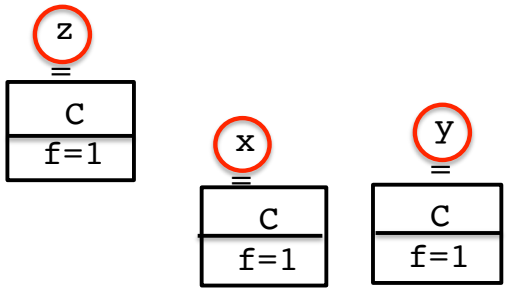

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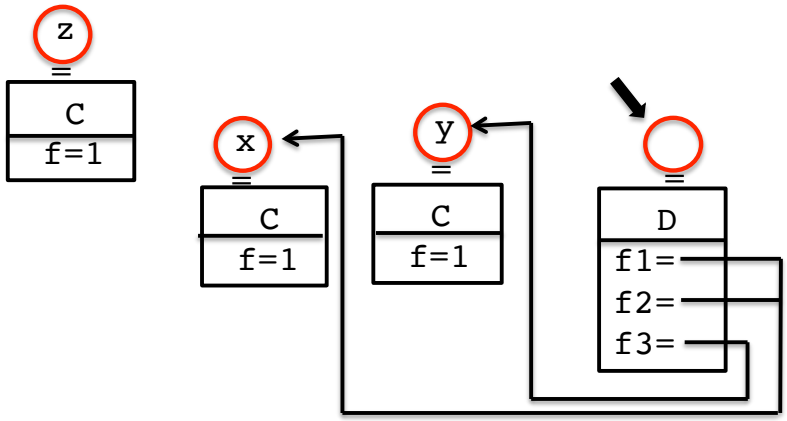

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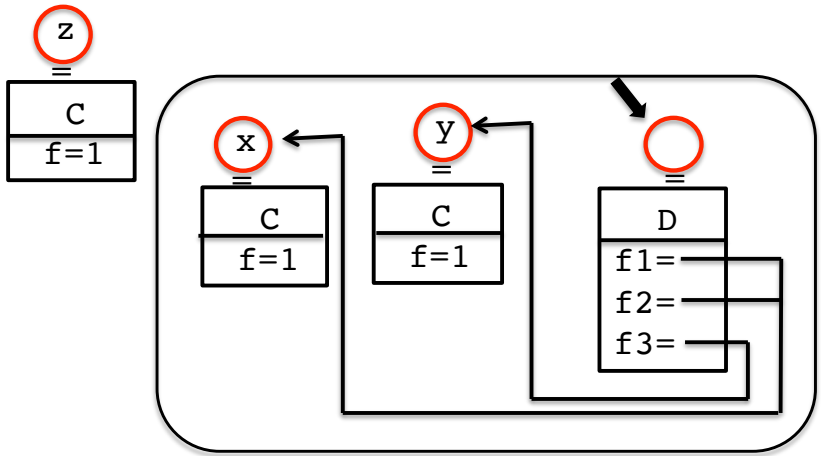

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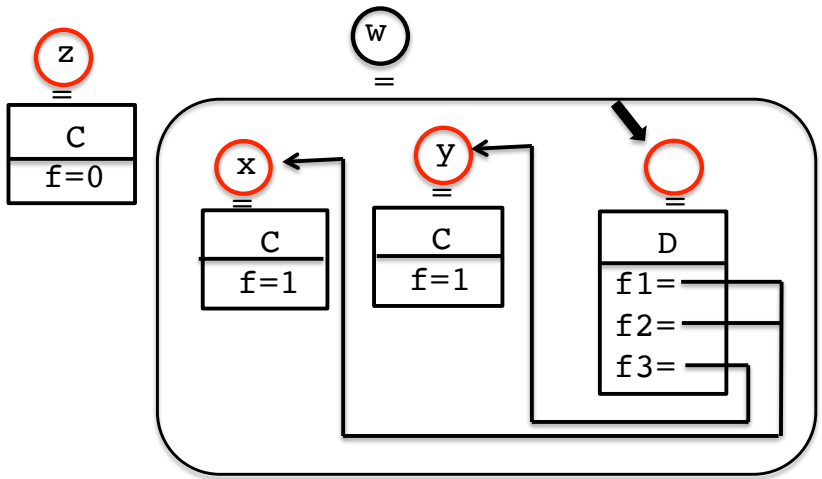

Since `w` is not connected to any mutable reference, then `w` is a capsule

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 C f1; C f2; C f3;
 D m(C z1){C x=new C(z1.f=z1.f+1); C y=new C(z1.f);  new D(x,x,y);}
}
```
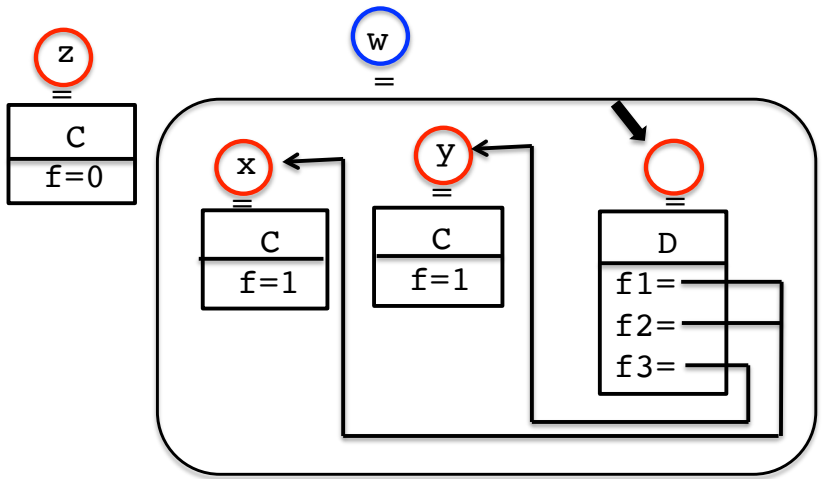

```
C z = new C(0);
D w = {C x=new C(1);C y=new C(1); new D(x,x,y)}
```



Since `w` is not connected to any mutable reference, then `w` is a capsule

Not a capsule

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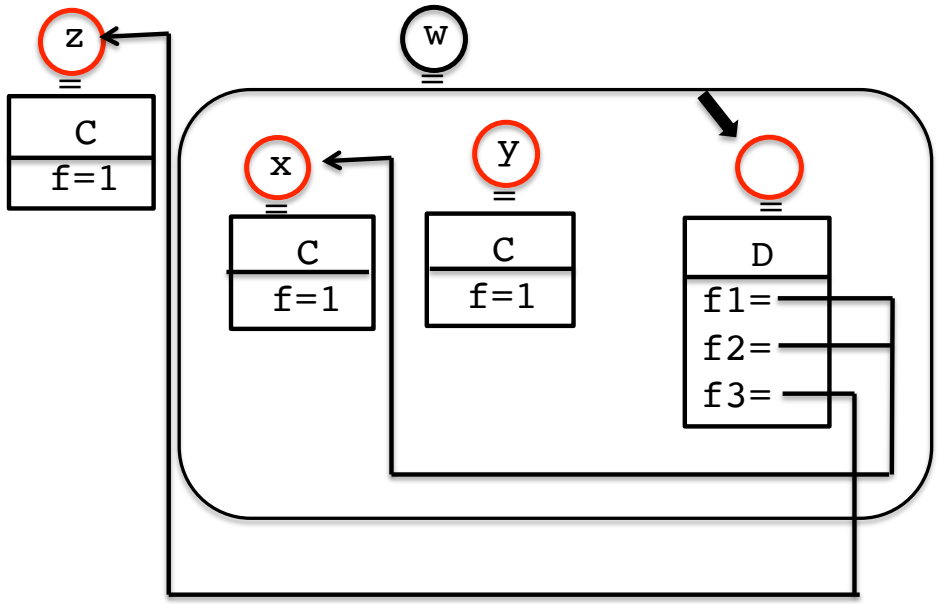

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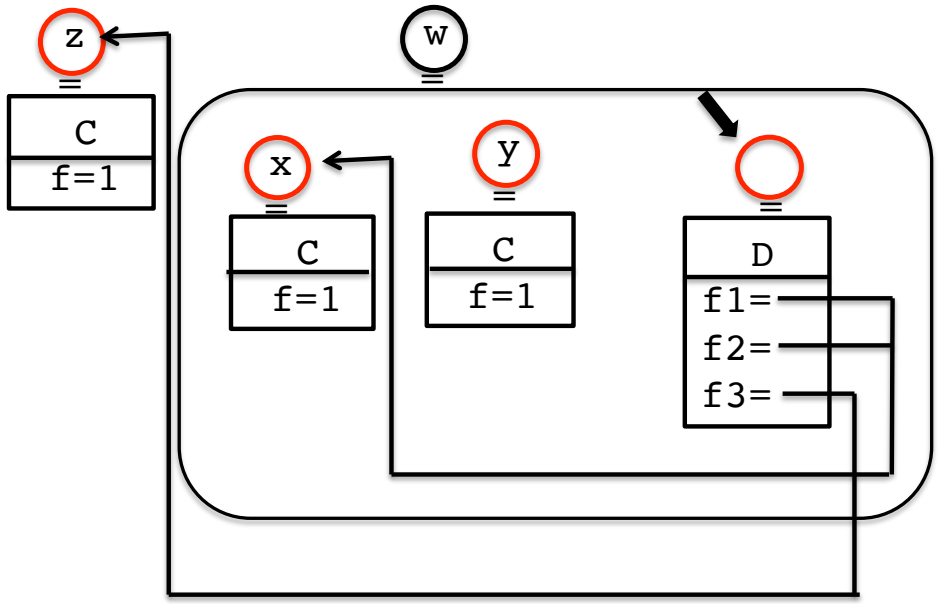

The reference `w` is connected to a mutable reference!

The reference `w` is just a mutable reference

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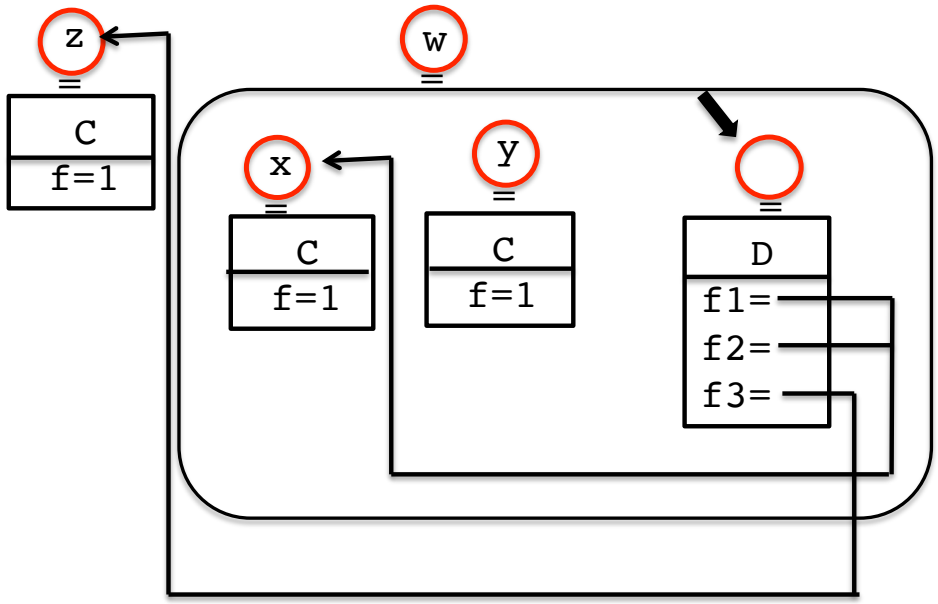
C z = new C(0);
D w = m(z);
z.f = 7;    // modifies w.f3
```



Outline

Our proposal: static checks via a type and effect system

- enrich types with type modifiers
- define syntax directed rules that
  1. infer sharing (possibly) introduced by the evaluation of an expression
  2. enforce the restriction that only objects referred to by mutable references can be mutated
  3. check that unique references refers to capsules

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$$\textbf{caps} \leq \textbf{mut} \leq \textbf{read} \qquad \textbf{caps} \leq \textbf{imm} \leq \textbf{read}$$

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  evaluation of e returns a reference in sharing with x

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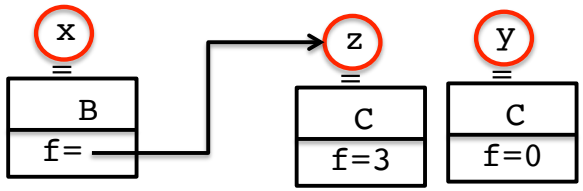

`{x,z},{y}`

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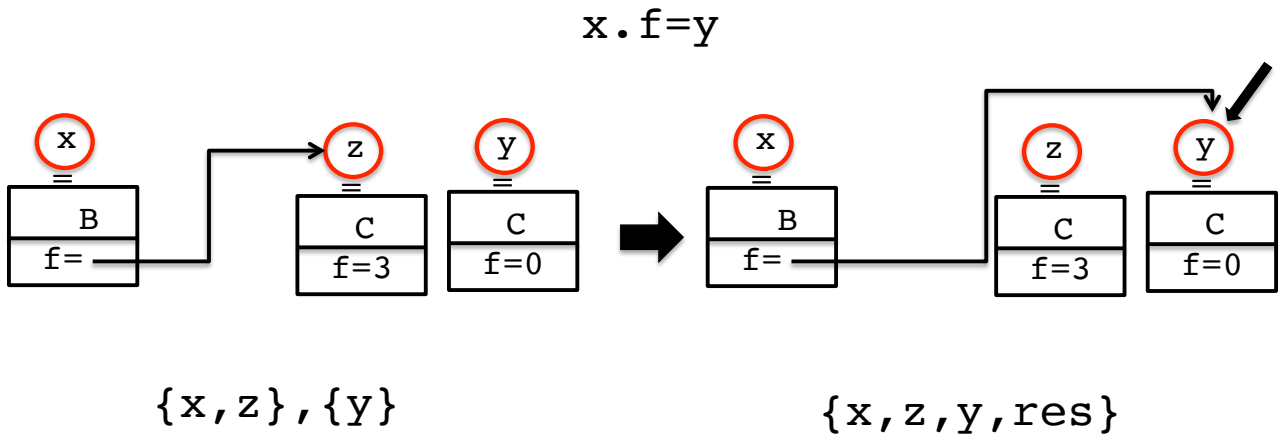

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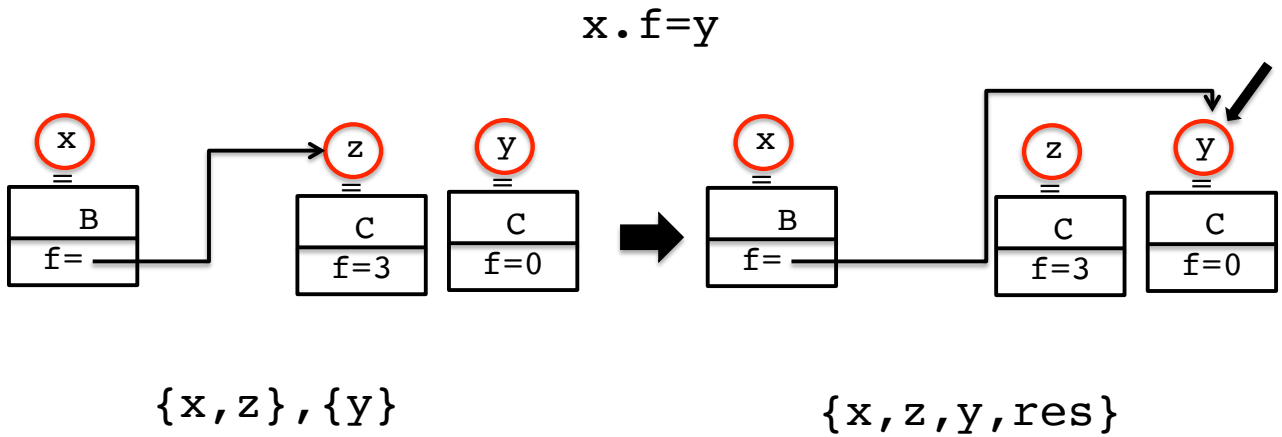

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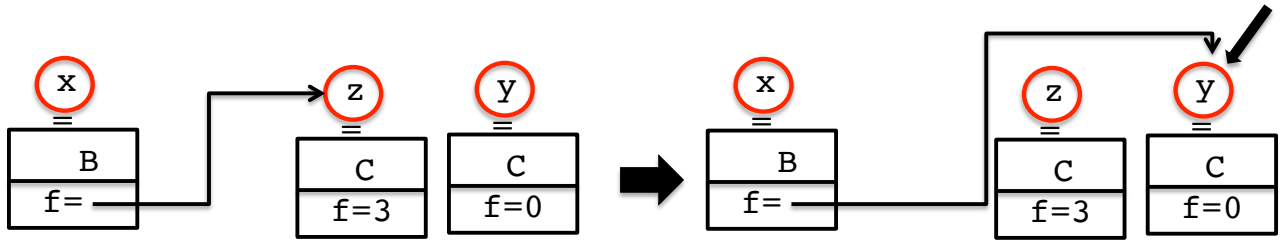
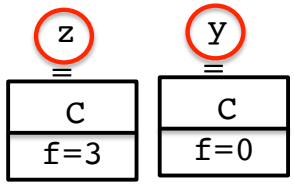



```
{x,z},{y}
```

```
{x,z,y,res}
```

- object creation

```
new D(z,y)
```

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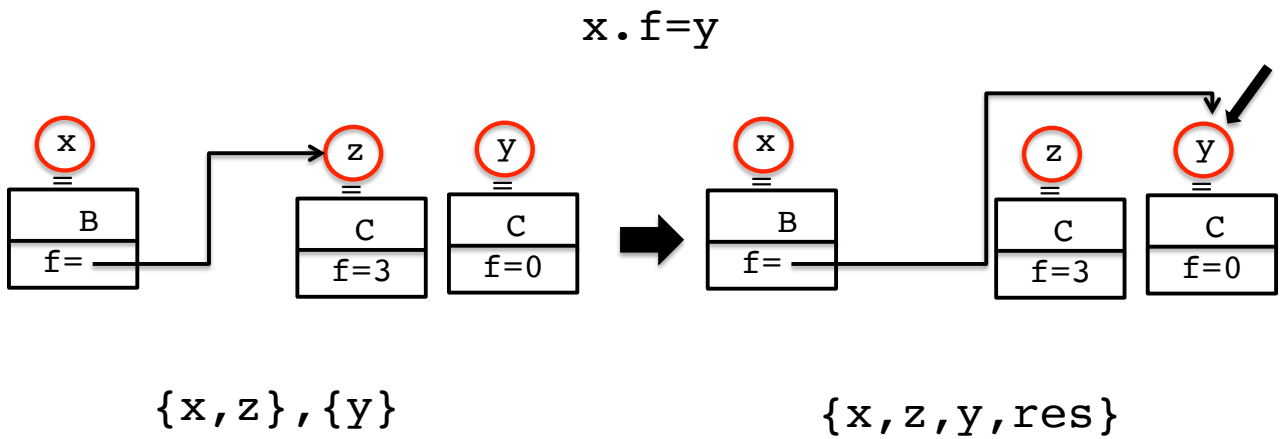

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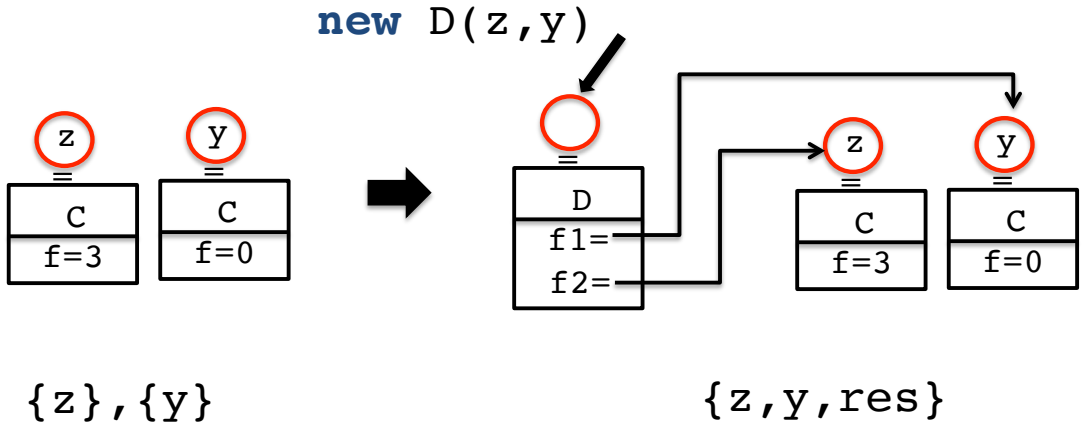

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Outline

Programming examples

modifier of `this` in violet

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```
class List { ...

 caps List deepcopy(read)/*{this},{res}*/{ ... }

 mut List concat (mut, read List other)
    /*{this,res,other}*/{ ... }

 caps List concatcopy (read, read List other)
  /*{this},{res},{other}*/{ ... }
 }
```

Programming examples

```
class IntListReader {
  static caps IntList readIntList (mut Scanner s) /*{s},{res}*/{
    mut IntList list=new IntList()
    while(s.hasNextNum()){
      list.addInt(s.nextNum())
    }
    return list// capsule recovery
  }
}

class Scanner { ...
  boolean hasNextNum (read)
  int nextNum (mut)
}
```

Programming examples

```
class IntListReader {...//as before
  static  caps IntList update(caps IntList old, mut Scanner s)
  /*{s},{res}*/ {
    mut IntList list=old//we open the capsule 'old'
    while(s.hasNextNum()){
      list.addInt(s.nextNum())
    }
    return list
  }
}
```

Programming examples

```
class Person{
  private mut PersonList friends;
  read PersonList readFriends (read)/*{this,res}*/{
    return this.friends;
  }
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two getter methods with different type annotations:

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two getter methods with different type annotations:

`p.readFriends()` can be invoked on any `p`, **`imm`** if `p` is **`imm`**

`p.getFriends()` p cannot be **`read`** or **`imm`**

Outline

(Some) related work

- (variants of) capsule property:
  isolated [Gordon et al. OOPSLA'12]
  external uniqueness [Clarke&Wrigstadt ECOOP'03]
  balloon [Almeida ECOOP'97, Servetto et al. WODET'14]
  island [Dietl et al. ECOOP'07]
- ownership: *x* is "owned" by *y*, always true, capsule notion more dynamic
- types as compositions of capabilities
  [Haller&Odersky ECOOP'10, Clebsch et al. AGERE'15,Castegren&Wrigstad ECOOP'16]
- the Rust language `rust-lang.org`
- the Pony language `ponylang.org`

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- very expressive
- we have a formalisation in Coq of the typing and the evaluation (modelling sharing relations is the most challenging part and is still not completely satisfying)
- we have proved the correctness of the dynamic semantics of our syntactic model for an imperative OO language w.r.t. the standard semantics of imperative calculi relying on a global memory

Future work

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- (short term) handle lent (borrowed) references
  = the reachable graph can be manipulated, but not shared, by a client
- (long term) investigate (a form of) Hoare logic on top of our model

References


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Thanks