Aliasing control in an imperative pure calculus

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- imperative object calculus with two modifiers for aliasing control
- a `lent` reference cannot introduce aliasing
  between the denoted portion of store [reachable object graph] and others
  cannot be used in assignment and as constructor arguments
- a `capsule` reference denote an isolated portion of store [reachable object graph]
  unique entry point is the `capsule` reference itself

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Novelties

1. expressivity enhanced by promotion and swapping rules

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2. execution model as pure calculus
   - no memory, just rewriting source code
   - object graphs are represented at the syntactic level

1. Execution model
2. Type system
3. Examples
4. Conclusion

Syntax

convention: *ds* is a sequence of *d*

Java-like flavour is matter of taste

cd	$::=$	$\texttt{class}\ C\ \{fds\ mds\}$	class declaration
fd	$::=$	$C\ f$	field declaration
md	$::=$	$T\ m\ \mu\ (T_1\,x_1,\ldots,T_n\,x_n)\ \{\texttt{return}\ e\}$	method declaration
e	$::=$	$x \mid e.f \mid e.m(es) \mid e.f = e' \mid \texttt{new}\ C(es) \mid (ds\ e)$	expression
d	$::=$	$T\ x = e$	variable declaration
T	$::=$	$\mu\ C$	type
μ	$::=$	$\texttt{capsule} \mid \texttt{lent} \mid \epsilon$	optional type modifier

Traditional imperative model

- $\langle e, \mu \rangle \longrightarrow \langle e', \mu' \rangle$
- μ memory or store
- map from locations into storable values
- locations are a runtime notion and memory is flat
- variables are a language notion and obey scoping rules (shadowing) and α-conversion

Our model

- $e \longrightarrow e'$
- key idea: the block construct, introducing local variable declarations, plays the role of store when such declarations have been evaluated

An example

```
class D { int f; ...}
class C { D f1; D f2; ...}
```

```
D z=new D(0)
C x=new C(z,z)
C y=x
D w=new D(y.f1.f+1)
x.f2=w
x
```

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C x=new C(z,z)          C x=new C(z,z)
D w=new D( 0+1 )  ⟶    D w=new D(1)
x.f2=w                  x.f2=w
x                       x
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```
D z=new D(0)
C x=new C(z,w)
D w=new D(1)
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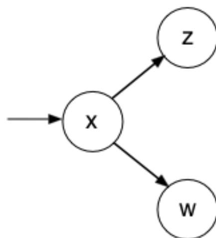
```

Final result

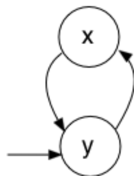



```
D z=new D(0)
C x=new C(z,w)
D w=new D(1)
x
```

Store can be recursive

```
class B { B f; ...}
```

```
B x= new B(y)
B y= new B(x)
y
```



Store can be hierarchical

```
D z= new D(0)
A w= (
   B x= new B(y)
   B y= new B(x)
   A u= new A(x,z)
   u )
w
```

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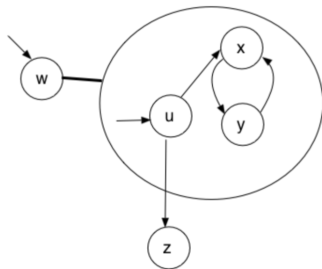


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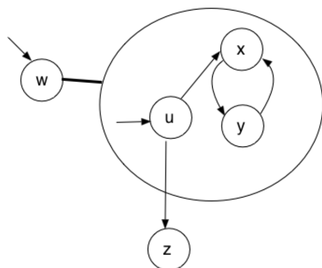


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```

Advantage: constraints about aliasing are modeled at the syntax level, notably

- the object denoted by `y` can only be reached through `w`: the block construct
- the object denoted by `w` is not isolated: the block has free variables

Types and type contexts

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μ	$::=$	$\texttt{capsule} \mid \texttt{lent} \mid \epsilon$	optional type modifier
Δ	$::=$	$\Gamma; xss$	type context
Γ	$::=$	$T_1\,x_1 \ldots T_n\,x_n$	type assignment

C with no modifier = standard type

Subtyping relation

$$\texttt{capsule}\, C \leq\ C \leq \texttt{lent}\, C$$

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$$\texttt{capsule}\ C \quad \overset{\textit{promotion}}{\Longleftarrow} \quad C$$

promotion can be used against the subtype hierarchy

Typing judgment

$$\Gamma; xs_1 \ldots xs_n \vdash e : T$$

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a group of lent-locked variables is introduced by promotion
a group can be unlocked by swapping

Typing rules (1)

$$(\text{T-PROM})\quad \frac{\Gamma; \mathit{xss}\ \mathit{xs} \vdash e :\ C}{\Gamma; \mathit{xss} \vdash e : \texttt{capsule}\ C} \quad \mathit{xs} = \texttt{dom}^{\texttt{std}}(\Gamma) \backslash \mathit{xss}$$

$$(\text{T-SWAP})\quad \frac{\Gamma; \mathit{xss}\ \mathit{xs}' \vdash e : \mu\ C}{\Gamma; \mathit{xss}\ \mathit{xs} \vdash e : \mu'\ C} \quad \begin{array}{l} \mathit{xs}' = \texttt{dom}^{\texttt{std}}(\Gamma) \backslash (\mathit{xss}\ \mathit{xs}) \\ \mu' = \begin{cases} \texttt{lent} & \text{if } \mu = \epsilon \\ \mu & \text{otherwise} \end{cases} \end{array}$$

Typing rules (2)

$$(\text{T-SUB})\quad \frac{\Delta \vdash e : T}{\Delta \vdash e : T'} \quad T \leq T'$$

$$(\text{T-VAR})\quad \frac{}{\Gamma; xss \vdash x : \mu'\, C} \quad \begin{array}{l} \Gamma(x) = \mu\, C \\ \mu' = \begin{cases} \texttt{lent} & \text{if } x \in xss \\ \mu & \text{otherwise} \end{cases} \end{array}$$

Typing rules (3)

$$(\textsc{t-field-access})\quad \frac{\Delta \vdash e : \mu\, C}{\Delta \vdash e.f : \mu\, C_i} \quad \begin{array}{l}\texttt{fields}(C) = C_1\ f_1 \ldots C_n\ f_n\\ f = f_i\end{array}$$

$$(\textsc{t-meth-call})\quad \frac{\Delta \vdash e_i : T_i \quad \forall i \in 0..n}{\Delta \vdash e_0.m(e_1, \ldots, e_n) : T} \quad \begin{array}{l}T_0 = \mu\, C\\ \texttt{mtype}(C, m) = \langle T, \mu, T_1 \ldots T_n\rangle\end{array}$$

$$(\textsc{t-field-assign})\quad \frac{\Delta \vdash e : C \quad \Delta \vdash e' : C_i}{\Delta \vdash e.f = e' : C_i} \quad \begin{array}{l}\texttt{fields}(C) = C_1\ f_1 \ldots C_n\ f_n\\ f = f_i\end{array}$$

$$(\textsc{t-new})\quad \frac{\Delta \vdash e_i : C_i \quad \forall i \in 1..n}{\Delta \vdash \texttt{new}\ C(e_1, \ldots, e_n) : C} \quad \texttt{fields}(C) = C_1\ f_1 \ldots C_n\ f_n$$

$$(\textsc{t-block})\quad \frac{\Gamma[\Gamma']; xss \vdash e_i : T_i\ \forall i \in 1..n \quad \Gamma[\Gamma']; xss \vdash e : T}{\Gamma; xss \vdash (T_1\ x_1 = e_1 \ldots T_n\ x_n = e_n\ e) : T} \quad \Gamma' = T_1\, x_1 \ldots T_n\, x_n$$

Promotion

How to introduce a `capsule`?

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D z= new D(0)
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capsule C x= (               capsule C x= (
  D y= new D(z.f+1)   -->*     D y= new D(1)
  new C(y,y) )                 new C(y,y) )
x                            x
```

Counterexample

```
D z= new D(0)
capsule C x= (   //ill-typed
  D y= z
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$\longrightarrow$

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x
```

Swapping

How to modify (the object denoted by) a `lent` reference?

```
lent D z= new D(0)
z.f=z.f+1
```

the singleton group `z` is swapped with the empty set

Swapping to achieve promotion

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Swapping to achieve promotion

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  D y= new D(z.f=z.f+1)
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x
```

$\longrightarrow^{\star}$

```
D z= new D(1)
capsule C x= (
  D y= new D(1)
  new C(y,y) )
x
```

A programming example

Example input file:

```
Bob
1 500 2 1300
Mark
42 8 99 100
```

Can we use a conventional Java Scanner to read the file and obtain new data as `capsule`?

```
class Reader {
  static capsule Customer readCustomer(lent Scanner s){
    Customer c=new Customer(s.nextLine())
    while(s.hasNextNum() ){
      c.addShopHistory(s.nextNum())
      }
    return c //ok, capsule promotion here
    }
  }
```

A programming example

```
class Reader {...//as before
  static capsule Customer updateCustomer(
                      capsule Customer old,lent Scanner s){
    Customer c=old//capsule 'old' is opened
    while(s.hasNextNum() ){
      c.addShopHistory(s.nextNum())
      }
    return c //ok, capsule promotion here
    }
  }
```

Results

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  If $\vdash e$, and $e \longrightarrow^{\star} e'$, then either e' is a value, or $e' \longrightarrow$
- Capsule has the expected behaviour
  If $\vdash \mathcal{E}[e]$, $\Gamma = \texttt{typectx}(\mathcal{E})$,
  $\Gamma; \emptyset \vdash e : \texttt{capsule}\ C$, and $\mathcal{E}[e] \longrightarrow^{\star} \mathcal{E}'[v]$,
  then v is closed

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- further work: simplify calculus and proof technique
- express and formally verify other properties of object graphs studied in literature on ownership, e.g., immutability
- long term goal: Hoare-like logic for local reasoning, as in separation logic

Thanks