Representation Independence, Confinement and Access Control

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Class signer bug (jdk1.1)

```java
public class Class {
    private Identity[] signers; //authenticated
    public Identity[] getSigners() {
        return signers;
    }
}
public class System {
    public Identity[] getKnownSigners() {
    ...
}
}
class Bad {
    void bad() {
        Identity[] s = getSigners(); //leak
        s[0] = System.getKnownSigners()[0];
        doPrivileged("something bad");
    }
}
```
Representation independence

class A {
   private Boolean g;  // rep object
   unit init(){
      g := new Boolean();
      g.set(~true);
   }
   unit setg(bool x){
      g.set(~x);
   }
   bool getg(){
      return ~g.get();
   }
}

Example: abstraction A using representation Boolean to hold current value (or its negation).

Information hiding: type safety, visibility and scope rules ensure that clients are not dependent on encapsulated representation.

   z:= new A(); z.setg(true); b:= z.getg();
representation exposure

class A {
  private Boolean g;  // rep object
  unit init(){  g := new Boolean();
                 g.set(~true);  }
  unit setg(bool x){  g.set(~x);  }
  bool getg(){  return ~g.get();  }
  Object bad(){  return g;  }
}

Client behavior depends on representation:

  z := new A();  w := (Boolean) z.bad();
  if (w.get()) skip else diverge;
class A {
    private Boolean g; // rep object
    unit init(){ g := new Boolean();
        g.set(~true); }
    unit setg(bool x){ g.set(~x); }
    bool getg(){ return ~g.get(); }
    Object bad(){ return g; }
}

Client behavior depends on representation:
    z := new A(); w := (Boolean) z.bad();
    if (w.get()) skip else diverge;

Leaks also allow clients to violate invariants, e.g.,
"signers have all been authenticated for this class".
Contribution

Formalization of pointer confinement and proof that it ensures representation independence, for rich fragment of Java.

Client objects | Interface objects | Representations
---|---|---
C | A | Boole
D | A | Boole

allowed

disallowed
Contribution

Formalization of pointer confinement and proof that it ensures representation independence, for rich fragment of Java.

- Justify *component replacement*: in software engineering (e.g., optimizing transformations, refactoring) and in theory (e.g., abstraction in model-checking; equivalence of lazy and eager access control).

- *Modular verification*: reason about component in terms of abstract interface specification.

- Secure *information flow* and other program analyses based on abstract interpretation.
Language

- pointers to mutable objects (but no ptr. arithmetic)
- subclassing, dynamic dispatch, type-cast and -test
- class-based visibility control
- recursive types and methods
- privilege-based access control

Major omissions: exceptions, threads, class loading and reflection.
Language

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Straightforward compositional semantics:

- object state contains locations and prim. vals.
- heap maps locations to object states
- methods bound to classes, not objects
- commands denote functions

\[
\text{method-meanings} \rightarrow \text{envir} \rightarrow \text{heap} \rightarrow (\text{envir} \times \text{heap})_\perp
\]
Heap confinement for $A$, $Rep$

$\text{conf } h$ iff $h$ has admissible partition

$h = h_{\text{C}} h_{A_1} h_{\text{Rep}_1} \ldots h_{A_n} h_{\text{Rep}_n}$ with $h_{\text{C}} \not\rightarrow h_{\text{Rep}_k}$

and $h_{A_k} h_{\text{Rep}_k} \not\rightarrow h_{A_j} h_{\text{Rep}_j}$ for $k \neq j$
Confinement

- Commands and method meanings *preserve heap confinement*; corresponding conditions on expressions and environments.
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- POPL version uses restrictions on signatures, but it suffices to impose semantic condition on arguments.

- Semantic confinement can be ensured by simple syntactic checks similar to ones in literature.
Static analysis for confinement

For designated class names $A, Rep, Rep'$.

\[
\begin{align*}
C \leq A & \Rightarrow U \not\leq A \\
\Gamma; \ C \triangleright e : U & \quad C \neq A \land C \not\leq Rep \Rightarrow B \not\leq Rep \\
\Gamma; \ C \triangleright x.f := e & \quad C \leq A \lor C \leq Rep \Rightarrow B \not\leq A \\
\Gamma; \ C \triangleright x := \text{new } B( ) &
\end{align*}
\]

\[
\begin{align*}
\text{mtype}(m, D) = (\overline{x} : \overline{T}) \rightarrow T \\
C \not\leq A \land C \not\leq Rep & \Rightarrow D \not\leq A \lor \overline{T} \not\leq A \\
\Gamma; \ C \triangleright e : D & \quad \Gamma; \ C \triangleright \overline{e} : \overline{U} \quad \overline{U} \leq \overline{T} \\
\Gamma; \ C \triangleright e.m(\overline{e}) : T &
\end{align*}
\]

Soundness: sufficient condition for semantic confinement.
Basic simulation

Classes $A, Rep, Rep'$ and confined class table $CT$ with

$CT(A) = \text{class } A \text{ extends } B \{ \overline{T} \overline{g}; \overline{M} \}$

$CT'(A) = \text{class } A \text{ extends } B \{ \overline{T}' \overline{g}'; \overline{M}' \}$
**Simulation**

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Relation $R \subseteq [\text{Heap}] \times [\text{Heap}]'$ for a single pair of $A$ objects at same location $\ell$.

$$h = hA \ast hRep$$

$$h' = hA' \ast hRep'$$
Simulation

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$$h = hA * hRep$$

$$h' = hA' * hRep'$$

Induced relations $\mathcal{R} \theta$

- $\mathcal{R} T d d'$ iff $d = d'$ (primitives and client-visible loc’s)
- $\mathcal{R} \text{Heap} h h'$ iff partition with $R (hA_k * hRep_k) (hA'_k * hRep'_k)$
**Main results**

*Abstraction theorem:* Given basic simulation for confined $CT, CT'$. If every method body of $A$ preserves $\mathcal{R}(\text{envir} \times \text{Heap})_{\perp}$ then so does every command.

(Commands in both clients and subclasses of $A$.)
Main results

Abstraction theorem:
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Identity extension lemma:
Suppose $R(\text{envir} \times \text{Heap}) (\eta, h) (\eta', h')$. Then $\text{garbage-collect}((\text{rng} \eta), h) = \text{garbage-collect}((\text{rng} \eta'), h')$, if these heaps are both $A$-free.

(Can also express in terms of heap visible to clients.)
On parametricity

Simulation is made unsound by rep exposure and also by non-parametric constructs like unchecked casts, 
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Our results hold for any parametric allocator \textit{fresh}:

- \textit{loctype}(\textit{fresh}(C, h)) = C \textbf{ and } \textit{fresh}(C, h) \notin \textit{dom} h
- \textit{dom} h_1 \cap \textit{locs} C = \textit{dom} h_2 \cap \textit{locs} C' \Rightarrow \textit{fresh}(C', h_1) = \textit{fresh}(C', h_2)
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Equal heaps aren’t enough for some equivalences:
\[
x := \text{new } C();\ y := \text{new } C();
\]
\[
y := \text{new } C();\ x := \text{new } C();
\]
Because constructs are “parametric in locations”, we can maintain bijection between domains of related heaps, and drop condition on allocator.

(Nondeterministic allocator?)
Access control

Access matrix: $\mathcal{A}(\text{user}) = \{p\}$ and $\mathcal{A}(\text{sys}) = \{p,w\}$.

class Sys signer sys {
    unit writepass(String x) {
        check w; write(x,"passfile");
    }
    unit passwd(String x) {
        check p; dopriv w in writepass(x);
    }
}

class User signer user {
    Sys s ...
    unit use() { dopriv p in s.passwd("me"); }
    unit try() { dopriv w in s.writepass("me"); }
}
Confinement and security

- POPL’02: semantics extended to access control; abstraction theorem holds.

Secure information flow [Banerjee & Naumann, CSFW 2002]: label inputs and outputs as High or Low secrecy; static analysis shown sound—no High leak to Low; depends on pointer confinement.
Confinement and security

- POPL’02: semantics extended to access control; abstraction theorem holds.
- New project: using access control to ensure confinement. Rather than using class names to designate confinement, use “principals”, use access control mechanism (cf. capabilities in [Boyland ECOOP’01]).

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Conclusion

Contribution: analysis of information hiding for pointers, subclassing, etc., using simple, extensible denotational semantics.

Ongoing and future work:

- **polymorphism** (essential to avoid Object)
- proof rules for simulation (A’s methods)
- **other confinement disciplines** (e.g., unique, read-only, package); static and dynamic enforcement
- static analysis and *transformation for access control* (proved Fournet&Gordon [POPL02] equiv’s in a denotational semantics for their funct. lang.)
- extending *information flow* to declassification
Related work

This paper, with other proof cases:


A simple semantics and static analysis for Java security: http://.../tr2001.ps


D. Clarke, J. Noble, J. Potter: Simple ownership types for object containment, ECOOP’01.


J. Reynolds: Types, abstraction, and parametric polymorphism, Info. Processing ’83

Appendix: Meyer-Sieber

\[
\begin{align*}
\text{var } x &:= 0 \text{ in } P(x := x + 2); \text{ if } \text{even}(x) \text{ diverge else skip} \\
\text{var } x &:= 0 \text{ in } P(\text{skip}); \text{ diverge}
\end{align*}
\]

O-O version with closure as explicit object (with method \(x := x + 2\) or \(\text{skip}\)).
Holds because locals \(\neq\) objects and name spaces flat.
Need confinement if the integer is itself an object.
Appendix: semantic domains

\[ \theta ::= T \mid \Gamma \mid C \text{ state} \mid \text{Heap} \mid (C, (\overline{x} : \overline{T}) \rightarrow T) \mid ME_{\text{Env}} \]
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\[
\begin{align*}
[\text{bool}] &= \{T, F\} \\
[C] &= \{\text{nil}\} \cup \{\ell \in \text{Loc} \mid \text{loctype } \ell \leq C\}
\end{align*}
\]

\(\eta \in [\Gamma]\) maps each identifier \(x\) to its value \(\eta x \in [\Gamma x]\)

\(s \in [C \text{ state}]\) maps (declared\&inherited) fields to values

\(h \in [\text{Heap}]\) is partial function on \(\text{Loc}\), with \(h\ell \in [\text{(loctype } \ell) \text{ state}]\)
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\[
[C, (\overline{x} : \overline{T}) \rightarrow T] = [\overline{x} : \overline{T}, \text{this} : C] \rightarrow [\text{Heap}] \rightarrow ([T] \times [\text{Heap}])_{\perp}
\]

\( \mu \in [\text{MEnv}] \) maps each \( C, m \) to \( \mu Cm \in [C, (\overline{x} : \overline{T}) \rightarrow T] \).
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\( \mu \in [\text{MEnv}] \) maps each \( C, m \) to \( \mu Cm \in [C, (x : T) \rightarrow T] \).

\[ [\Gamma; C \vdash e : T] \in [\text{MEnv}] \rightarrow [\Gamma] \rightarrow [\text{Heap}] \rightarrow [T]_\perp \]
\[ [\Gamma; C \vdash S : \text{com}] \in [\text{MEnv}] \rightarrow [\Gamma] \rightarrow [\text{Heap}] \rightarrow ([\Gamma] \times [\text{Heap}])_\perp \]