Reasoning about modules: data refinement and simulation

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Objectives of talk

- Introduce collaborative projects with
  - Paulo Borba, *Ana Cavalcanti*, Augusto Sampaio; Federal U. of Pernambuco, Recife.
  - Uday Reddy; University of Birmingham.
  - Hongseok Yang; Korean Advanced Inst. of Sci. and Tech. (ROPAS).
  - *Anindya Banerjee*; Kansas State University.
- Survey results on simulation for data refinement.
- Suggest an approach to pointer confinement.

Outline

- project overview
- simulation for alias-free programs
- simulation and aliasing (cf. POPL talk)
- confinement and patterns
- sidelights

Refinement calculus for OOP

Specification statements: $x : [pre, post]$ modifies "only x" and establishes $post$ if pre initially; else aborts.
Assertion: $\emptyset : [P, true]$.
Assumption: $\emptyset : [true, P]$.
Correctness: $x : [pre, post] \sqsubseteq prog$

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Applications:

- Formalize stepw ise development (to guide semi-informal methodology or etc.).
  Proof rules as refinement laws, e.g.,
  $x, y : [pre, post] \sqsubseteq x : [pre, mid];\ y : [mid, post]$
- Specifications, esp. design patterns with callbacks.
- Normal-form compilation.

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- Compiler status: normal form and VM defined. . .
- Design laws: unnesting etc., *complete* for rewriting to imperative normal form where classes are used only for type tagging and testing [BS01].

Class refinement

```
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(); } }
```

Equivalent or refined behavior for all clients, e.g.

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

if ~(pt instanceof ColorPt) skip else abort
```

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- Soundness of healthy forward simulation for class refinement (private fields) [CN01].

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- $[\![x : [pre, post]]\!]\psi = pre \wedge \forall x \bullet post \Rightarrow \psi$
- A solution: object invariant, choices among satisfying values.

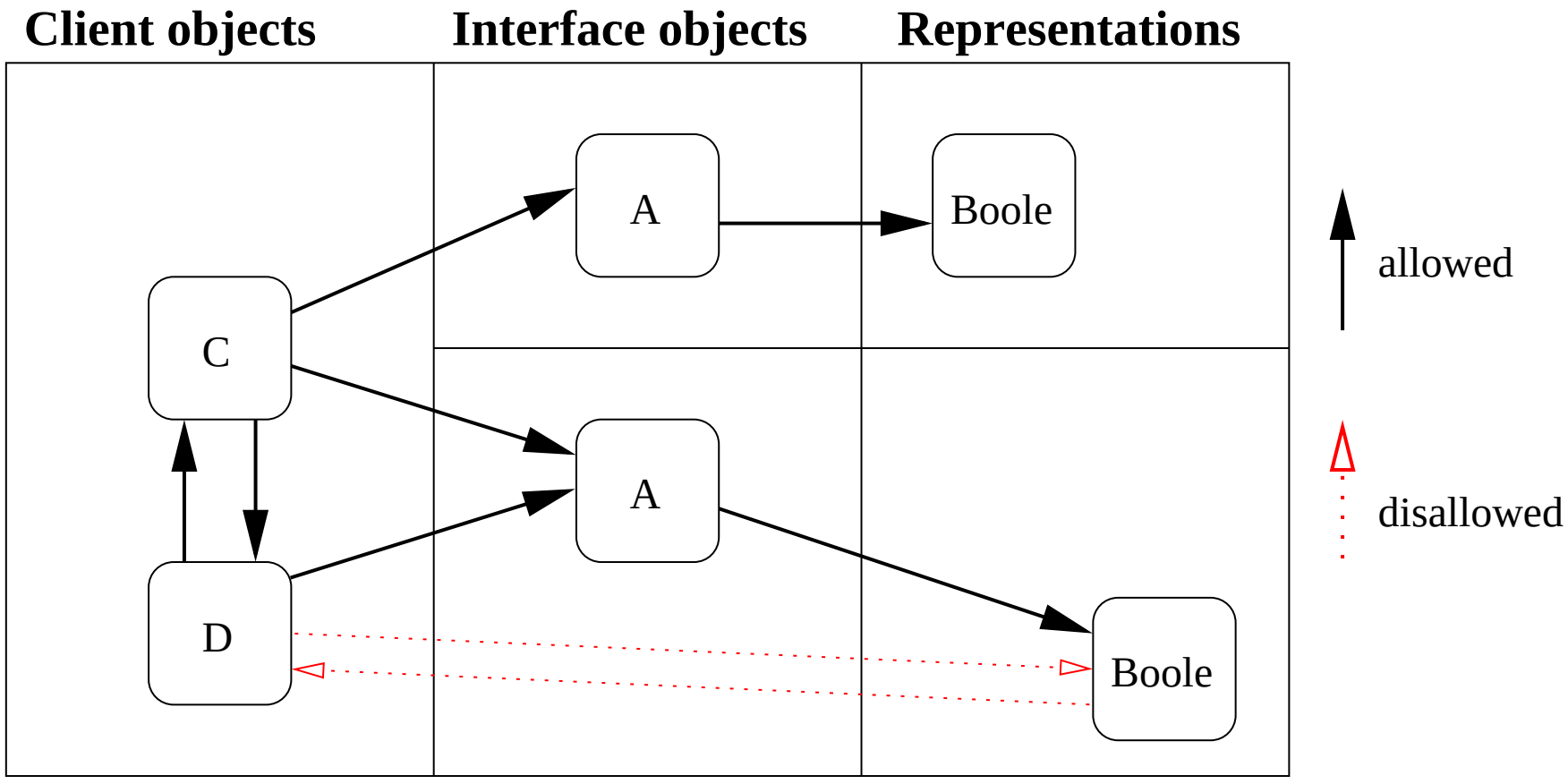
Representation exposure

```
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;
```

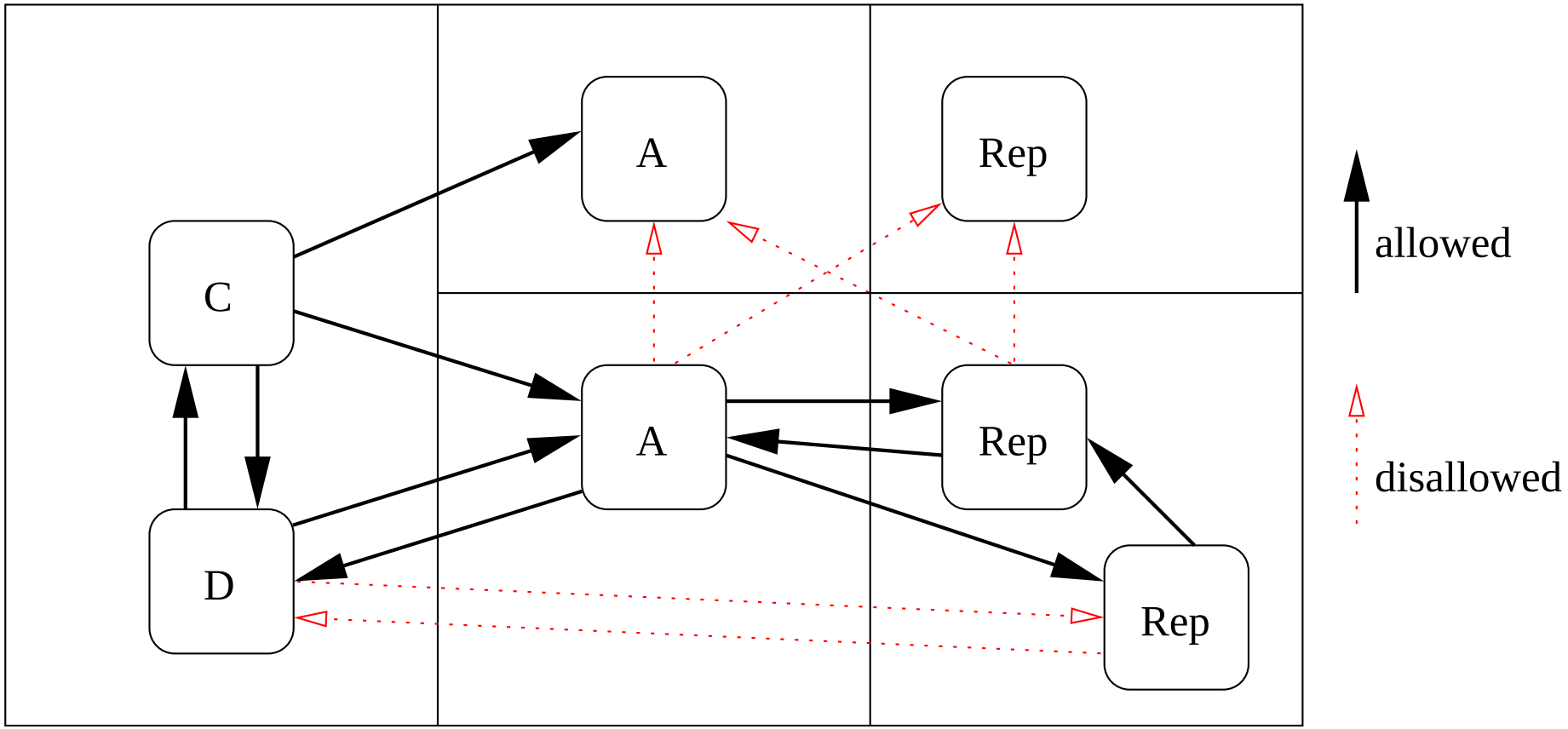
Confinement



Confinement

- Confinement is an end in itself [Boyland,Potter,Clark,Noble,Vitek,Bokowski...]
- Modular reasoning about modification of extended state [Leino,Poetzsch-Heffter,Müller...]
- Reasoning about modules: soundness of forward (bi)simulation for sequential Java (sans specifications and nondeterminacy) [BN02, BN].

Heap confinement for A, Rep



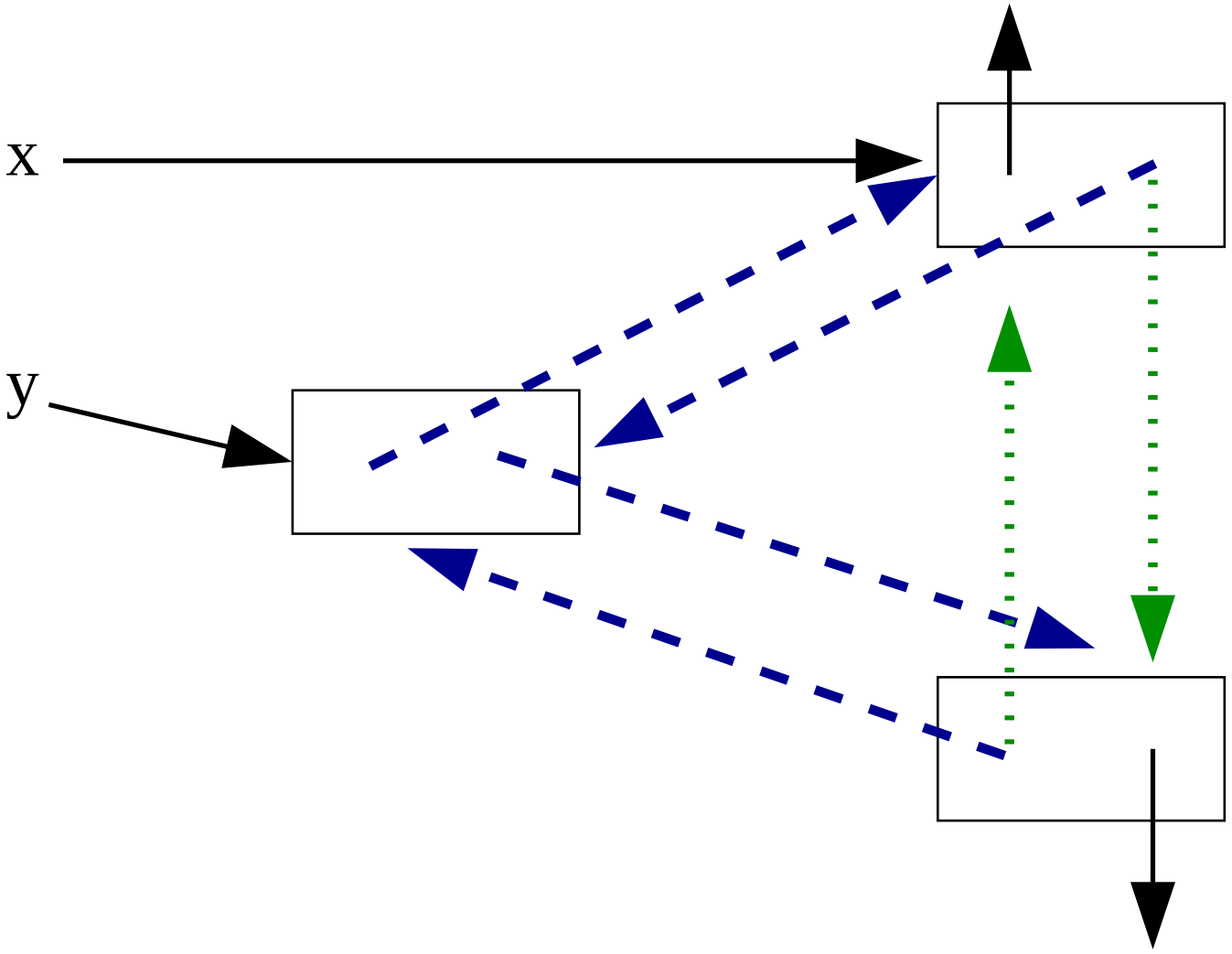
$conf\ h$ iff h has admissible partition

$h = hOut * hA_1 * hRep_1 * \ldots * hA_n * hRep_n$ with

$hOut \not\rightsquigarrow hRep_k$, $hRep_k \not\rightsquigarrow hOut$, and

$hA_k * hRep_k \not\rightsquigarrow hA_j * hRep_j$ for $k \neq j$

Pointers



patvar a, b, c, h

turn $(x \rightarrow a, b) * (y \rightarrow \text{-}, \text{-}) * (b \rightarrow x, c) * h$

into $(x \rightarrow a, y) * (y \rightarrow x, b) * (b \rightarrow y, c) * h$

Explicit confinement

Alternative to type system for tracking confinement.
To maintain $hOut \not\rightarrow hRep$ it suffices to check assignments to cells in $hOut$.

$//heap = hOut * (x \rightarrow \text{-}, b) * hRep$ with $hOut \not\rightarrow hRep$

$y := new\ Rep();$

$//heap = hOut * (x \rightarrow \text{-}, b) * hRep * (y \rightarrow \text{-}, nil)$ with

$//\qquad hOut \not\rightarrow hRep \wedge hOut \not\rightarrow (y \rightarrow \text{-}, nil)$

...

$//heap = hOut * (x \rightarrow \text{-}, y) * hRep * (y \rightarrow \text{-}, b) *$ with

$//\qquad hOut \not\rightarrow hRep \wedge hOut \not\rightarrow (y \rightarrow \text{-}, nil)$

Useful for tools that treat types as predicates in an untyped logic?

Sidelights

- Established theories of parametricity using existential types: apply to instance-based visibility [Red98] [elaborating Reynolds]

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- Established theories of parametricity using existential types: apply to instance-based visibility [Red98] [elaborating Reynolds]
- Semantics of specification statements: sets-of-state-transformers corresponds to conjunctive predicate transformers [YR00, Nau01a] [Leino&Manohar]

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Appendix: static confinement

Signatures: $C \leq Rep \Rightarrow U \leq A \vee U \leq Rep$ for all $U \in \overline{T}$

Phrases:

$$\frac{C \leq A \Rightarrow U \not\leq A \qquad \Gamma;\ C \rhd e : U}{\Gamma;\ C \rhd x.f := e} \qquad \frac{C \neq A \Rightarrow B \not\leq Rep \qquad C \leq A \Rightarrow B \not\leq A}{\Gamma;\ C \rhd x := \mathsf{new}\ B(\ )}$$

$$\frac{\mathrm{mtype}(m, D) = (\overline{x} : \overline{T}) \to T \qquad C \leq A \Rightarrow T \not\leq A \qquad \Gamma;\ C \rhd e : D \quad \Gamma;\ C \rhd \overline{e} : \overline{U}}{\Gamma;\ C \rhd e.m(\overline{e}) : T}$$

These suffice for semantic condition stronger than needed for abstraction theorem.