Re-classification and Multi-threading: $\mathcal{F}ickle_{\mathtt{MT}}$

MYTHS/MIKADO/DART Meeting, Venice, June 14, 2004

joint work with Ferruccio Damiani and Paola Giannini

Contents of the talk

- Introduction and Motivation through examples
- Operational Semantics
- Type System
- Soundness
- Translation

Example

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class Player{ int age;   void wake(){...}   }

class Frog extends Player{                class Prince extends Player{
  Vocal pouch;                              Weapon sword;
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}                                         }
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but then, ...

Example cont.

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root class $\mathsf{Player}\{\mathbf{int}\ \mathsf{age};\quad \mathbf{void}\ \mathsf{wake}()\{\ldots\}\ \ \mathbf{void}\ \mathsf{kissed}()\{\ldots\}\ \ \}$

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root class  Player{int age;  void wake(){...}  void kissed(){...}  }

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This allows us to express frogs turning into princes, windows being iconified and expanded, empty stacks becoming non-empty and non-empty stacks becoming empty, *etc.*, *etc.*, *etc.*

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          (new Game).play(new Frog)
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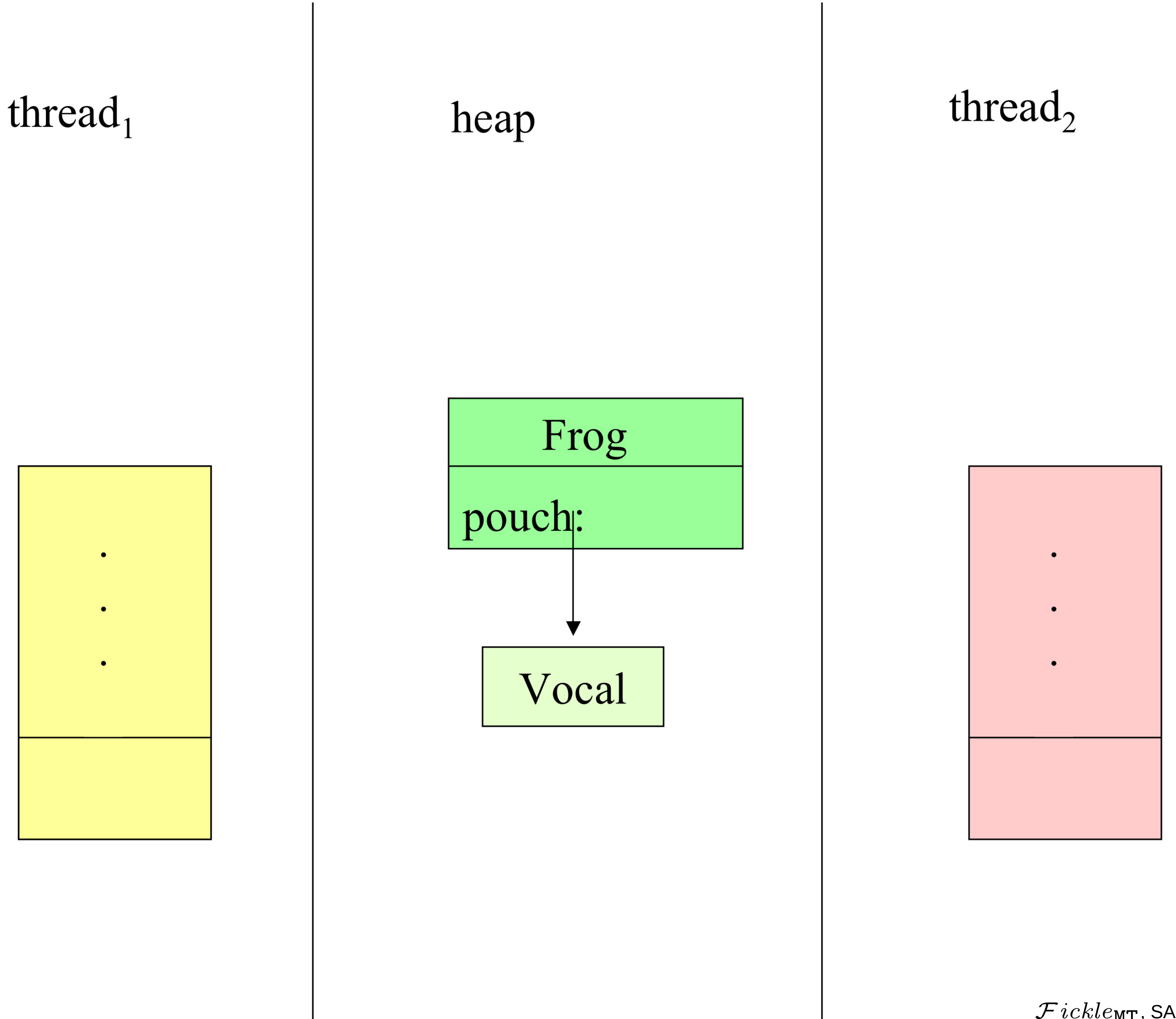
Key Example



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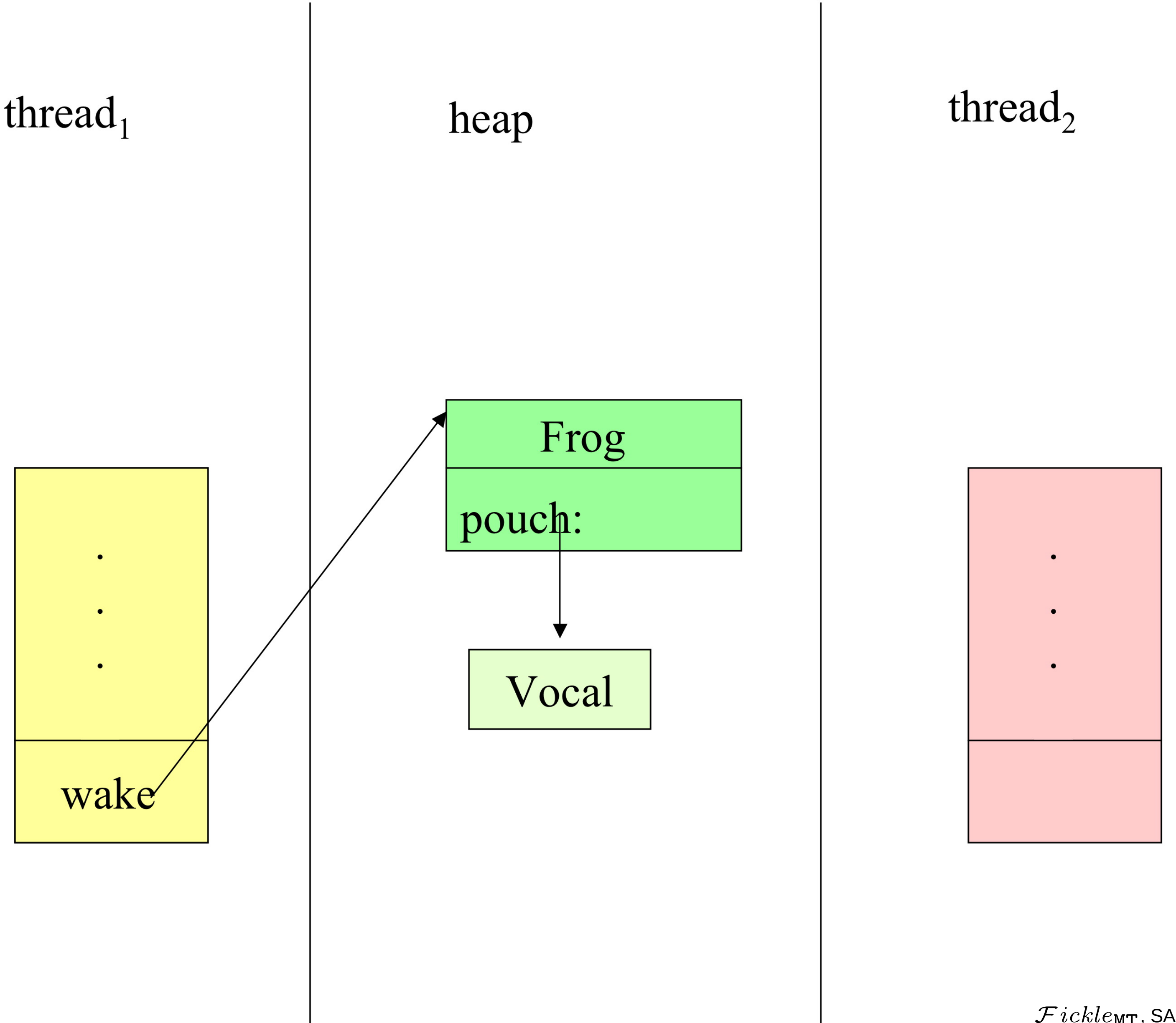

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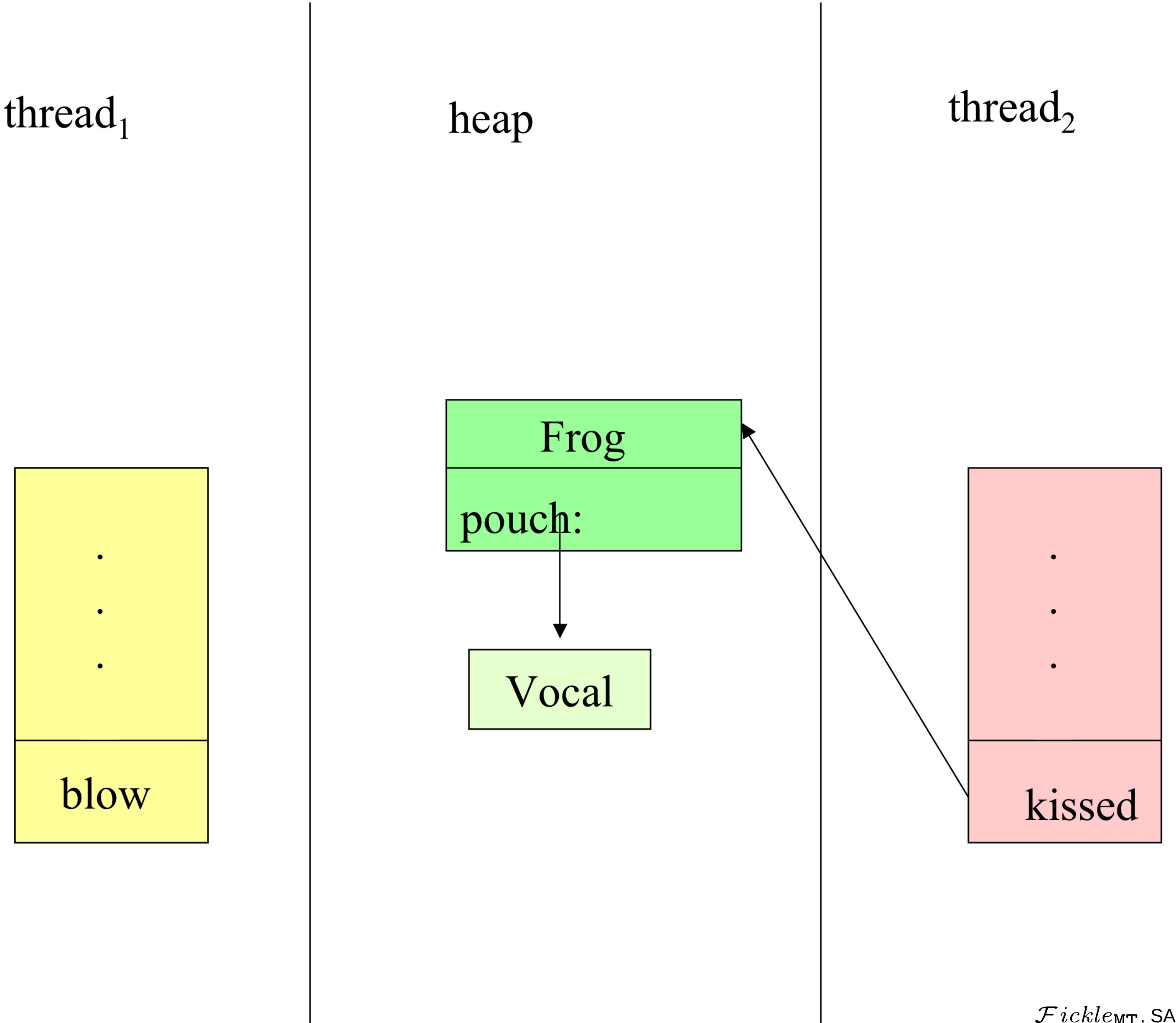

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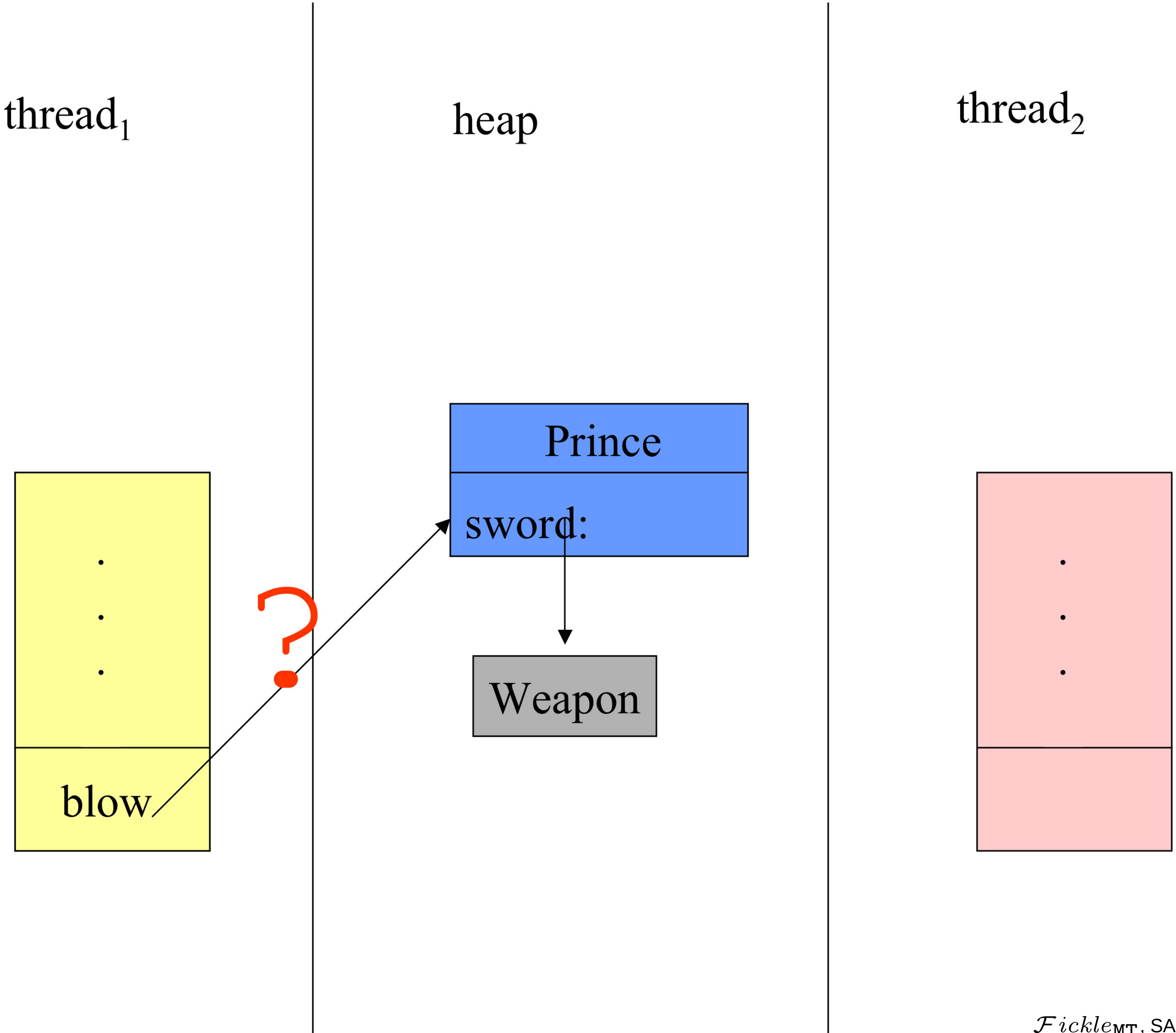

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Prevent executions in which one thread reclassifies an object while another one is executing a method on the same object

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- The type system gathers information on the type of objects reclassified and/or used as receivers
- The operational semantics uses this static information to block threads that could cause errors (dynamic check)
- This blocking threads does not cause deadlock : a top-level method call acquires the right to have all the objects that may be reclassified or be method call's receivers during its call.

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Progress: a well-typed configuration either is a final one or it reduces (no deadlock)

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- a class Gamma monitoring objects by means of synchronised methods:
  - each method call waits until it can look the required objects;
  - each method return notifies objects unlocks.

Configuration

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- λ is the local object state: Addresses $\rightarrow \{-1, 0, 1\}$
  - $\lambda(\iota) = -1$ means that the object at address ι could be re-classified by the current thread
  - $\lambda(\iota) = 0$ means that the current thread does not use the object at address ι as receiver
  - $\lambda(\iota) = 1$ means that the current thread uses the object at address ι as receiver.

Top Level Method Call

$$\ll \chi, \gamma, \{ ..., \langle \rho, \lambda_0, \langle \{\}, \{\} \rangle, \iota.\mathsf{m}(\mathsf{v}) \rangle, ... \} \gg$$

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$\rho' = [\mathsf{x} \mapsto \mathsf{v}, \mathtt{this} \mapsto \iota]$
γ' is -1 for all objects belonging to classes in ϕ

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γ is 0 for all objects belonging to classes in ϕ
γ is ≥ 0 for all objects belonging to classes in $\psi \cup \{\mathsf{c}\}$

$$\begin{gathered} \ll \chi, \gamma, \{\ldots, \langle \rho, \lambda_0, \langle \{\}, \{\} \rangle, \iota.\mathsf{m}(\mathsf{v}) \rangle, \ldots\} \gg \\ \big\downarrow P \\ \ll \chi, \gamma', \{\ldots, \langle \rho, \lambda', \langle \phi, \psi \cup \{\mathsf{c}\} \rangle, \mathbf{return}^{\mathsf{o}}(\rho', \mathsf{e}) \rangle, \ldots\} \gg \end{gathered}$$

$\rho' = [\mathsf{x} \mapsto \mathsf{v}, \mathtt{this} \mapsto \iota]$
γ' is -1 for all objects belonging to classes in ϕ
γ' is $\gamma + 1$ for all objects belonging to classes in $\psi \cup \{\mathsf{c}\}$

Top Level Method Call

$\chi(\iota) = [[\ldots]]^{\mathsf{c}}$
$\mathcal{M}(P, \mathsf{c}, \mathsf{m}) = \mathsf{t}\,\mathsf{m}\ (\mathsf{t}'\,\mathsf{x})\ \langle \phi, \psi \rangle\ \ \{\,\mathsf{e}\,\}$
γ is 0 for all objects belonging to classes in ϕ
γ is ≥ 0 for all objects belonging to classes in $\psi \cup \{\mathsf{c}\}$

$$\ll \chi, \gamma, \{\ldots, \langle \rho, \lambda_0, \langle \{\}, \{\} \rangle, \iota.\mathsf{m}(\mathsf{v}) \rangle, \ldots\} \gg$$
$$\Big\downarrow P$$
$$\ll \chi, \gamma', \{\ldots, \langle \rho, \lambda', \langle \phi, \psi \cup \{\mathsf{c}\} \rangle, \mathbf{return}^{\mathsf{o}}(\rho', \mathsf{e}) \rangle, \ldots\} \gg$$

$\rho' = [\mathsf{x} \mapsto \mathsf{v}, \mathtt{this} \mapsto \iota]$
γ' is -1 for all objects belonging to classes in ϕ
γ' is $\gamma + 1$ for all objects belonging to classes in $\psi \cup \{\mathsf{c}\}$
λ' is -1 for all objects belonging to classes in ϕ

Top Level Method Call

$\chi(\iota) = [[\ldots]]^{\mathsf{c}}$
$\mathcal{M}(P, \mathsf{c}, \mathsf{m}) = \mathsf{t}\,\mathsf{m}\ (\mathsf{t}'\,\mathsf{x})\ \langle\phi, \psi\rangle\ \ \{\,\mathsf{e}\,\}$
γ is 0 for all objects belonging to classes in ϕ
γ is ≥ 0 for all objects belonging to classes in $\psi \cup \{\mathsf{c}\}$

$$\begin{array}{c}
\ll \chi, \gamma, \{\ldots, \langle\rho, \lambda_0, \langle\{\}, \{\}\rangle, \iota.\mathsf{m}(\mathsf{v})\rangle, \ldots\} \gg \\
\Big\downarrow P \\
\ll \chi, \gamma', \{\ldots, \langle\rho, \lambda', \langle\phi, \psi \cup \{\mathsf{c}\}\rangle, \mathbf{return}^{\mathsf{o}}(\rho', \mathsf{e})\rangle, \ldots\} \gg
\end{array}$$

$\rho' = [\mathsf{x} \mapsto \mathsf{v}, \mathtt{this} \mapsto \iota]$
γ' is -1 for all objects belonging to classes in ϕ
γ' is $\gamma + 1$ for all objects belonging to classes in $\psi \cup \{\mathsf{c}\}$
λ' is -1 for all objects belonging to classes in ϕ
λ' is 1 for all objects belonging to classes in $\psi \cup \{\mathsf{c}\}$

Inner Method Call

$$\ll \chi, \gamma, \{\ldots, \langle\rho, \lambda, \Theta, \iota.\mathsf{m}(\mathsf{v})\rangle, \ldots\} \gg$$

Inner Method Call

$\chi(\iota) = [\![\ldots]\!]^{\mathsf{c}}$

$$\ll \chi, \gamma, \{\ldots, \langle \rho, \lambda, \Theta, \iota.\mathsf{m}(\mathsf{v})\rangle, \ldots\} \gg$$

Inner Method Call

$$\chi(\iota) = [[\ldots]]^{\mathsf{c}}$$
$$\mathcal{M}(P, \mathsf{c}, \mathsf{m}) = \mathsf{t}\,\mathsf{m}\ (\mathsf{t}'\,\mathsf{x})\ \langle\phi, \psi\rangle\ \ \{\,\mathsf{e}\,\}$$

$$\ll \chi, \gamma, \{\ldots, \langle\rho, \lambda, \Theta, \iota.\mathsf{m}(\mathsf{v})\rangle, \ldots\} \gg$$

Inner Method Call

$\chi(\iota) = [[\ldots]]^{\mathsf{c}}$
$\mathcal{M}(P, \mathsf{c}, \mathsf{m}) = \mathsf{t}\,\mathsf{m}\ (\mathsf{t}'\,\mathsf{x})\ \langle \phi, \psi \rangle\ \ \{\,\mathsf{e}\,\}$
$\Theta \neq \langle \{\}, \{\} \rangle$

$$\ll \chi, \gamma, \{\ldots, \langle \rho, \lambda, \Theta, \iota.\mathsf{m}(\mathsf{v}) \rangle, \ldots\} \gg$$

Inner Method Call

$\chi(\iota) = [[\ldots]]^{\mathsf{c}}$
$\mathcal{M}(P, \mathsf{c}, \mathsf{m}) = \mathsf{t}\,\mathsf{m}\ (\mathsf{t}'\,\mathsf{x})\ \langle \phi, \psi \rangle\ \ \{\, \mathsf{e} \,\}$
$\Theta \neq \langle \{\}, \{\} \rangle$

$$\ll \chi, \gamma, \{ \ldots, \langle \rho, \lambda, \Theta, \iota.\mathsf{m}(\mathsf{v}) \rangle, \ldots \} \gg$$
$$\Big\downarrow P$$
$$\ll \chi, \gamma, \{ \ldots, \langle \rho, \lambda, \Theta, \mathbf{return}^{\mathsf{i}}(\rho', \mathsf{e}) \rangle, \ldots \} \gg$$

Inner Method Call

$\chi(\iota) = [[\ldots]]^{\mathsf{c}}$
$\mathcal{M}(P, \mathsf{c}, \mathsf{m}) = \mathsf{t}\,\mathsf{m}\ (\mathsf{t}'\,\mathsf{x})\ \langle \phi, \psi \rangle\ \ \{\,\mathsf{e}\,\}$
$\Theta \neq \langle \{\}, \{\} \rangle$

$$\ll \chi, \gamma, \{\ldots, \langle \rho, \lambda, \Theta, \iota.\mathsf{m}(\mathsf{v}) \rangle, \ldots\} \gg \Big\downarrow P \ll \chi, \gamma, \{\ldots, \langle \rho, \lambda, \Theta, \mathbf{return}^{\mathsf{i}}(\rho', \mathsf{e}) \rangle, \ldots\} \gg$$

$\rho' = [\mathsf{x} \mapsto \mathsf{v}, \mathtt{this} \mapsto \iota]$

Spawn

$$\ll \chi, \gamma, \{..., \langle \rho, \lambda, \Theta, \mathcal{C}[\mathbf{spawn}(\mathsf{e})]\rangle, ...\} \gg$$

Spawn

$\mathcal{C}$ does not contain $\mathbf{return}^{\eta}(...,...)$

$$\ll \chi, \gamma, \{..., \langle \rho, \lambda, \Theta, \mathcal{C}[\mathbf{spawn}(\mathsf{e})]\rangle, ...\} \gg$$

Spawn

$\mathcal{C}$ does not contain $\mathbf{return}^{\eta}(...,...)$

$$\begin{array}{c}\ll \chi, \gamma, \{..., \langle \rho, \lambda, \Theta, \mathcal{C}[\mathbf{spawn}(\mathsf{e})]\rangle, ...\} \gg \\ \big\downarrow P \\ \ll \chi, \gamma, \{..., \langle \rho, \lambda, \Theta, \mathcal{C}[\mathsf{true}]\rangle, \langle \rho, \lambda_0, \Theta_0, \mathsf{e}\rangle, ...\} \gg\end{array}$$

Spawn

$\mathcal{C}$ does not contain $\mathbf{return}^{\eta}(...,...)$

$$\ll \chi, \gamma, \{..., \langle \rho, \lambda, \Theta, \mathcal{C}[\mathbf{spawn}(\mathsf{e})]\rangle, ...\} \gg$$

$$\big\downarrow P$$

$$\ll \chi, \gamma, \{..., \langle \rho, \lambda, \Theta, \mathcal{C}[\mathsf{true}]\rangle, \langle \rho, \lambda_0, \Theta_0, \mathsf{e}\rangle, ...\} \gg$$

$\Theta_0 = \langle \{\}, \{\} \rangle$

Spawn

$\mathcal{C}$ does not contain $\mathbf{return}^{\eta}(...,...)$

$$\ll \chi, \gamma, \{..., \langle \rho, \lambda, \Theta, \mathcal{C}[\mathbf{spawn}(\mathsf{e})]\rangle, ...\} \gg$$
$$\downarrow P$$
$$\ll \chi, \gamma, \{..., \langle \rho, \lambda, \Theta, \mathcal{C}[\mathsf{true}]\rangle, \langle \rho, \lambda_0, \Theta_0, \mathsf{e}\rangle, ...\} \gg$$

$\Theta_0 = \langle \{\}, \{\} \rangle$

$$\ll \chi, \gamma, \{..., \langle \rho, \lambda, \Theta, \mathcal{E}[\mathbf{return}^{\eta}(\rho', \mathcal{C}[\mathbf{spawn}(\mathsf{e})])]\rangle, ...\} \gg$$

back

Spawn

$\mathcal{C}$ does not contain $\mathbf{return}^{\eta}(\ldots, \ldots)$

$$\ll \chi, \gamma, \{\ldots, \langle \rho, \lambda, \Theta, \mathcal{C}[\mathbf{spawn}(\mathsf{e})]\rangle, \ldots\} \gg$$

$$\Big\downarrow P$$

$$\ll \chi, \gamma, \{\ldots, \langle \rho, \lambda, \Theta, \mathcal{C}[\mathsf{true}]\rangle, \langle \rho, \lambda_0, \Theta_0, \mathsf{e}\rangle, \ldots\} \gg$$

$\Theta_0 = \langle \{\}, \{\} \rangle$

$$\ll \chi, \gamma, \{\ldots, \langle \rho, \lambda, \Theta, \mathcal{E}[\mathbf{return}^{\eta}(\rho', \mathcal{C}[\mathbf{spawn}(\mathsf{e})])]\rangle, \ldots\} \gg$$

$$\Big\downarrow P$$

$$\ll \chi, \gamma, \{\ldots, \langle \rho, \lambda, \Theta, \mathcal{E}[\mathbf{return}^{\eta}(\rho', \mathcal{C}[\mathsf{true}])]\rangle, \langle \rho', \lambda_0, \Theta_0, \mathsf{e}\rangle, \ldots\} \gg$$

back

Typing Rules

$$\frac{\begin{array}{l}\mathsf{c}' = \text{root-superclass of } \mathsf{c} \\ \quad = \text{ root-superclass of } \Gamma(\mathtt{this})\end{array}}{P, \Gamma \vdash \mathtt{this}{\Downarrow}\mathtt{c} : \mathtt{c} \parallel \mathsf{c} \parallel \langle \{\mathsf{c}'\}, \{\} \rangle} \quad (recl)$$

back

Typing Rules

$$\frac{\begin{array}{l}\mathsf{c}' = \text{root-superclass of } \mathsf{c} \\ \quad = \text{ root-superclass of } \Gamma(\mathtt{this})\end{array}}{P, \Gamma \vdash \mathtt{this}\Downarrow\mathsf{c} \ : \ \mathsf{c} \parallel \mathsf{c} \parallel \langle\{\mathsf{c}'\}, \{\}\rangle} \quad (recl)$$

$$\frac{P, \{\mathsf{t}_1 \ \mathsf{x}, \mathsf{Object} \ \mathtt{this}\} \vdash \mathsf{e} \ : \ \mathsf{t} \parallel \mathsf{Object} \parallel \Theta}{P, \{\mathsf{t}_1 \ \mathsf{x}, \mathsf{c} \ \mathtt{this}\} \vdash \mathbf{spawn}(\mathsf{e}) \ : \ \mathsf{bool} \parallel \mathsf{c} \parallel \langle\{\}, \{\}\rangle} \quad (spawn)$$

back

Typing Rules

$$\frac{\begin{array}{l} \mathsf{c}' = \text{root-superclass of } \mathsf{c} \\ \quad = \text{ root-superclass of } \Gamma(\texttt{this}) \end{array}}{P, \Gamma \vdash \texttt{this}{\Downarrow}\mathsf{c} : \mathsf{c} \parallel \mathsf{c} \parallel \langle \{\mathsf{c}'\}, \{\} \rangle} \quad (\mathit{recl})$$

$$\frac{P, \{\mathsf{t}_1\ \mathsf{x}, \mathsf{Object}\ \texttt{this}\} \vdash \mathsf{e} : \mathsf{t} \parallel \mathsf{Object} \parallel \Theta}{P, \{\mathsf{t}_1\ \mathsf{x}, \mathsf{c}\ \texttt{this}\} \vdash \mathbf{spawn}(\mathsf{e}) : \mathsf{bool} \parallel \mathsf{c} \parallel \langle \{\}, \{\} \rangle} \quad (\mathit{spawn})$$

$$\frac{\begin{array}{l} P, \Gamma \vdash \mathsf{e}_0 : \mathsf{c} \parallel \Gamma(\texttt{this}) \parallel \langle \phi_0, \psi_0 \rangle \\ P, \Gamma \vdash \mathsf{e}_1 : \mathsf{t}_1 \parallel \Gamma(\texttt{this}) \parallel \langle \phi_1, \psi_1 \rangle \\ \text{root-superclass of } \Gamma(\texttt{this}) \notin \phi_0 \cup \phi_1 \\ \mathcal{M}(P, \mathsf{c}, \mathsf{m}) = \mathsf{t}\ \mathsf{m}(\mathsf{t}_1\ \mathsf{x})\ \langle \phi, \psi \rangle\ \{\ \ldots\ \} \end{array}}{\begin{array}{c} P, \Gamma \vdash \mathsf{e}_0.\mathsf{m}(\mathsf{e}_1) : \mathsf{t} \parallel \phi @_P \Gamma(\texttt{this}) \parallel \Theta \\ \Theta = \langle \phi, \psi \rangle \cup \langle \phi_0, \psi_0 \rangle \cup \langle \phi_1, \psi_1 \rangle \cup \langle \{\}, \{\mathsf{c}\} \rangle \end{array}} \quad (\mathit{meth})$$

back

Subject Reduction

$$\begin{tikzcd} \ll \chi, \gamma, \{\ldots, \langle \rho, \lambda, \Theta, \mathsf{e} \rangle, \ldots\} \gg \arrow[d, "P"] \\ \ll \chi', \gamma', \{\ldots, \langle \rho', \lambda', \Theta', \mathsf{e}' \rangle, \ldots\} \gg \end{tikzcd}$$

$$P, \Gamma \vdash \mathsf{e} : \mathsf{t} \parallel \mathsf{c} \parallel \Theta''$$

Subject Reduction

$$\begin{tikzcd}\ll \chi, \gamma, \{\ldots, \langle \rho, \lambda, \Theta, \mathsf{e} \rangle, \ldots\} \gg \arrow[d, "P"] \\ \ll \chi', \gamma', \{\ldots, \langle \rho', \lambda', \Theta', \mathsf{e}' \rangle, \ldots\} \gg\end{tikzcd}$$

$$P, \Gamma \ \vdash \ \mathsf{e} \ : \ \mathsf{t} \parallel \mathsf{c} \parallel \Theta''$$

$$\Downarrow$$

$$P, \Gamma' \ \vdash \ \mathsf{e}' \ : \ \mathsf{t} \parallel \mathsf{c} \parallel \Theta''$$

Subject Reduction cont.

$$\ll \chi, \gamma, \{..., \langle \rho, \lambda, \Theta, \mathcal{E}[\mathbf{spawn}(\mathsf{e})]\rangle, ...\} \gg$$

$$\downarrow P$$

$$\ll \chi, \gamma, \{..., \langle \rho, \lambda, \Theta, \mathcal{E}[\mathsf{true}]\rangle, \langle \rho', \lambda_0, \Theta_0, \mathsf{e}\rangle, ...\} \gg$$

$$P, \Gamma \ \vdash \ \mathcal{E}[\mathbf{spawn}(\mathsf{e})] \ : \ \mathsf{t} \parallel \mathsf{c} \parallel \Theta''$$

Subject Reduction cont.

$$\ll \chi, \gamma, \{\ldots, \langle \rho, \lambda, \Theta, \mathcal{E}[\mathbf{spawn}(\mathsf{e})]\rangle, \ldots\} \gg$$

$$\downarrow P$$

$$\ll \chi, \gamma, \{\ldots, \langle \rho, \lambda, \Theta, \mathcal{E}[\mathsf{true}]\rangle, \langle \rho', \lambda_0, \Theta_0, \mathsf{e}\rangle, \ldots\} \gg$$

$$P, \Gamma \ \vdash \ \mathcal{E}[\mathbf{spawn}(\mathsf{e})] \ : \ \mathsf{t} \parallel \mathsf{c} \parallel \Theta''$$

$$\Downarrow$$

$$P, \Gamma \ \vdash \ \mathcal{E}[\mathsf{true}] \ : \ \mathsf{t} \parallel \mathsf{c} \parallel \Theta''$$

$$P, \Gamma' \ \vdash \ \mathsf{e} \ : \ \mathsf{t}' \parallel \mathsf{Object} \parallel \Theta'''$$

$$\Gamma' = \{\Gamma(\mathsf{x})\ \mathsf{x}, \mathsf{Object}\ \mathtt{this}\}$$

Progress

e_0 is a well-typed expression

$$\ll \chi_0, \gamma_0, \{\langle \rho_0, \lambda_0, \Theta_0, \mathsf{e}_0 \rangle\} \gg$$

$$\downarrow P$$

$$\vdots$$

$$\downarrow P$$

$$\ll \chi, \gamma, \{\langle \rho_1, \lambda_1, \Theta_1, \mathsf{e}_1 \rangle, \ldots, \langle \rho_\mathsf{n}, \lambda_\mathsf{n}, \Theta_\mathsf{n}, \mathsf{e}_\mathsf{n} \rangle\} \gg$$

there is one e_i which is not a value

back

Progress

e_0 is a well-typed expression

$$\ll \chi_0, \gamma_0, \{\langle \rho_0, \lambda_0, \Theta_0, \mathsf{e}_0 \rangle\} \gg$$

$$\downarrow P$$

$$\vdots$$

$$\downarrow P$$

$$\ll \chi, \gamma, \{\langle \rho_1, \lambda_1, \Theta_1, \mathsf{e}_1 \rangle, \ldots, \langle \rho_\mathsf{n}, \lambda_\mathsf{n}, \Theta_\mathsf{n}, \mathsf{e}_\mathsf{n} \rangle\} \gg$$

there is one e_i which is not a value

$$\Downarrow$$

$$\ll \chi, \gamma, \{\langle \rho_1, \lambda_1, \Theta_1, \mathsf{e}_1 \rangle, \ldots, \langle \rho_\mathsf{n}, \lambda_\mathsf{n}, \Theta_\mathsf{n}, \mathsf{e}_\mathsf{n} \rangle\} \gg$$

$$\downarrow P$$

$$\cdots$$

back