Information Flow Security for Asynchronous, Distributed, and Mobile Applications

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Agenda

- Introduction

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- Context (*informal* and *formal* perspectives)

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  - ProActive

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  - ASP calculus and communication reduction rules

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- Implementation of the Security Model

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- The ASP Security Model
- Implementation of the Security Model
- Conclusion

Introduction

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Recent paradigms

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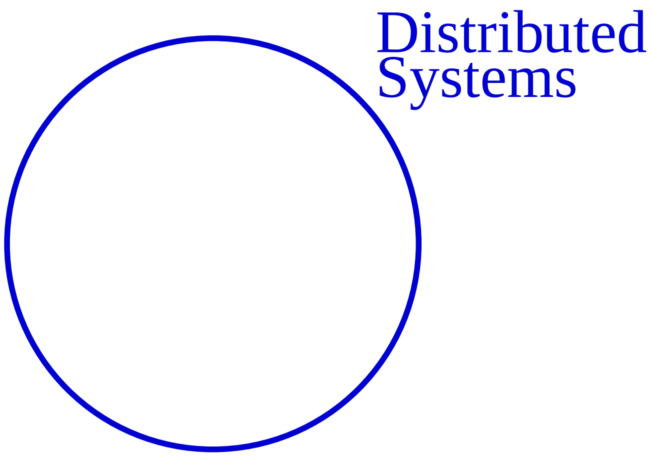

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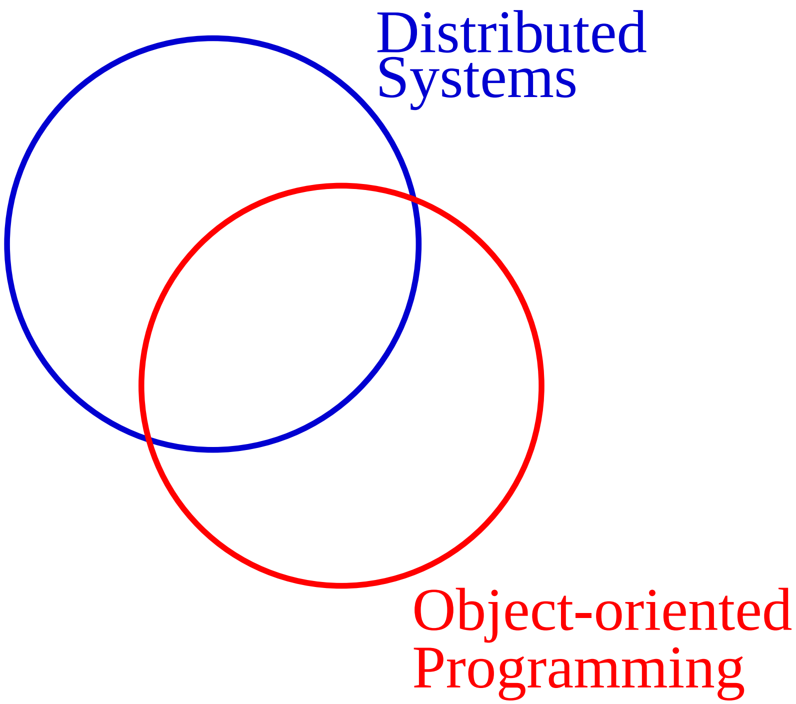

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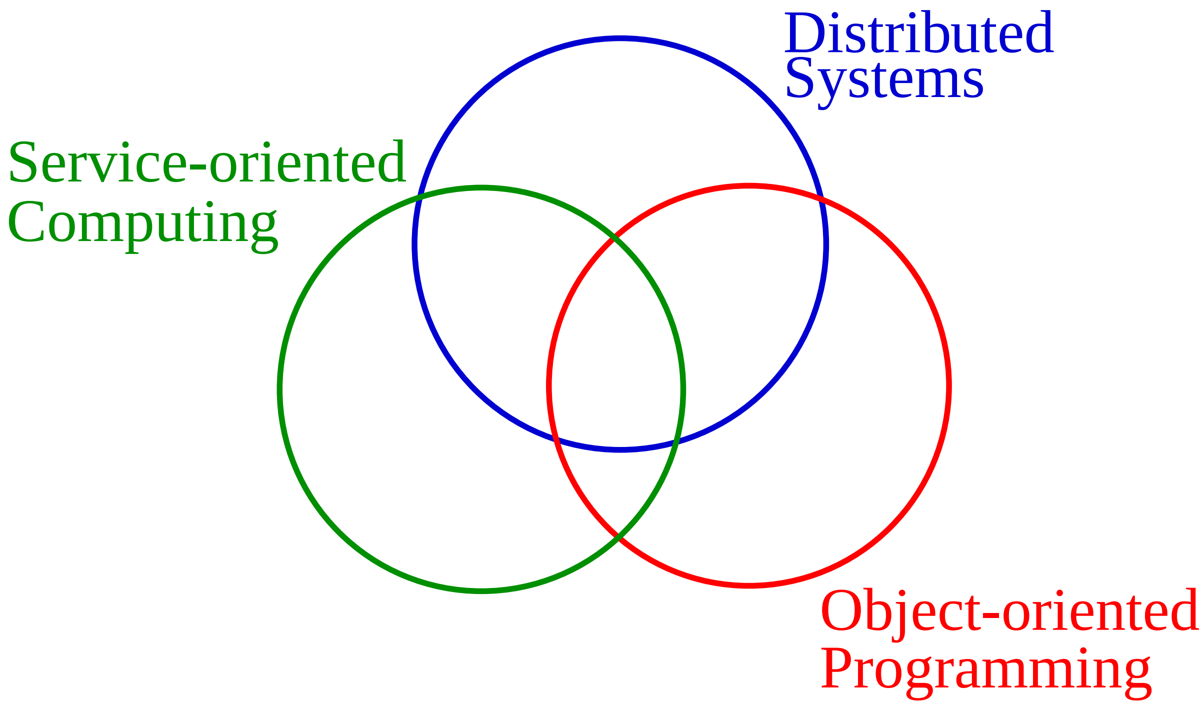

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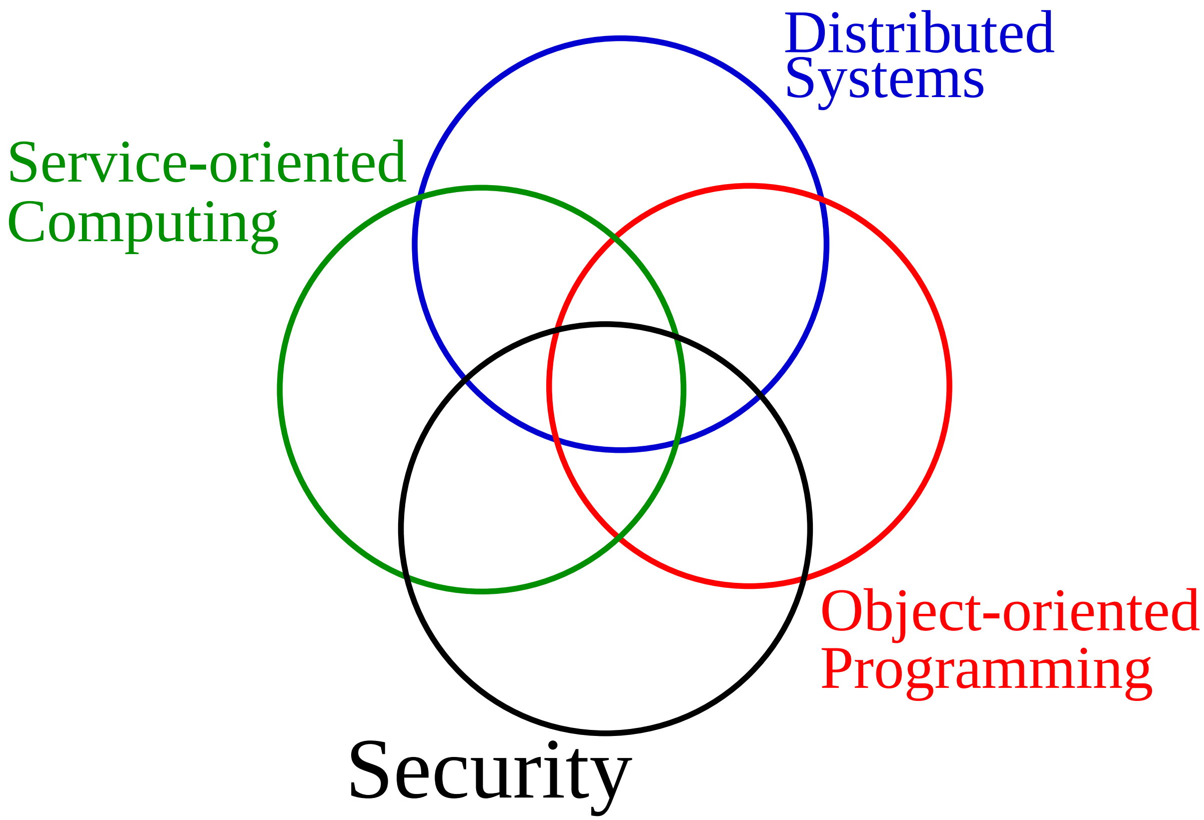

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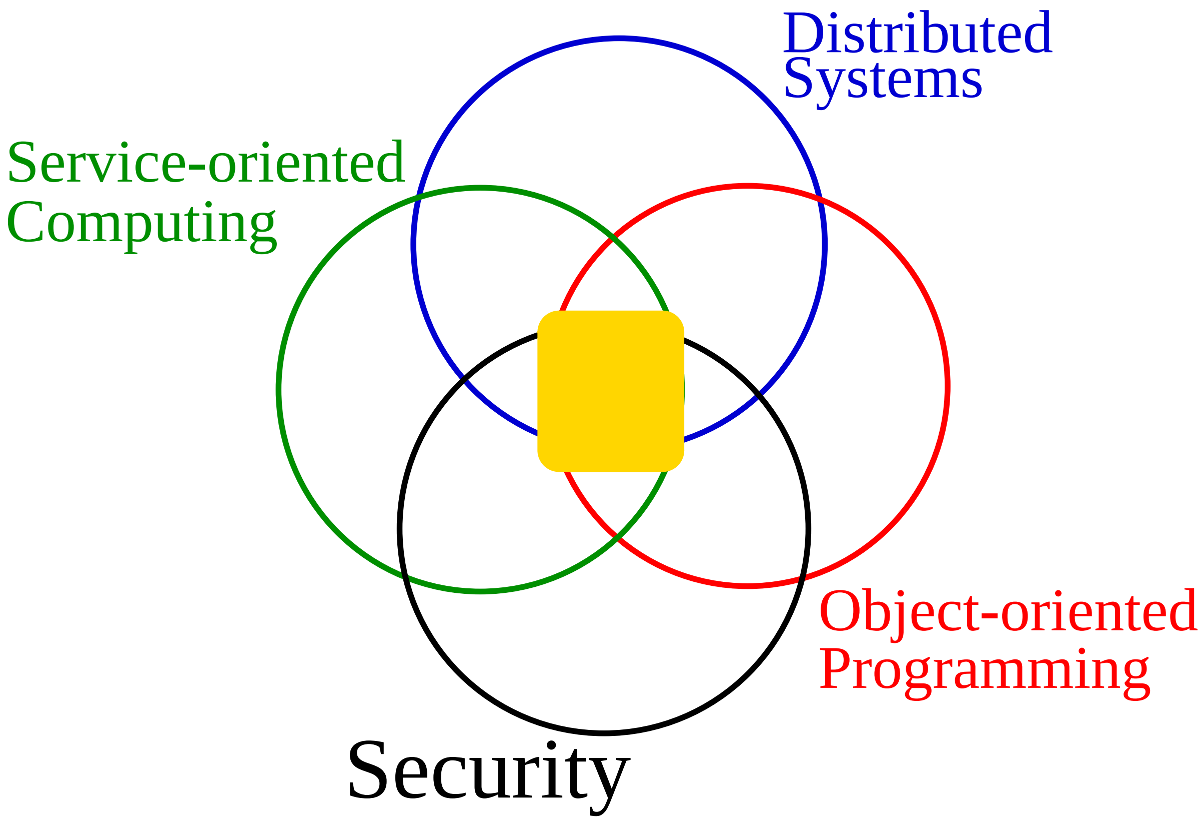

Security focused specifically on *Information Flow*

Context

ProActive main characteristics

- Middleware library for distributed applications

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       (ex.: http://www.anysite.com/anypage.html)

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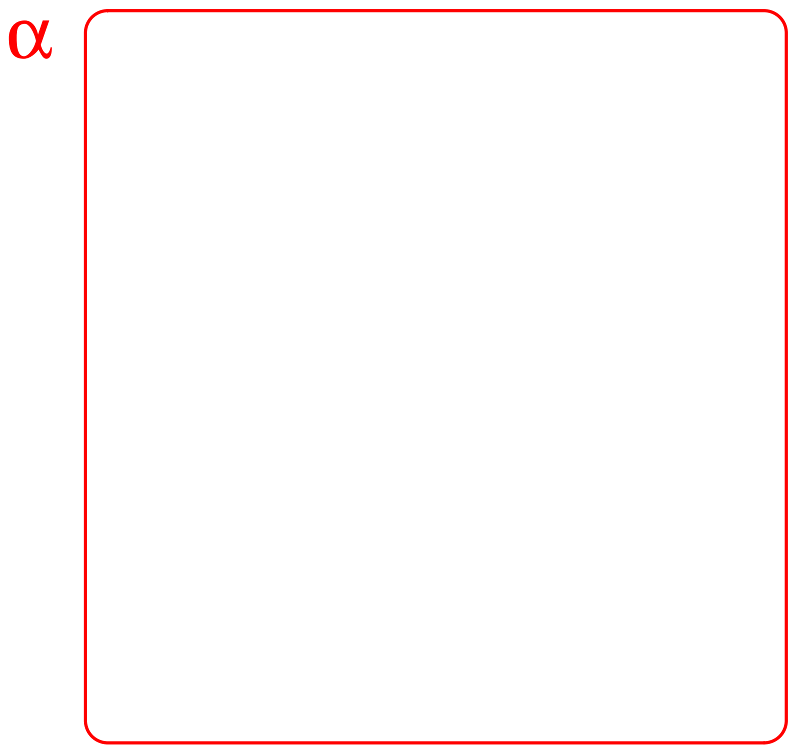
       (ex.: HTML error: 404 Not Authorized)

ASP semantics and ProActive

- The ASP language entities:
  - activity α



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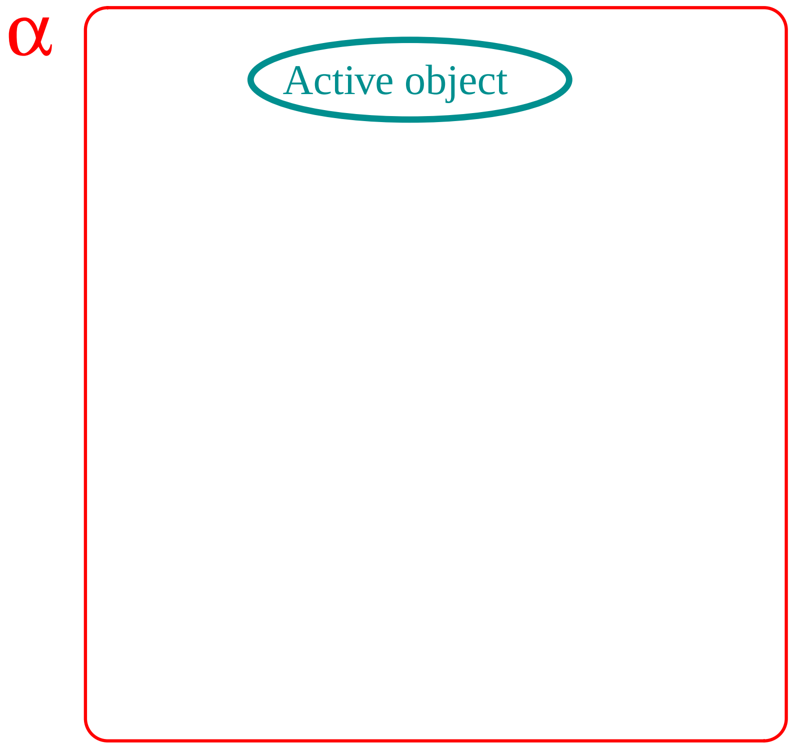

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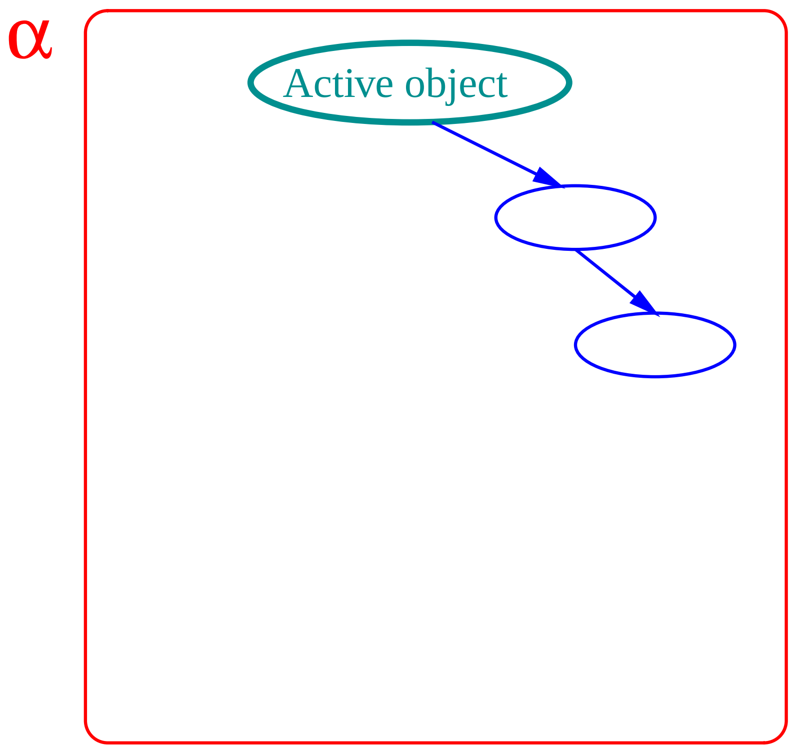

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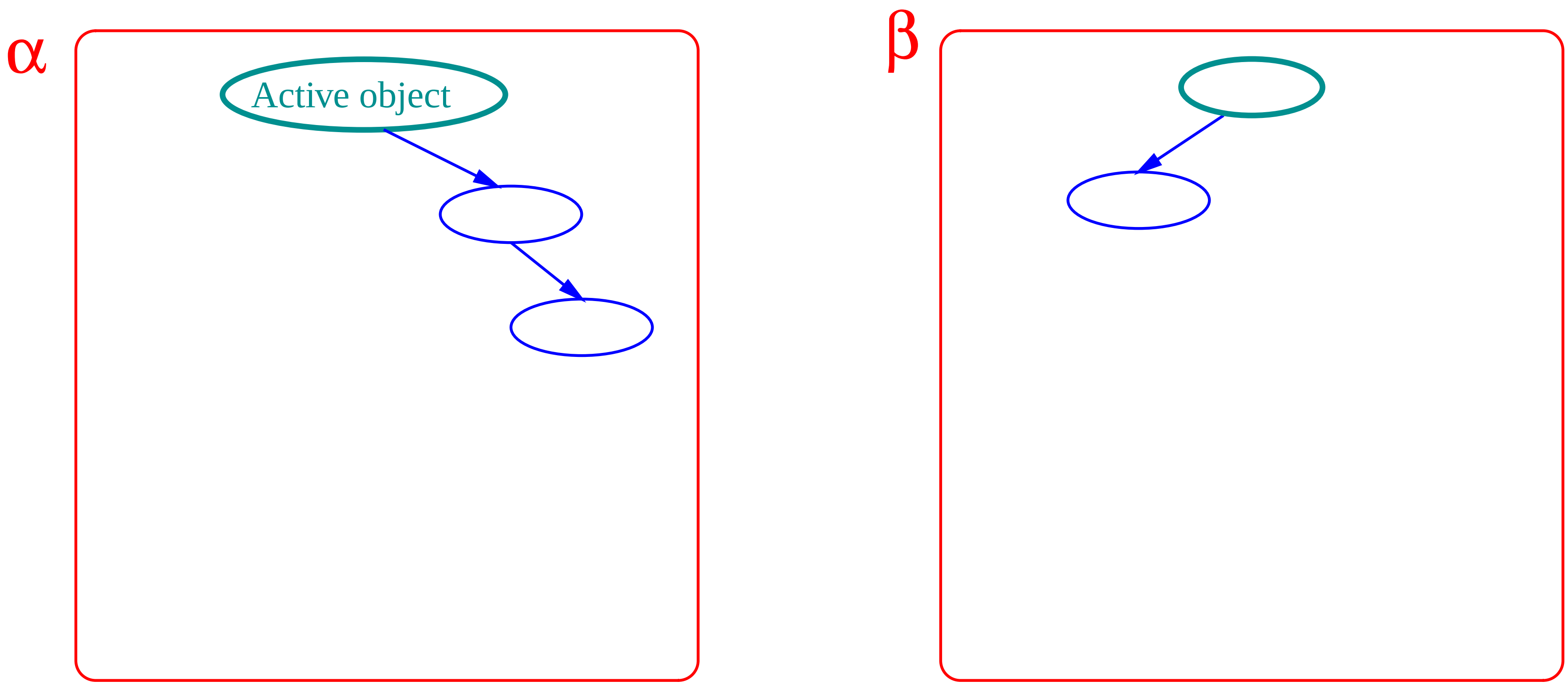

ASP semantics and ProActive

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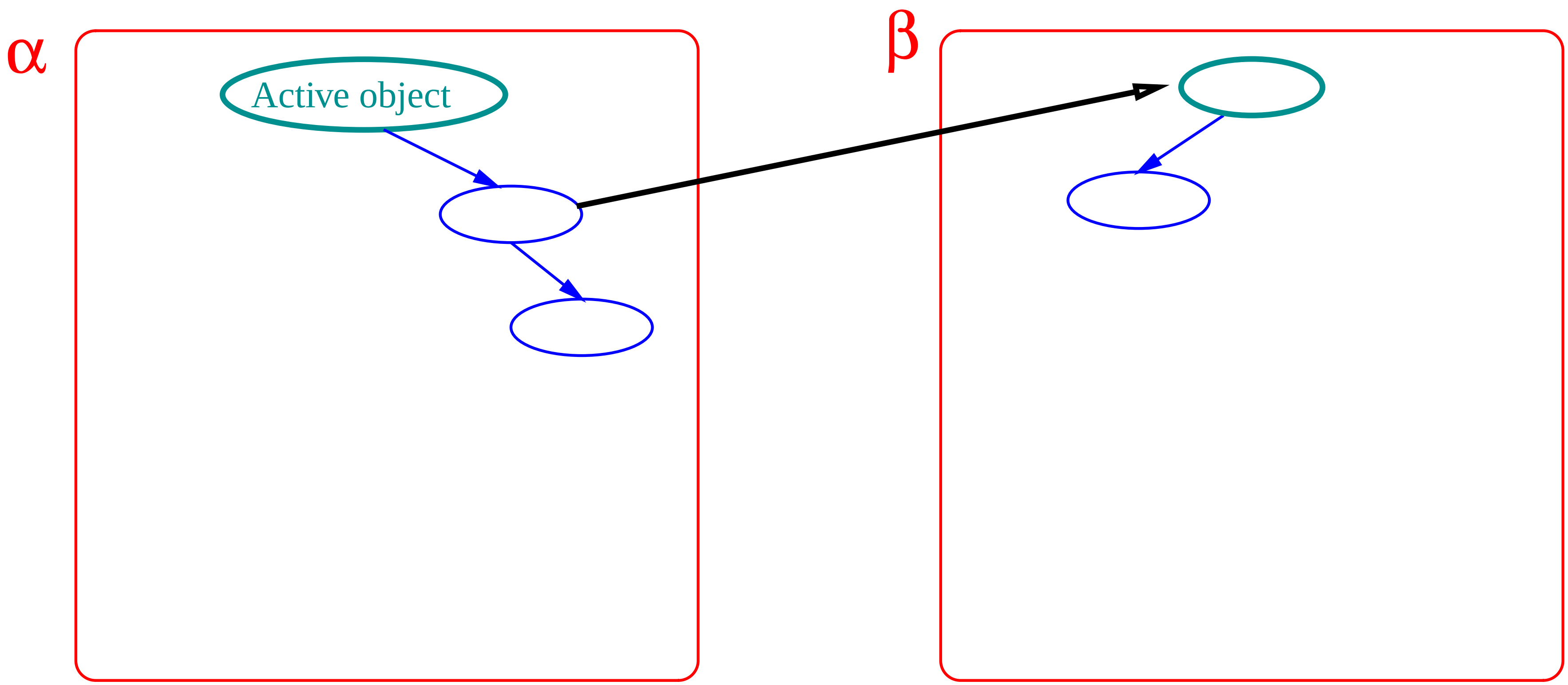

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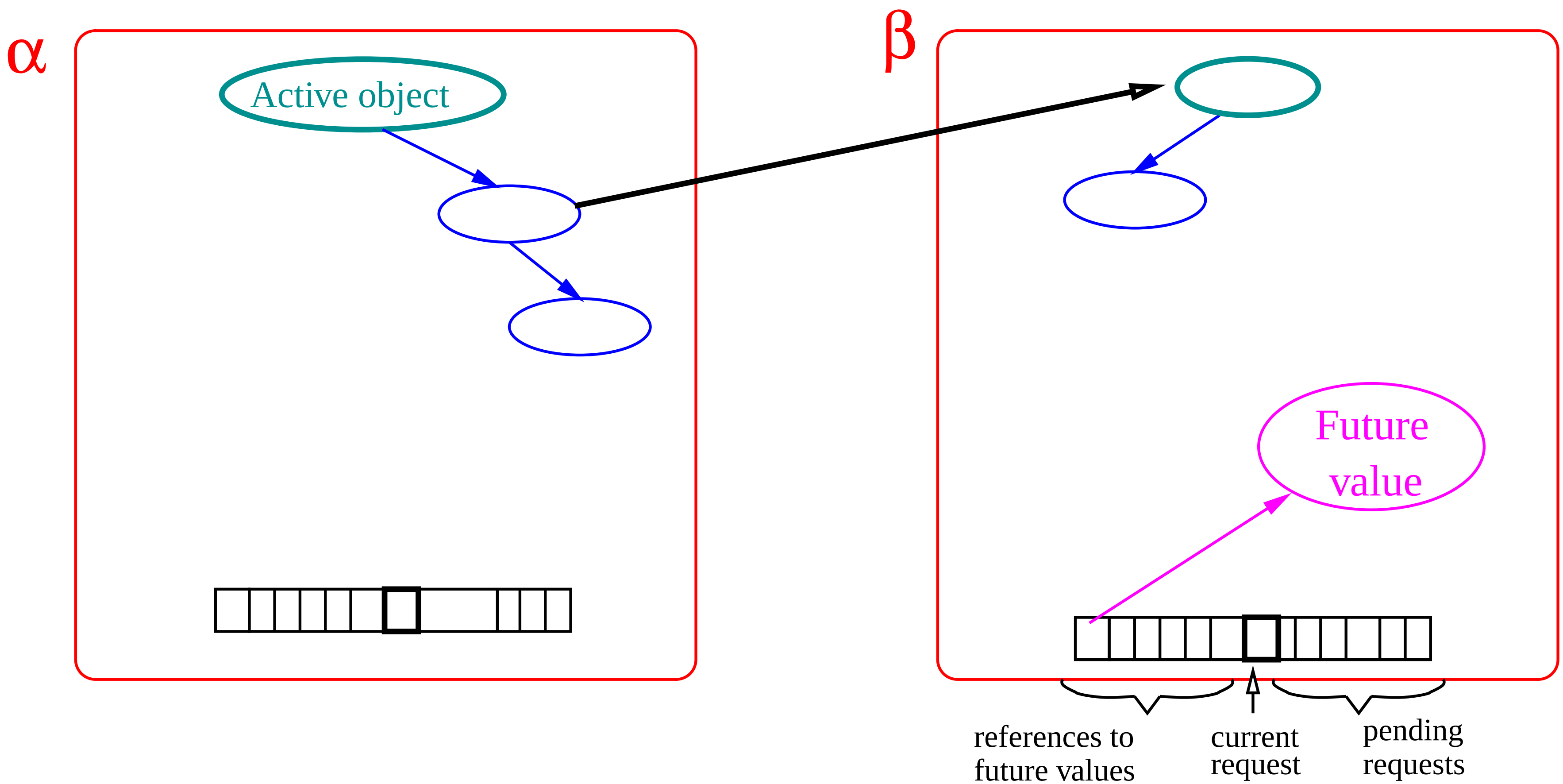

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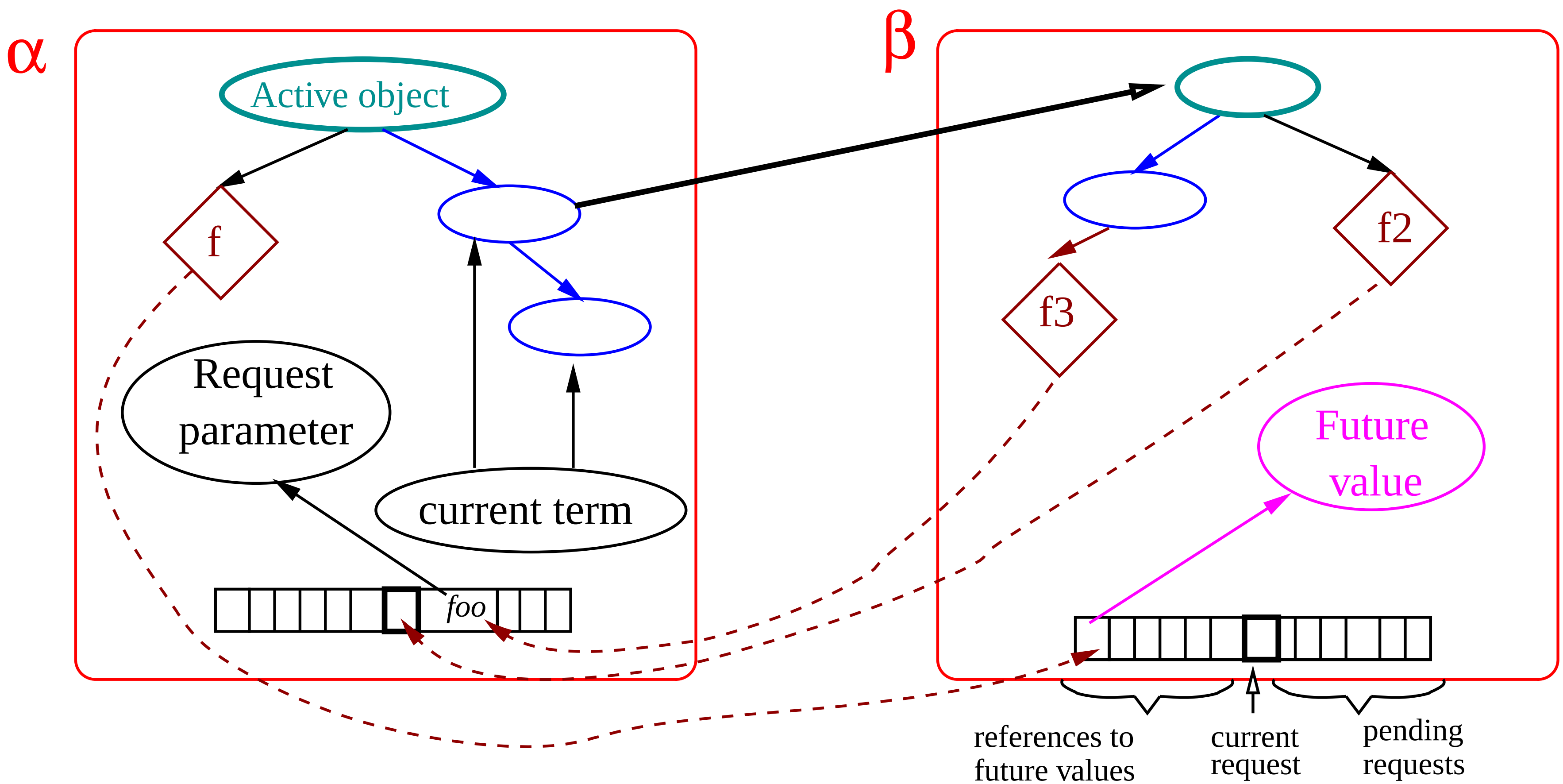

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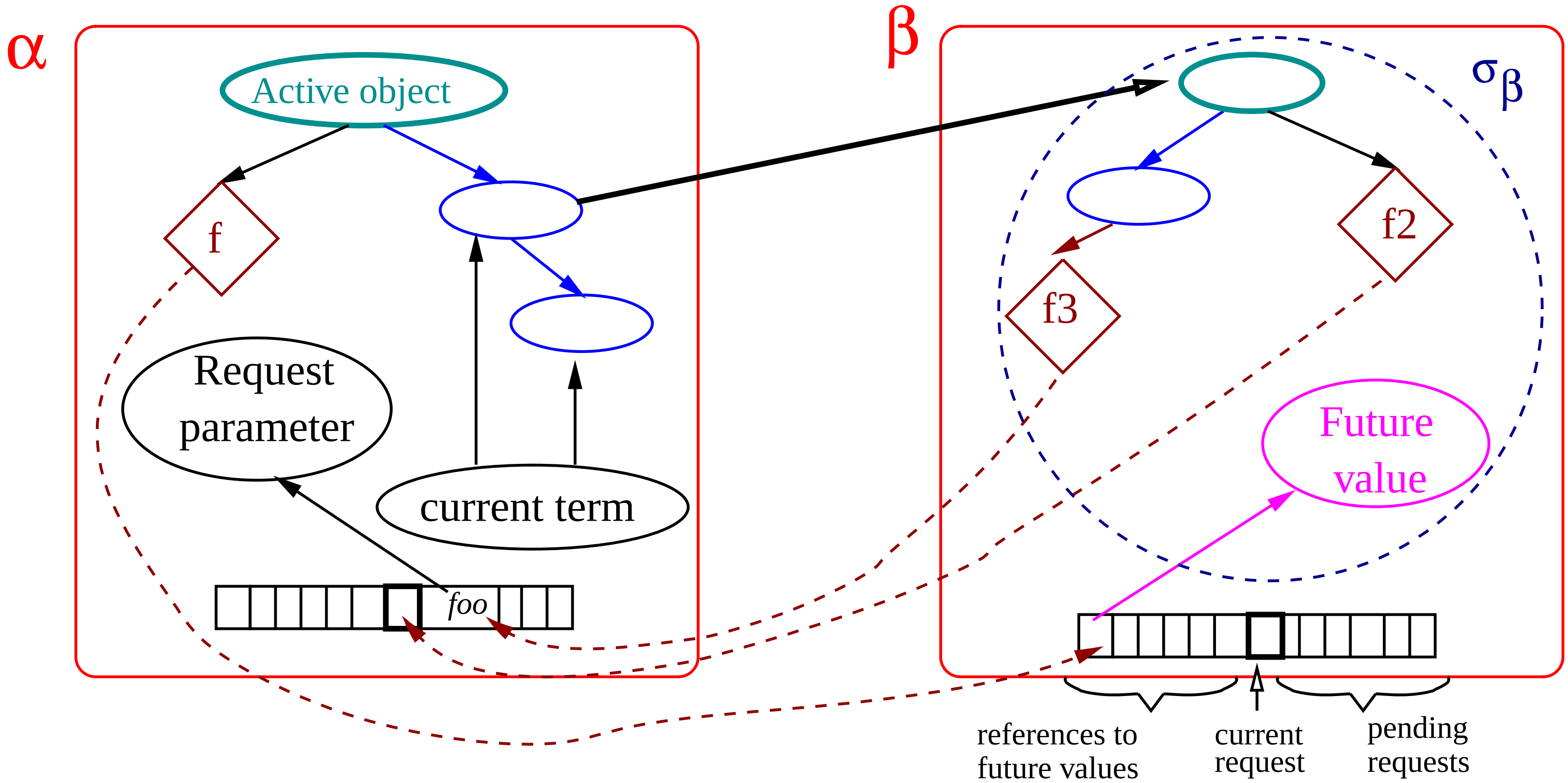

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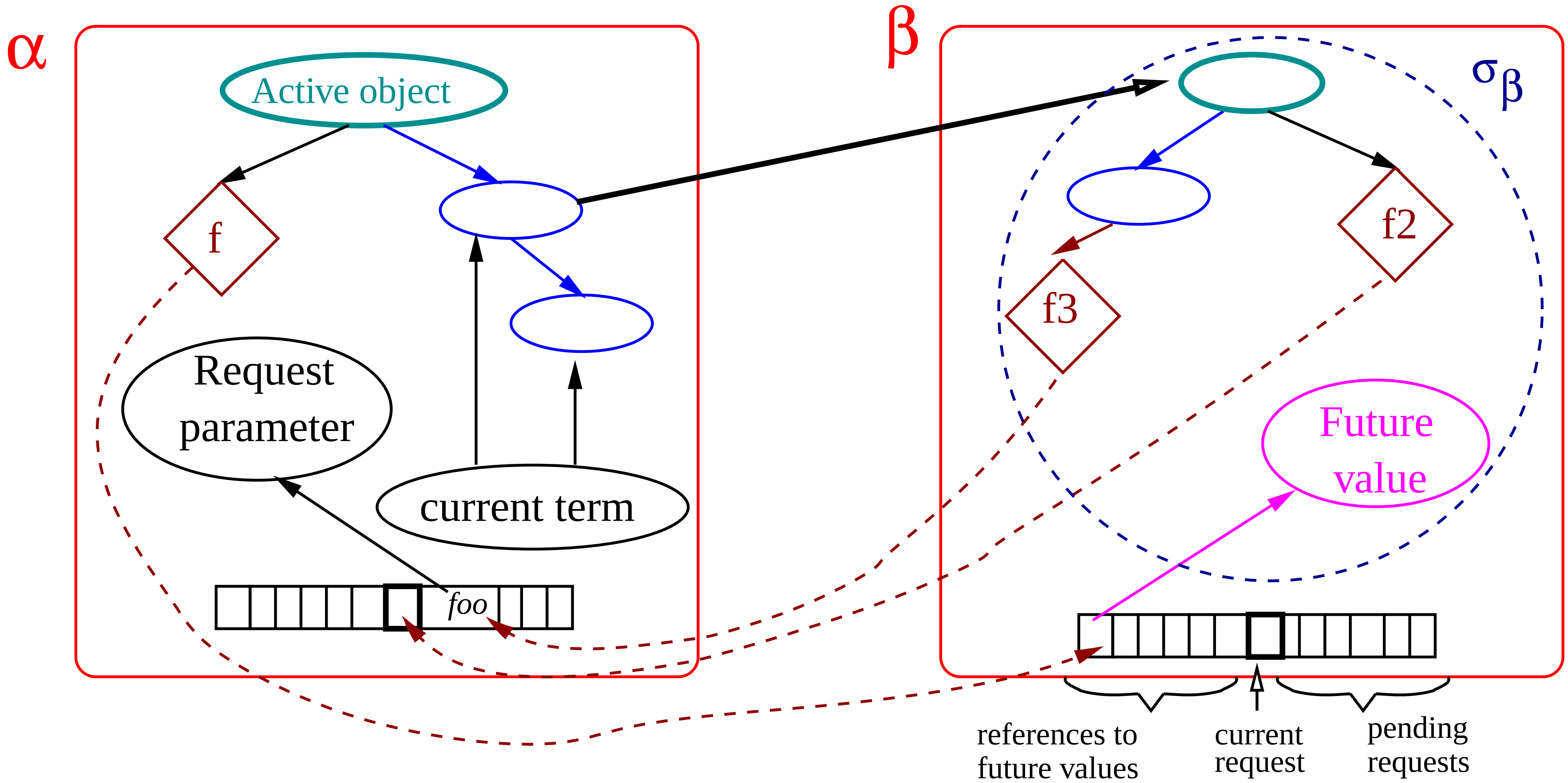

- Parallel configurations are then of the form: P,Q ::= $\alpha\ [a;\sigma;\iota;F;R;f] \parallel \beta\ [\cdots] \parallel \cdots$

ASP parallel reduction rules

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$$\frac{(a,\sigma)\rightarrow_S(a',\sigma') \qquad \rightarrow_S \text{ does not clone a future}}{\alpha[a;\sigma;\iota;F;R;f] \parallel P \longrightarrow \alpha[a';\sigma';\iota;F;R;f] \parallel P}\ (\text{LOCAL})$$

$$\frac{\gamma \text{ fresh activity} \qquad \iota' \not\in dom(\sigma) \qquad \sigma' = \{\iota' \mapsto AO(\gamma)\} :: \sigma \qquad \sigma_\gamma = copy(\iota'',\sigma)}{\alpha[\mathcal{R}[Active(\iota'',m_j)];\sigma;\iota;F;R;f] \parallel P \longrightarrow \alpha[\mathcal{R}[\iota'];\sigma';\iota;F;R;f] \parallel \gamma[\iota''.m_j();\sigma_\gamma;\iota'';\emptyset;\emptyset;\emptyset] \parallel P}\ (\text{NEWACT})$$

$$\frac{\begin{array}{c}\sigma_\alpha(\iota) = AO(\beta) \qquad \iota'' \not\in dom(\sigma_\beta) \qquad f_i^{\alpha\rightarrow\beta} \text{ new future} \qquad \iota_f \not\in dom(\sigma_\alpha)\\ \sigma'_\beta = Copy\&Merge(\sigma_\alpha,\iota'\ ;\ \sigma_\beta,\iota'') \qquad \sigma'_\alpha = \{\iota_f \mapsto fut(f_i^{\alpha\rightarrow\beta})\} :: \sigma_\alpha\end{array}}{\begin{array}{c}\alpha[\mathcal{R}[\iota.m_j(\iota')];\sigma_\alpha;\iota_\alpha;F_\alpha;R_\alpha;f_\alpha] \parallel \beta[a_\beta;\sigma_\beta;\iota_\beta;F_\beta;R_\beta;f_\beta] \parallel P \longrightarrow\\ \alpha[\mathcal{R}[\iota_f];\sigma'_\alpha;\iota_\alpha;F_\alpha;R_\alpha;f_\alpha] \parallel \beta[a_\beta;\sigma'_\beta;\iota_\beta;F_\beta;R_\beta :: [m_j;\iota'';f_i^{\alpha\rightarrow\beta}];f_\beta] \parallel P\end{array}}\ (\text{REQUEST})$$

$$\frac{R = R' :: [m_j;\iota_r;f'] :: R'' \qquad m_j \in M \qquad \forall m \in M,\ m \not\in R'}{\alpha[\mathcal{R}[Serve(M)];\sigma;\iota;F;R;f] \parallel P \longrightarrow \alpha[\iota.m_j(\iota_r) \Uparrow f, \mathcal{R}[[]];\sigma;\iota;F;R' :: R'';f'] \parallel P}\ (\text{SERVE})$$

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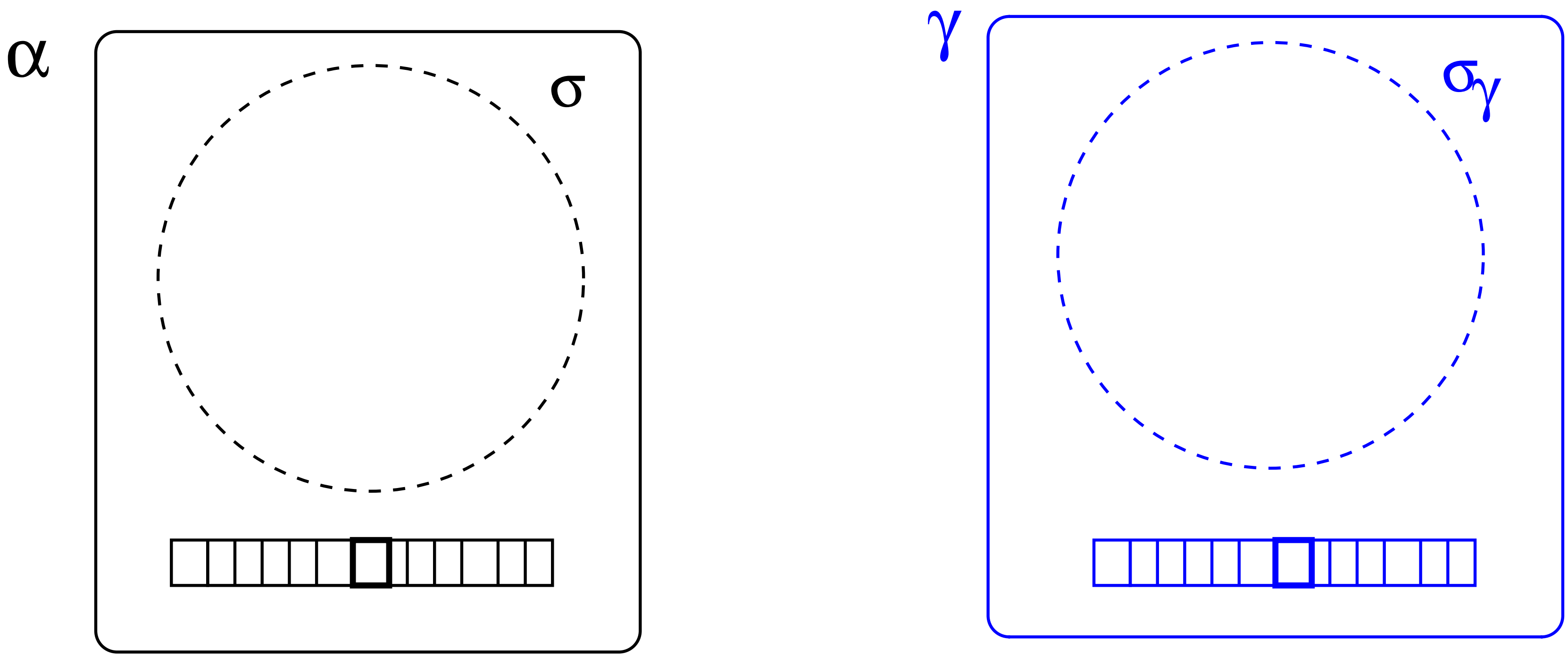
Reduction rules: 1) New Activity

γ fresh activity



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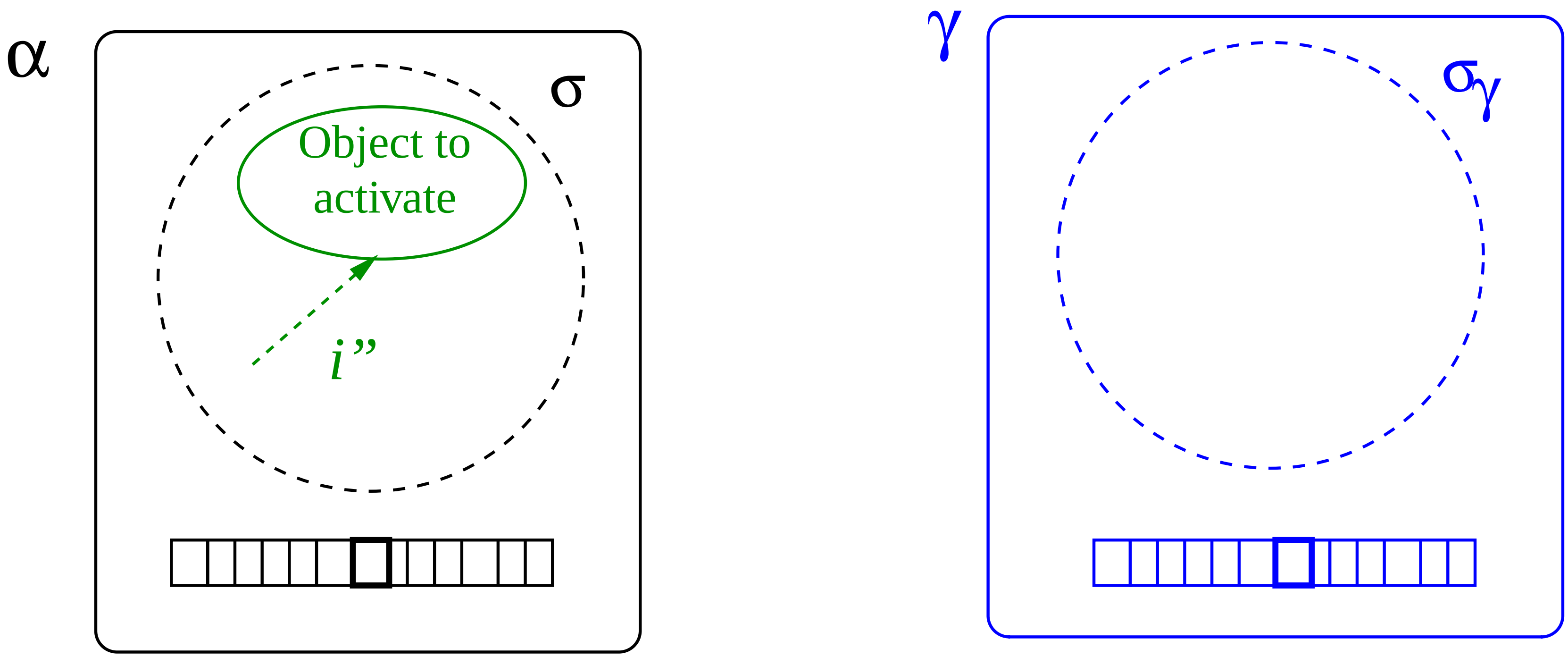

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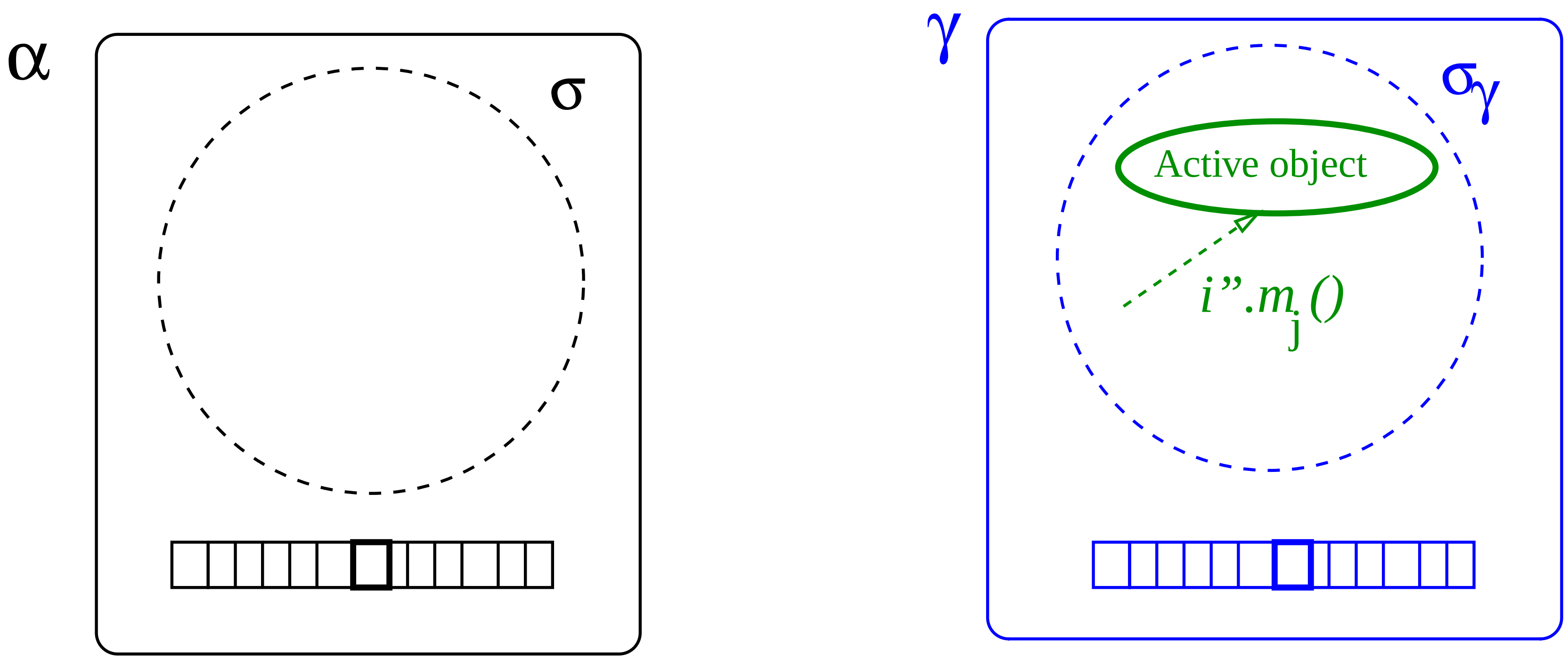
γ fresh activity $\quad copy(\iota'', \sigma) = \sigma_\gamma$



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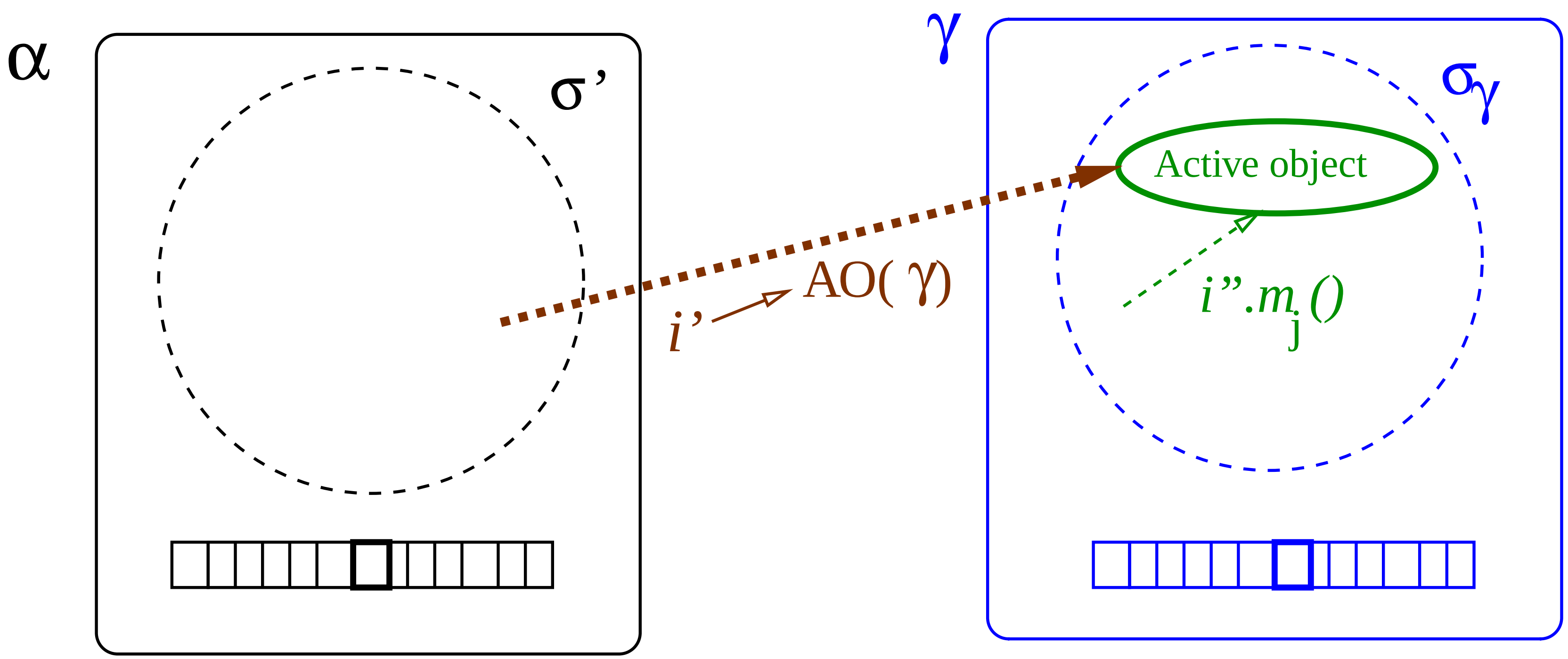
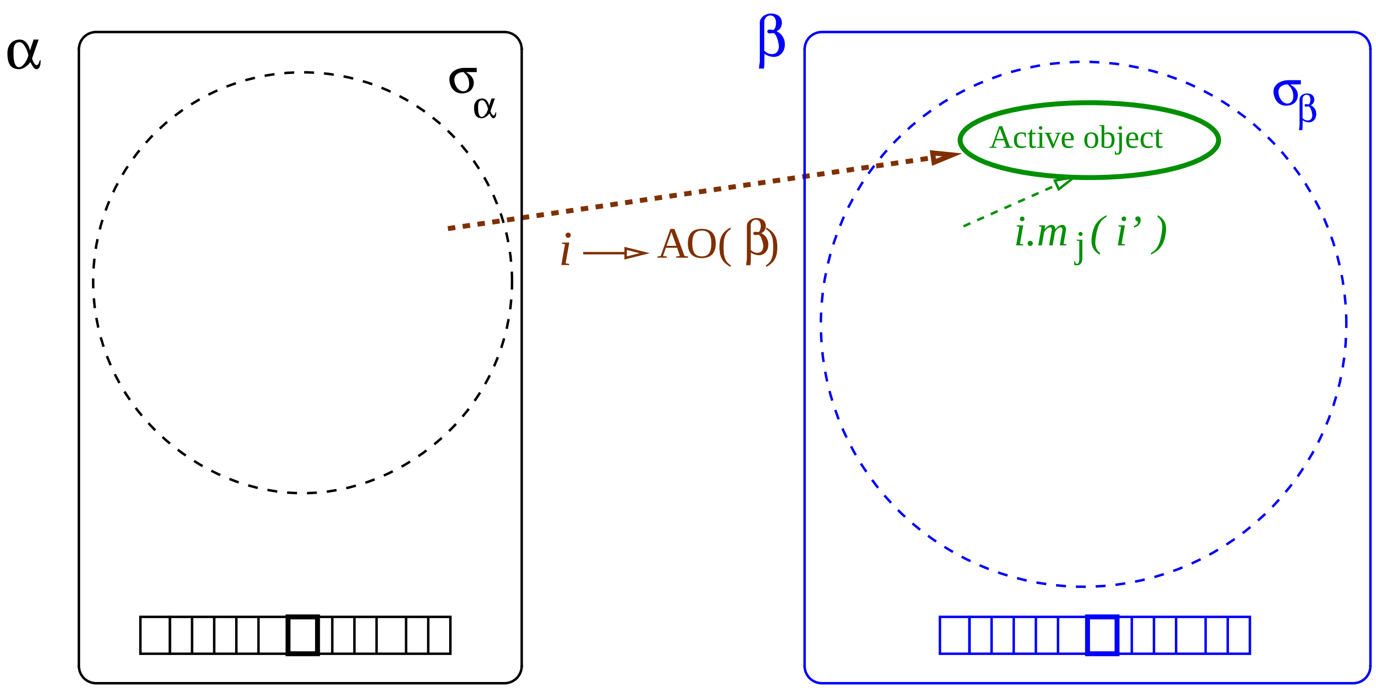


Reduction rules: 2) Request

$\sigma_\alpha(\iota) = AO(\beta)$



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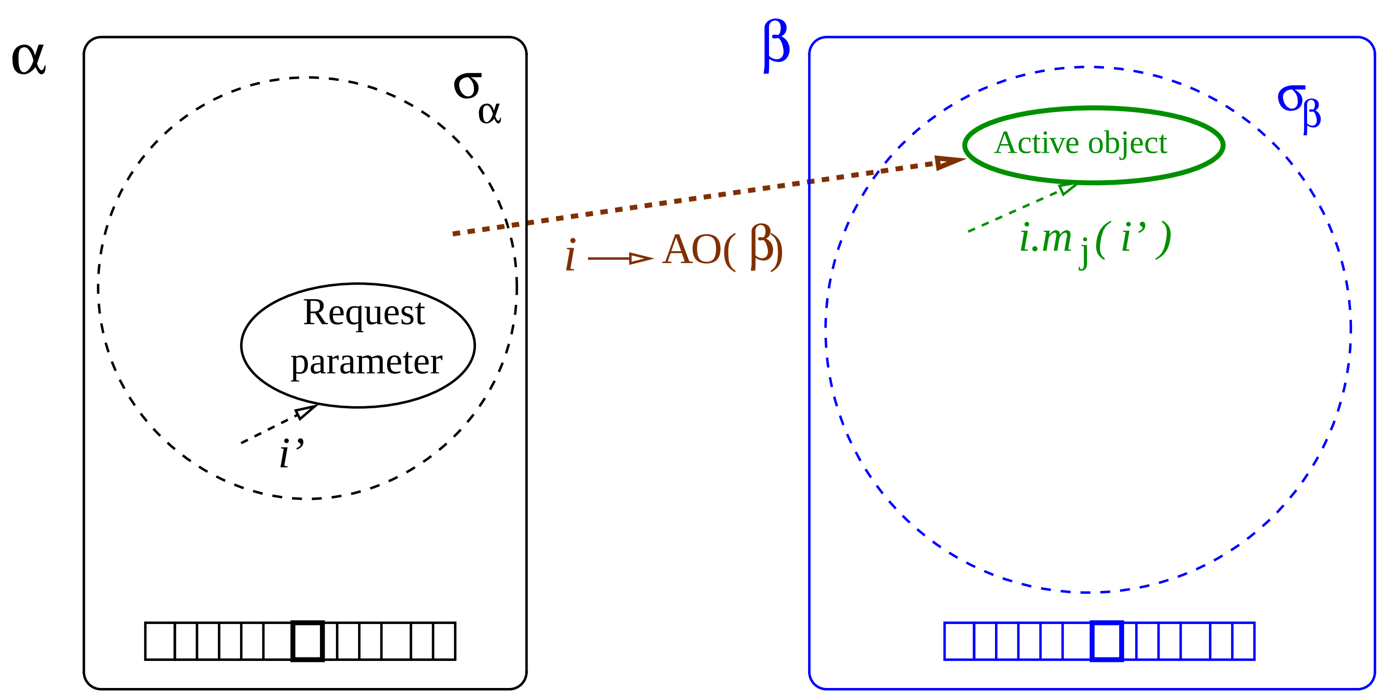

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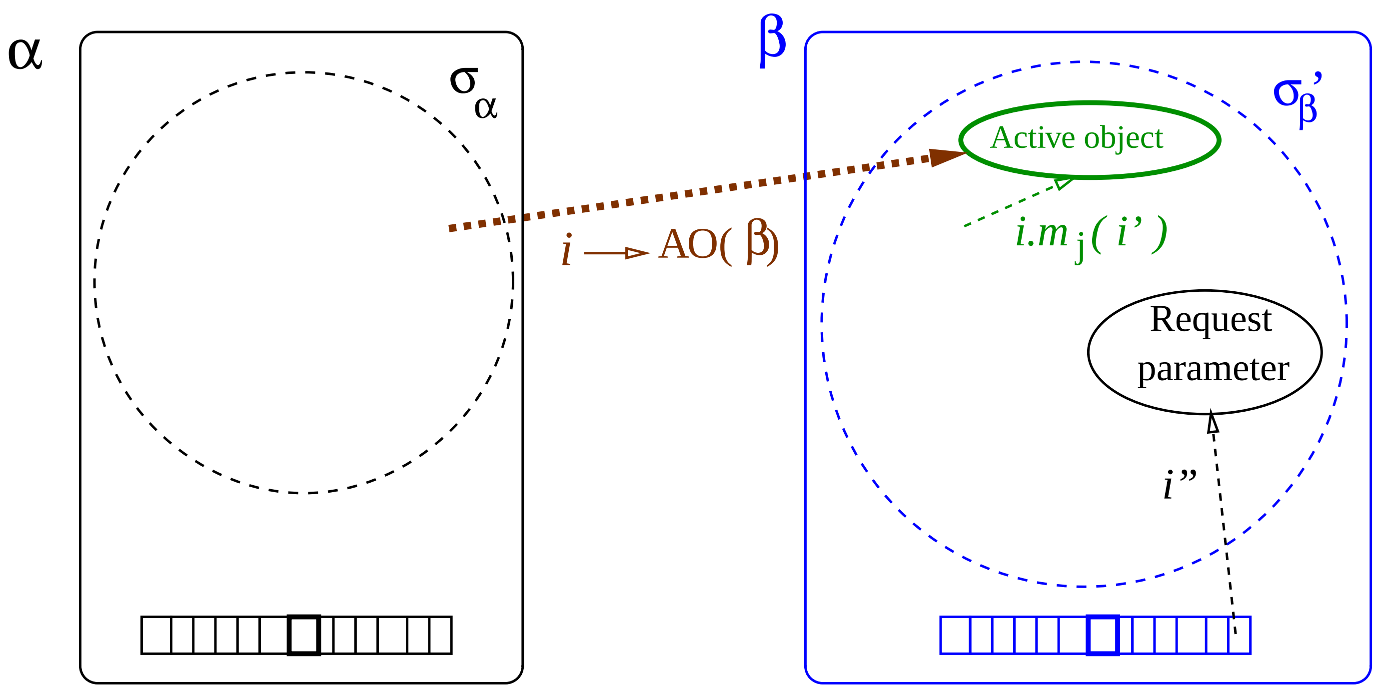

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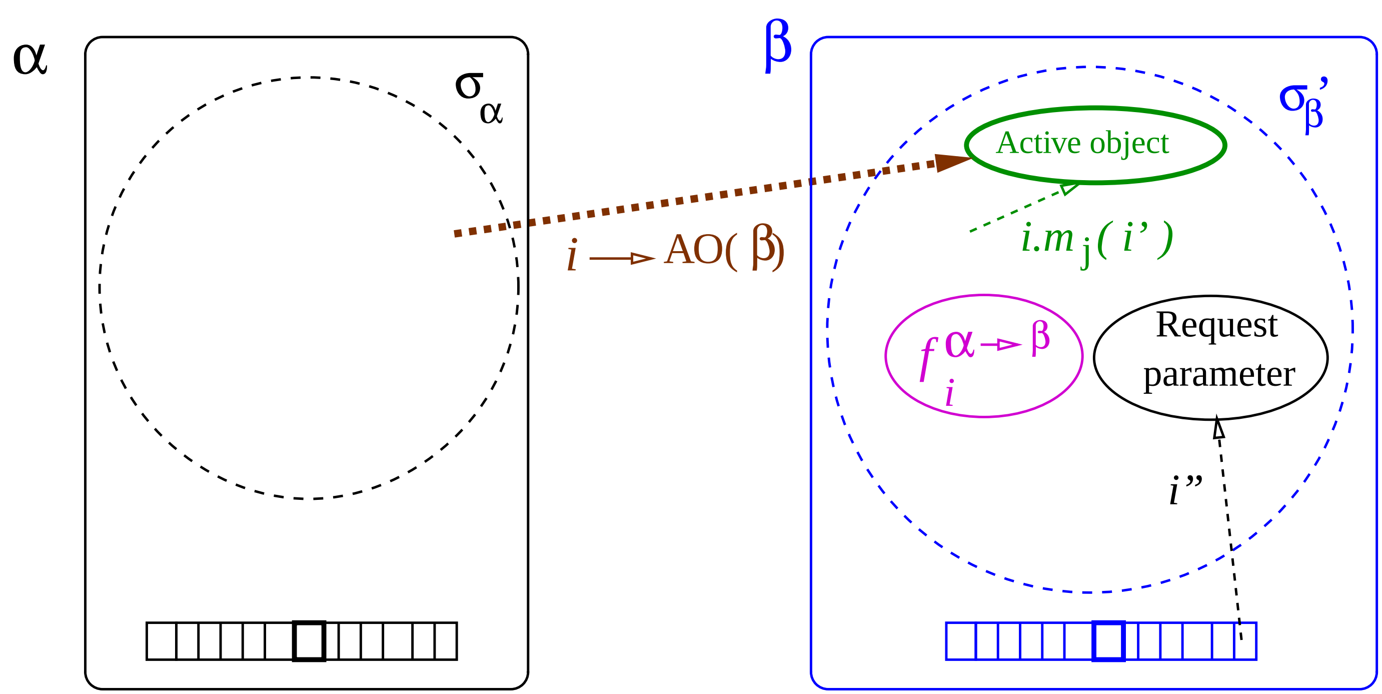

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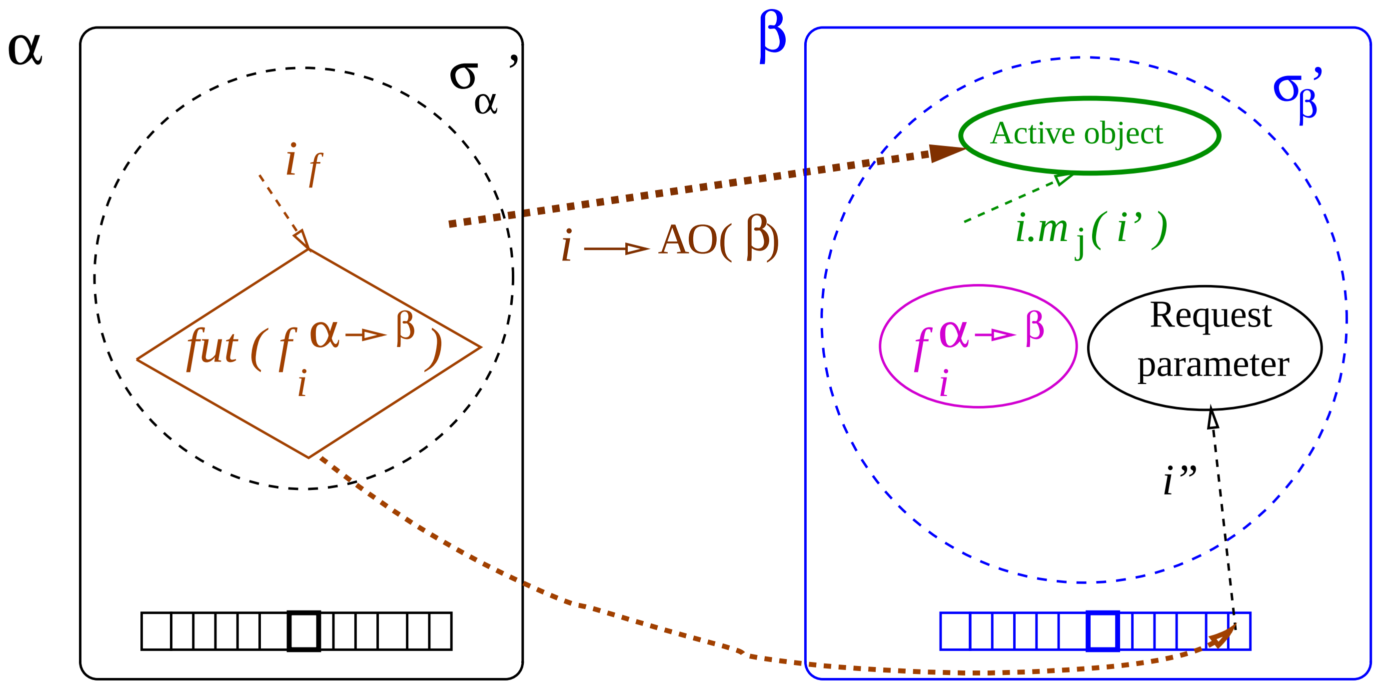

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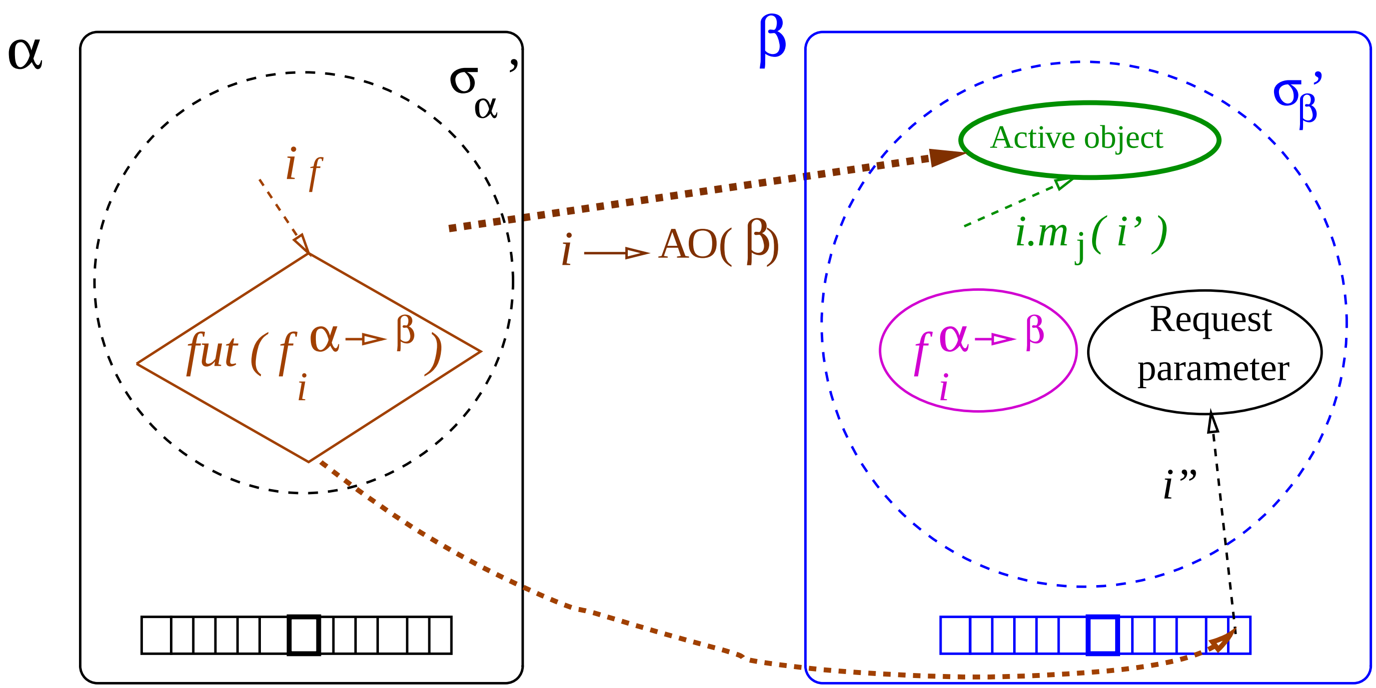

Reduction rules: 3) Reply

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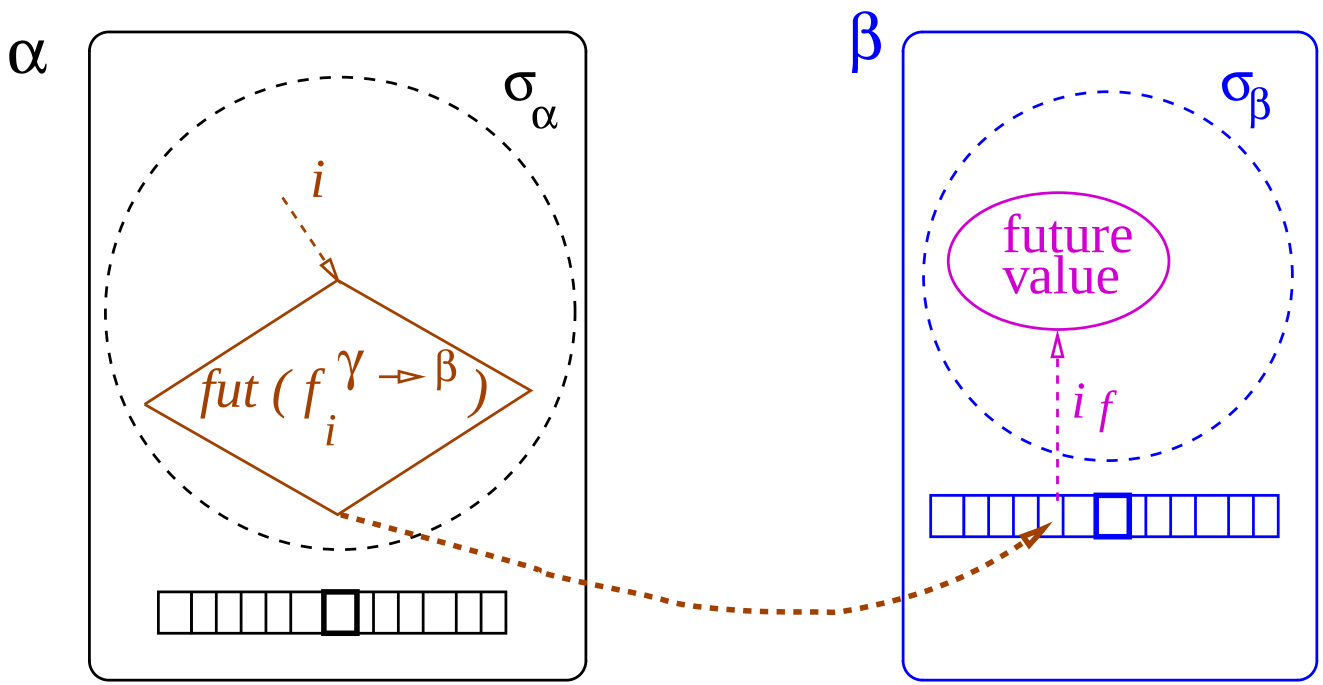

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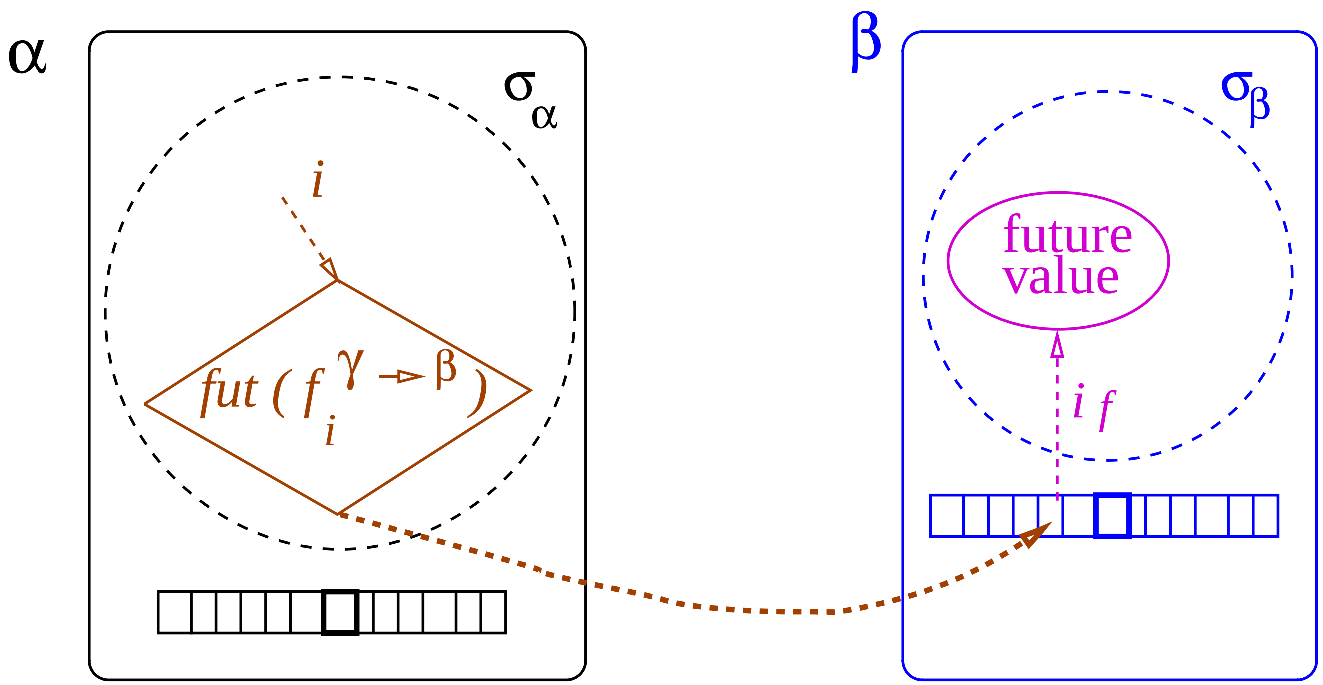

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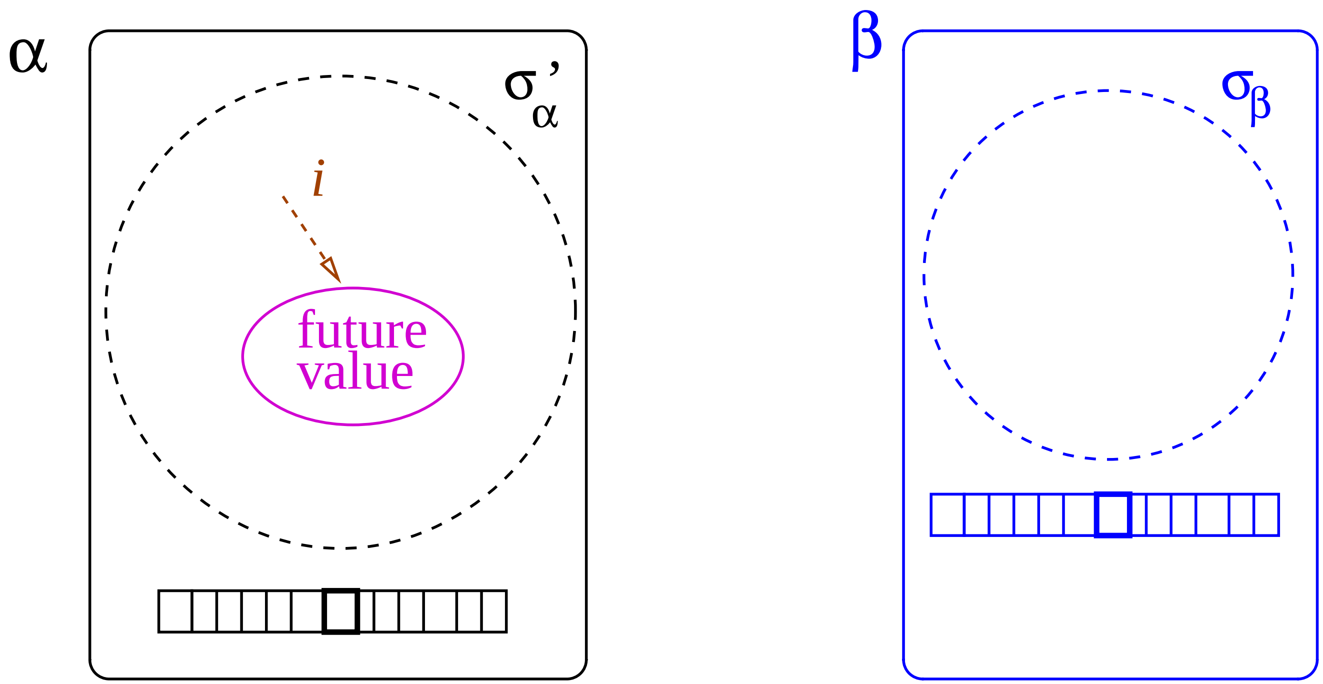

Objectives

Agenda

Main objective: Information Flow Control

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3. Provide a formal security model which is verifiable mathematically

4. Propose an architecture for the implementation of the security model

Related Security Mechanisms

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- Models

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- Models
  - Mandatory Access Controls (MAC)

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- Models
  - Mandatory Access Controls (MAC)
  - Discretionary Access Controls (DAC)

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The ASP Security Model

Syntax and semantics of the security framework

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- $\mathcal{D}$ set of data objects sent as arguments in REQUEST actions: $Rq_{\alpha \rightarrow \beta}(d)$
- $\mathcal{R}$ is the set of objects associated to *futures*, and returned in REPLY actions: $Rp_{\beta \rightarrow \alpha}(r)$

The ASP Security Model *(cntd.)*

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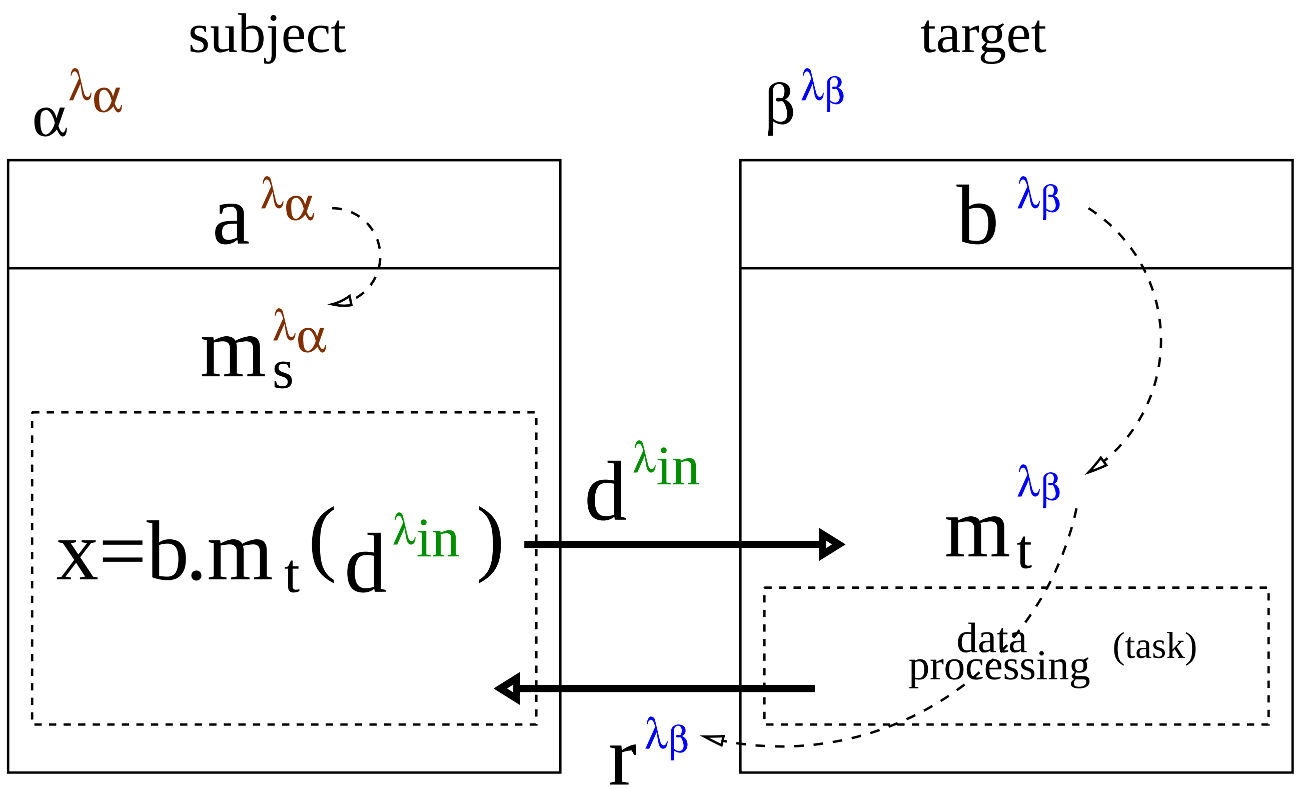

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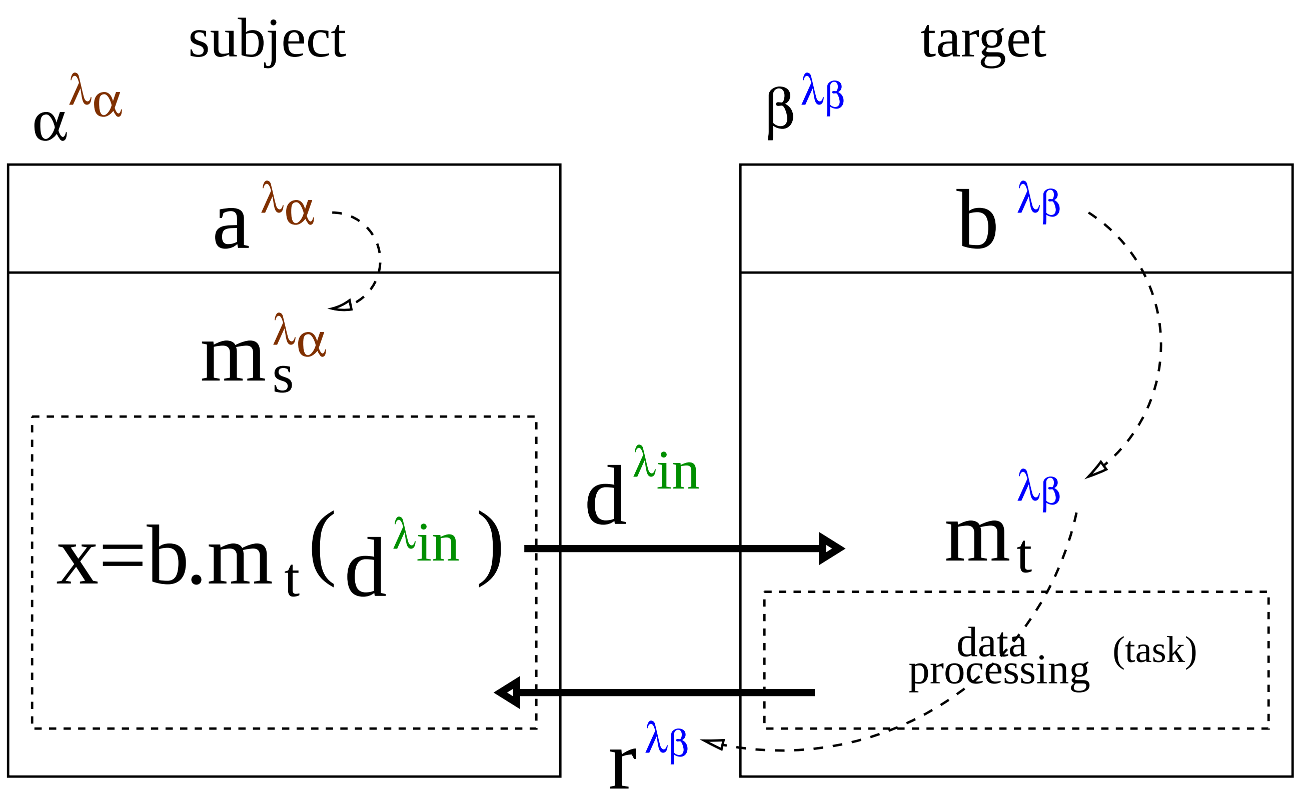

- Transmissions of d and r are restricted by the security rules

The ASP Security Model *(cntd.)*

Agenda

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- In general,
  $a = \{Nw(\gamma, \lambda_\gamma), Rq_{\alpha \to \beta}(d, \lambda_{in}), Rp_{\beta \to \alpha}(r)\}$

The ASP Security Model *(cntd.)*

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Application of the security framework

Agenda

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3.- Results:

Confidentiality, from end-to-end in a flow-path, is guaranteed

Secure Activity Creation

Agenda

- Introduction
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Secure Activity Creation

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$\forall \alpha, \gamma \in \mathcal{S}$: $(\alpha, \gamma, Nw(\gamma, \lambda_\gamma)) \in \mathcal{T} \Longleftrightarrow$

A new activity action is considered secure iff:

Secure Activity Creation

Agenda

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1. The new activity has a higher security level compared to its creator

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2. or, in case the new activity has a lower security (i.e. a downgrade), the creation action must be explicitly allowed

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Special case: Migration of an existing activity

Secure Request Transmission

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Secure Request Transmission

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Agenda

Secure Request Transmission

$$\forall \alpha, \beta \in \mathcal{S}\colon (\alpha, \beta, Rq_{\alpha \to \beta}(d, \lambda_{in})) \in \mathcal{T} \iff$$

A request transmission action is considered secure iff:

Secure Request Transmission

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Secure Reply Transmission

Agenda

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$$\forall \alpha, \beta \in \mathcal{S}\text{: } (\alpha, \beta, Rp_{\beta\rightarrow\alpha}(r)) \in \mathcal{T} \iff$$

A reply transmission action is considered secure iff:

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Secure ASP reduction rules

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$$\frac{\gamma \text{ fresh activity} \qquad \iota' \notin dom(\sigma) \qquad \sigma' = \{\iota' \mapsto AO(\gamma)\} :: \sigma \qquad \sigma_\gamma = copy(\iota'', \sigma) \qquad (\alpha, \gamma, Nw(\gamma, \lambda_\gamma)) \in \mathcal{T}}{\alpha^\lambda[\mathcal{R}[Active^{\lambda a}(\iota'', m_j)]; \sigma; \iota; F; R; f] \parallel P \longrightarrow \alpha^\lambda[\mathcal{R}[\iota']; \sigma'; \iota; F; R; f] \parallel \gamma^{\lambda a}[\iota''.m_j(); \sigma_\gamma; \iota''; \emptyset; \emptyset; \emptyset] \parallel P} \text{ (SecNEWACT)}$$

$$\frac{\sigma_\alpha(\iota) = AO(\beta) \qquad \iota'' \notin dom(\sigma_\beta) \qquad f_i^{\alpha\to\beta} \text{ new future} \qquad \iota_f \notin dom(\sigma_\alpha) \qquad \sigma'_\beta = Copy\&Merge(\sigma_\alpha, \iota' \; ; \; \sigma_\beta, \iota'') \qquad \sigma'_\alpha = \{\iota_f \mapsto fut(f_i^{\alpha\to\beta})\} :: \sigma_\alpha \qquad (\alpha, \beta, Rq_{\alpha\to\beta}(\sigma_\alpha(\iota'), \lambda_{in})) \in \mathcal{T}}{\alpha^{\lambda\alpha}[\mathcal{R}[\iota.m_j(\iota'^{\lambda in})]; \sigma_\alpha; \iota_\alpha; F_\alpha; R_\alpha; f_\alpha] \parallel \beta^{\lambda\beta}[a_\beta; \sigma_\beta; \iota_\beta; F_\beta; R_\beta; f_\beta] \parallel P \longrightarrow \alpha^{\lambda\alpha}[\mathcal{R}[\iota_f]; \sigma'_\alpha; \iota_\alpha; F_\alpha; R_\alpha; f_\alpha] \parallel \beta^{\lambda\beta}[a_\beta; \sigma'_\beta; \iota_\beta; F_\beta; R_\beta :: [m_j; \iota''; f_i^{\alpha\to\beta}]; f_\beta] \parallel P} \text{ (SecREQUEST)}$$

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Parallel configurations are now of the form:

$$P, Q ::= \alpha^{\lambda_\alpha}[a; \sigma; \iota; F; R; f] \parallel \beta^{\lambda_\beta}[\cdots] \parallel \cdots$$

The Secure Information Flow

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- Hence, it is derived the **secure information flow** notion:

$$\frac{(\alpha, \beta, Rq_{\alpha \to \beta}(\sigma(\iota'), \lambda_{in})) \in \mathcal{T}}{Sec\varphi_{\emptyset}(\alpha, \beta)} \qquad \frac{(\beta, \alpha, Rp_{\beta \to \alpha}(\sigma_{\alpha}(\iota_f))) \in \mathcal{T}}{Sec\varphi_{\emptyset}(\beta, \alpha)}$$

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The syntax $Sec\varphi_{\emptyset}(\alpha, \beta)$ means there is a secure flow ($Sec\varphi$), with no other intermediate activities ($\emptyset$), happening between activities α and β

The Secure Path for Information Flow

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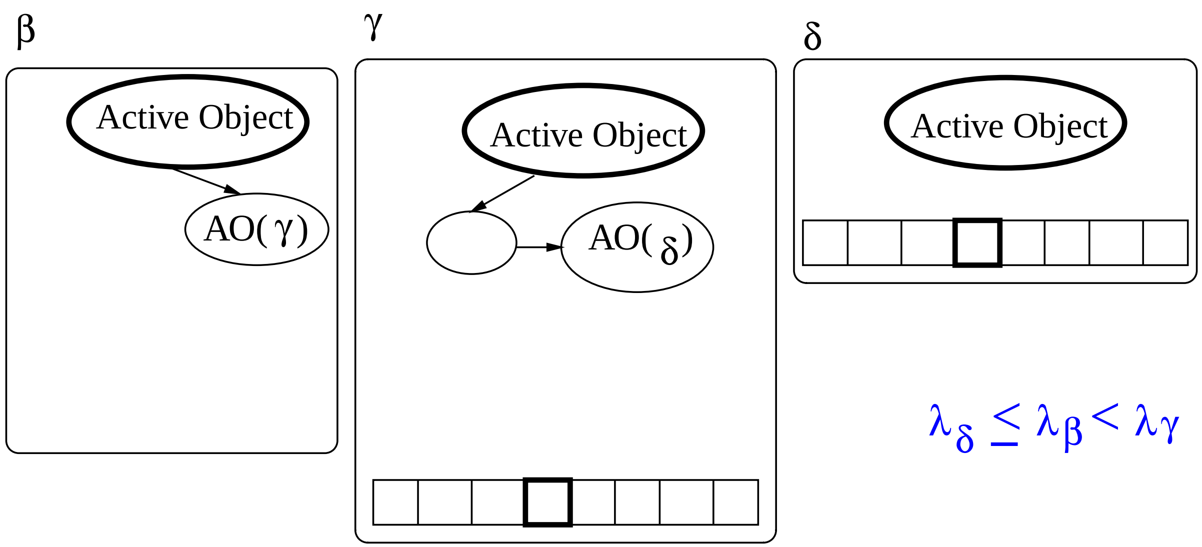
- There is a secure information flow from end-to-end on any flow path when:

$$Sec\varphi_{\gamma_1\cdots\gamma_n}(\alpha,\beta) \iff$$
$$Sec\varphi_{\emptyset}(\alpha,\gamma_1) \wedge Sec\varphi_{\emptyset}(\gamma_1,\gamma_2) \wedge \cdots \wedge Sec\varphi_{\emptyset}(\gamma_n,\beta)$$

Service-Oriented Computing and *futures*

Impossible future updates with symmetric patterns of communications



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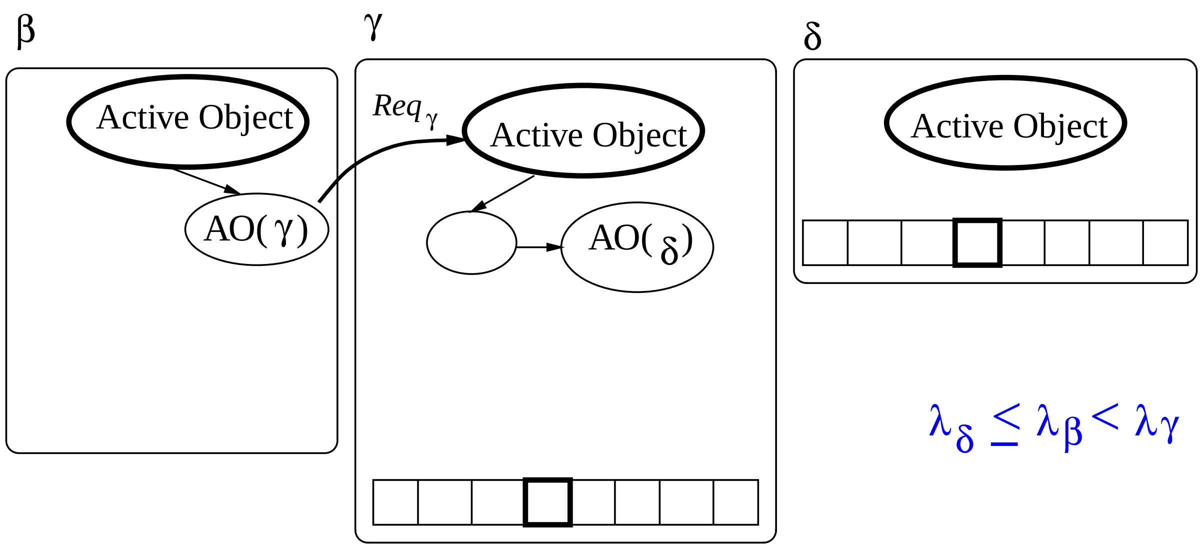

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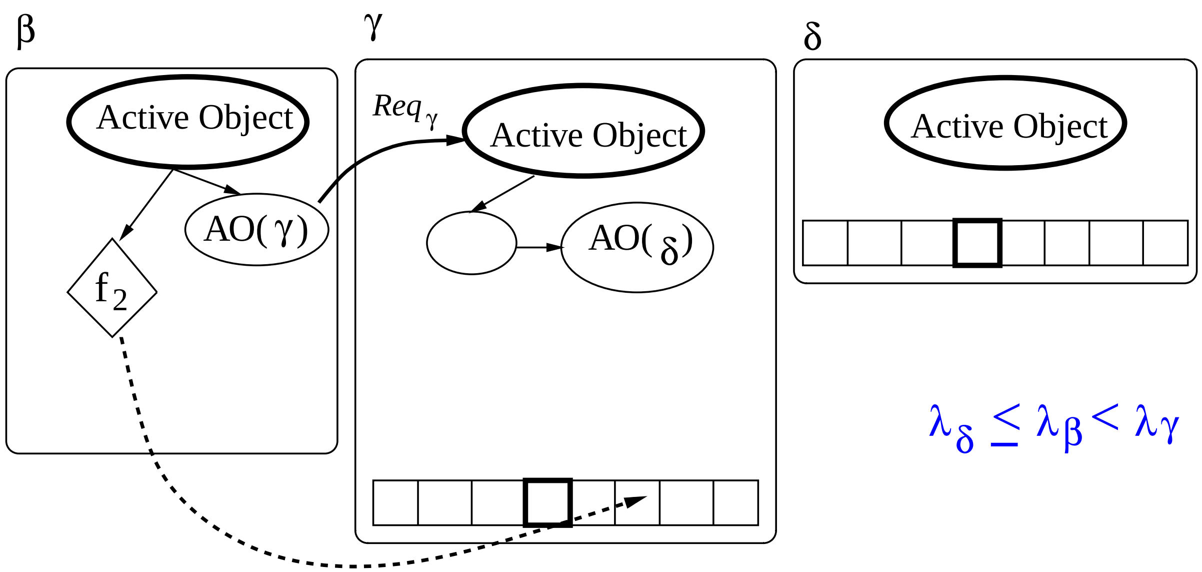

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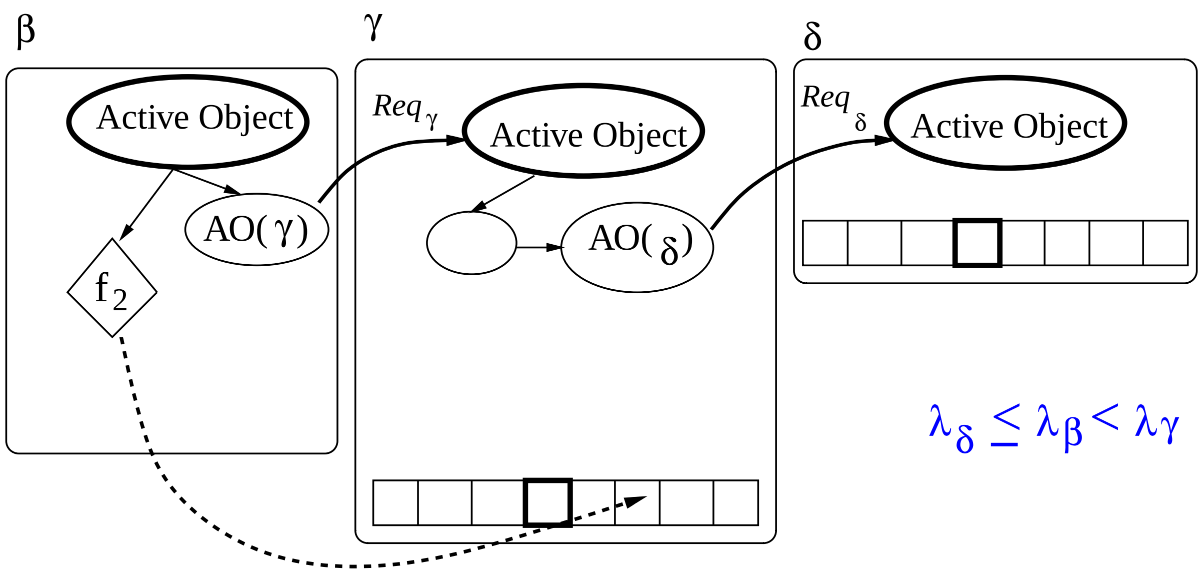

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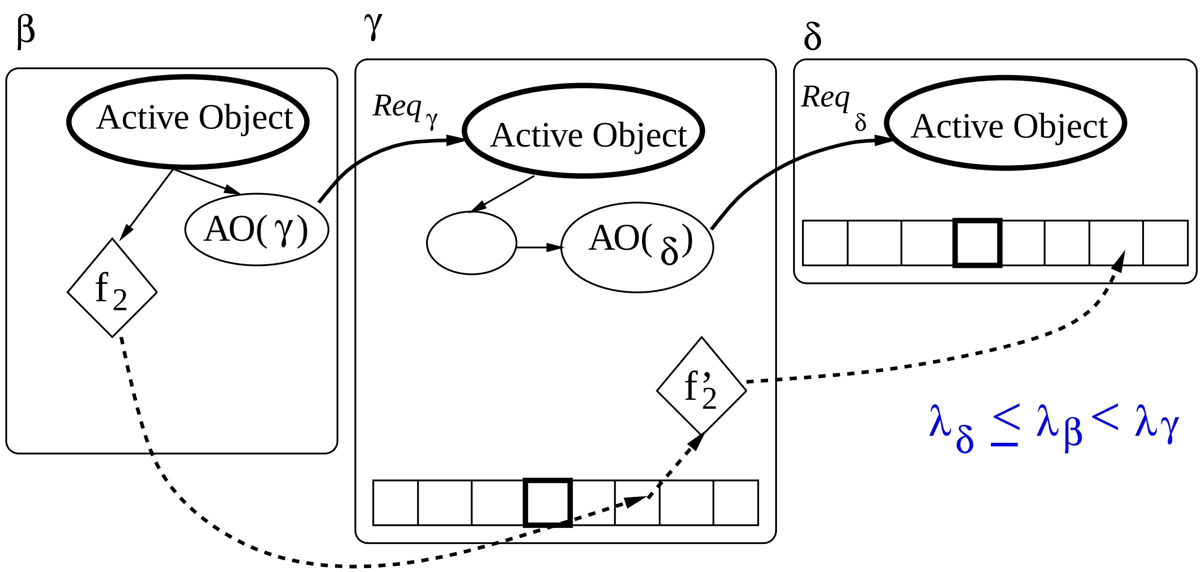

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Agenda

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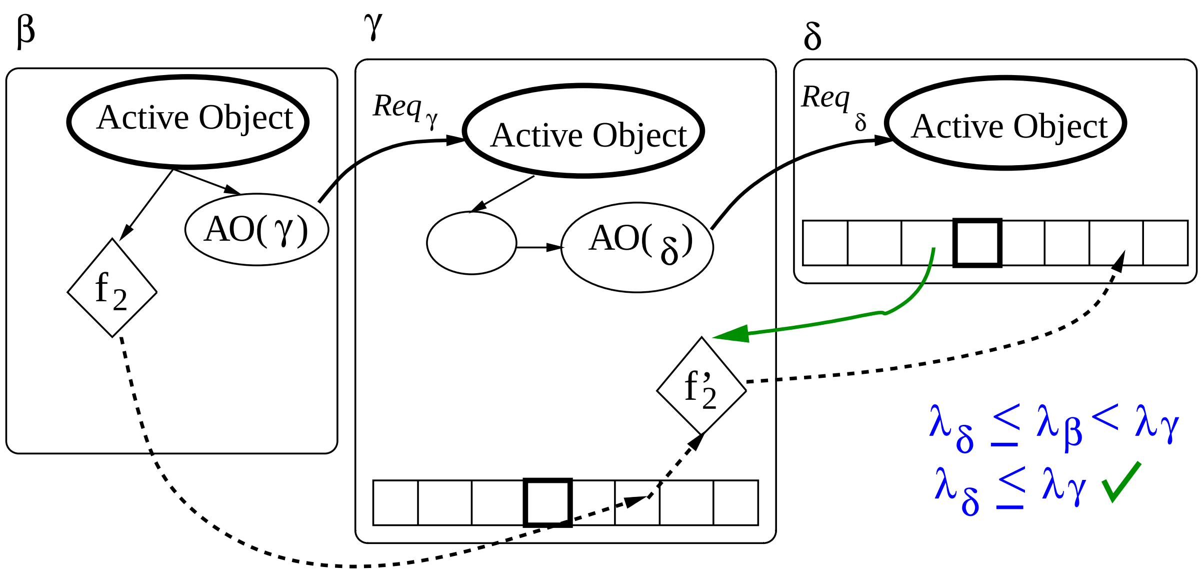

$\lambda_\delta \leq \lambda_\beta < \lambda_\gamma$

$\lambda_\delta \leq \lambda_\gamma$ ✓

Service-Oriented Computing and *futures*

Agenda

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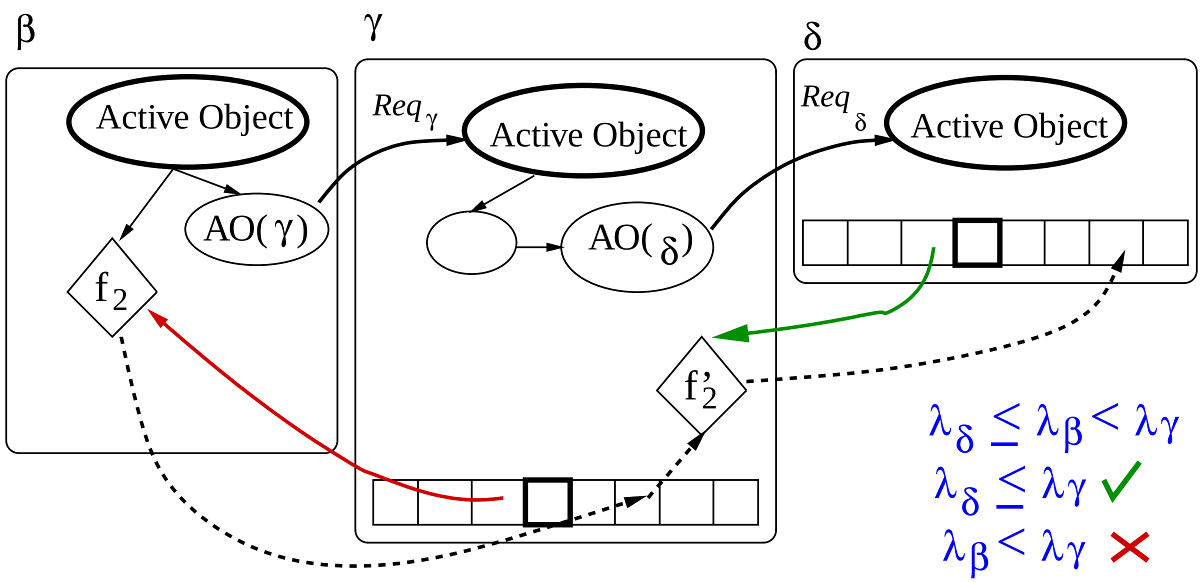

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Service-Oriented Computing and *futures* (contd.)

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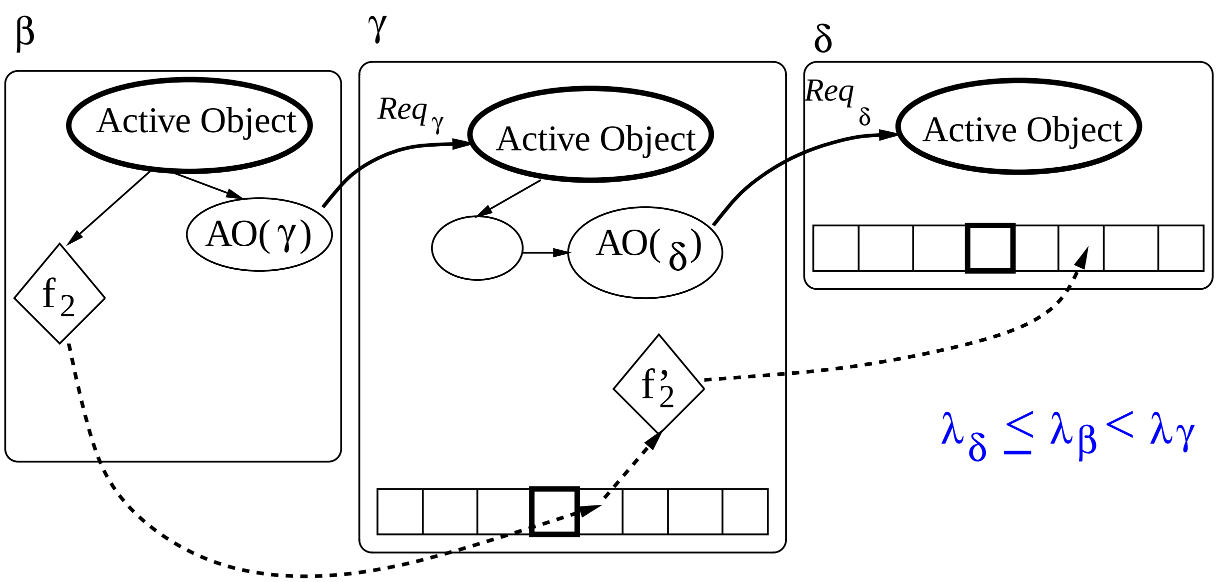

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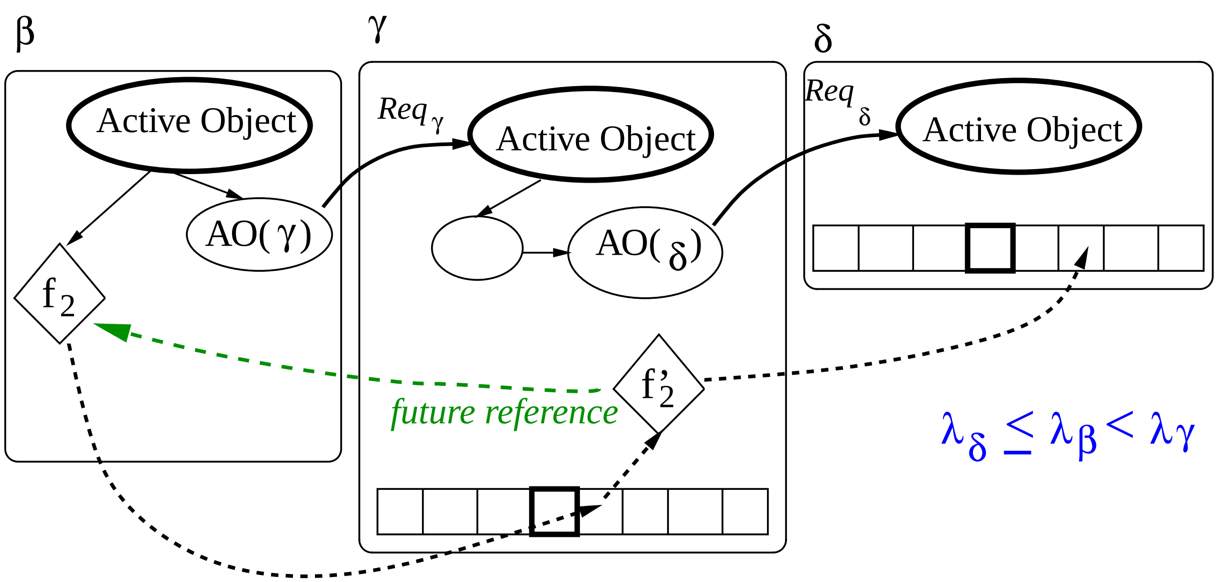

Service-Oriented Computing and *futures* (contd.)

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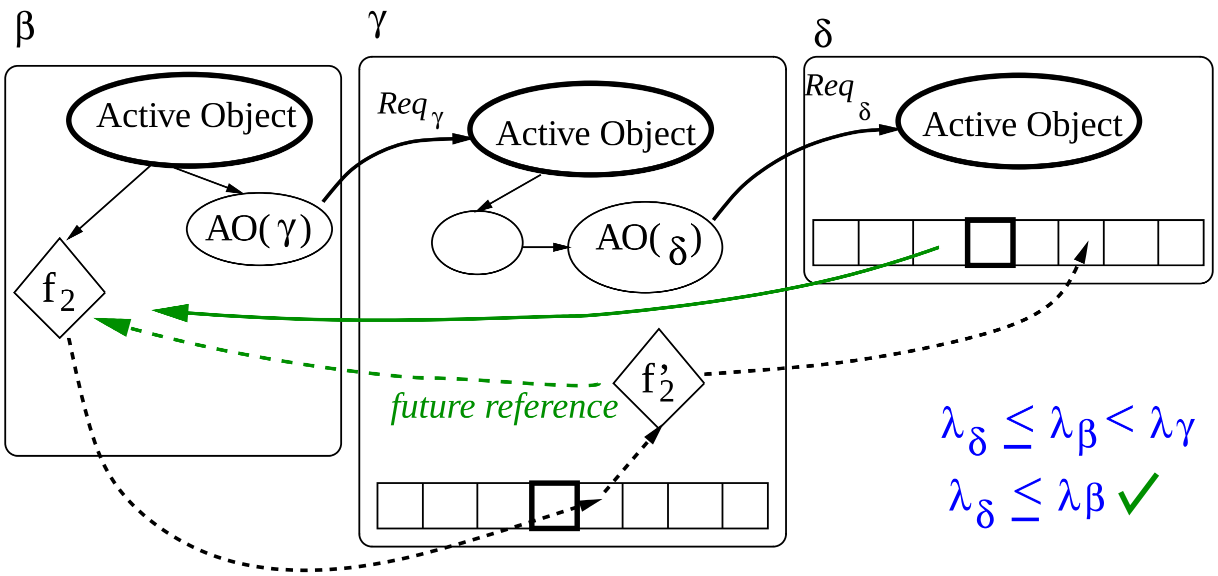

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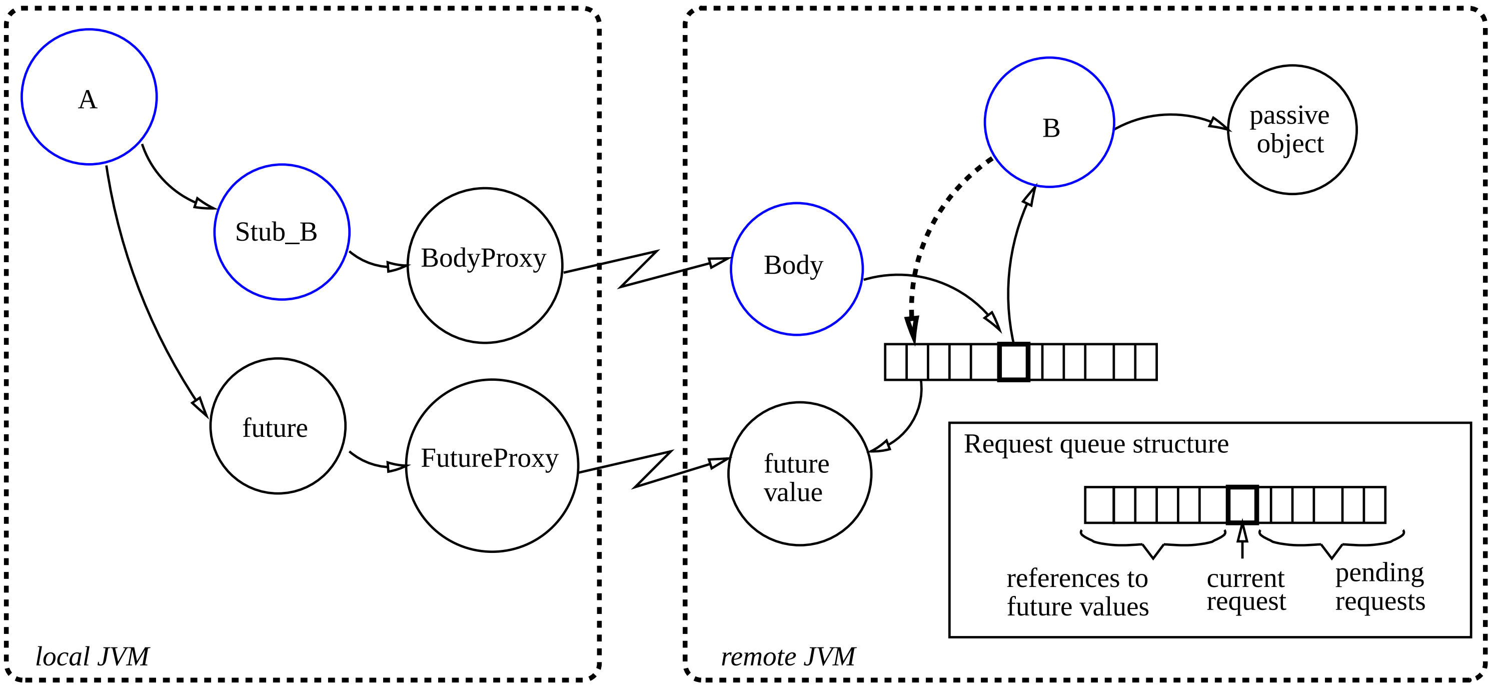
Implementation of the Security Model

Architecture of *active objects*



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Implementation of the Security Model *(contd.)*

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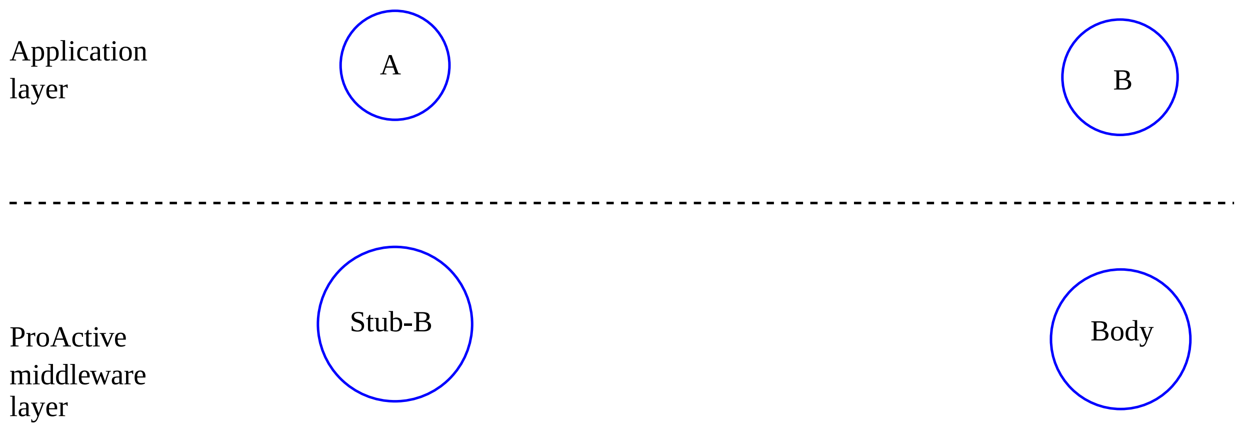
Security schema for *active objects*



Implementation of the Security Model *(contd.)*

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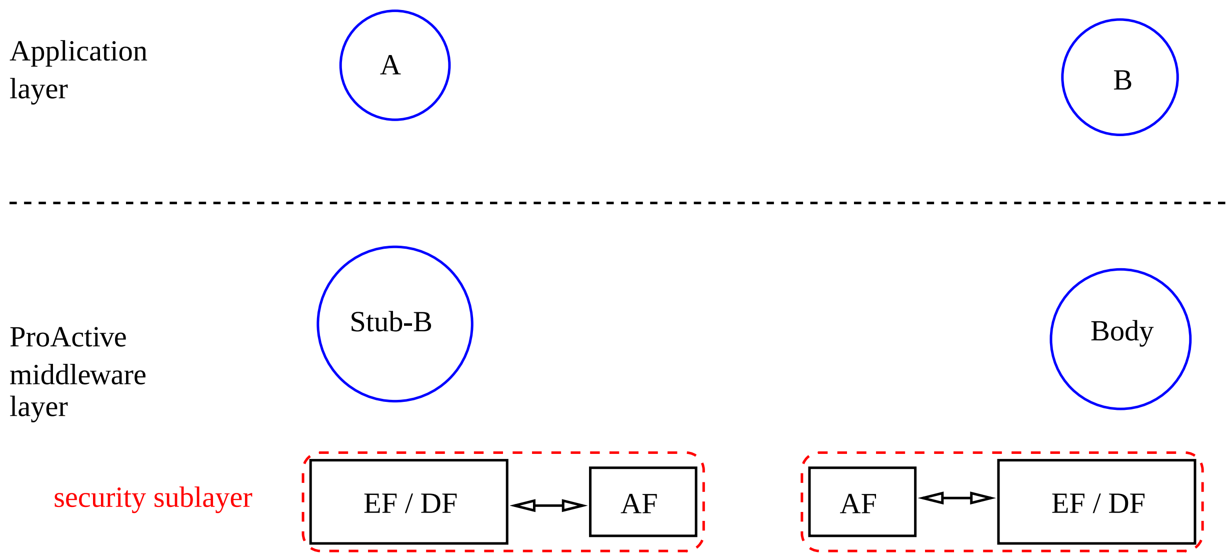

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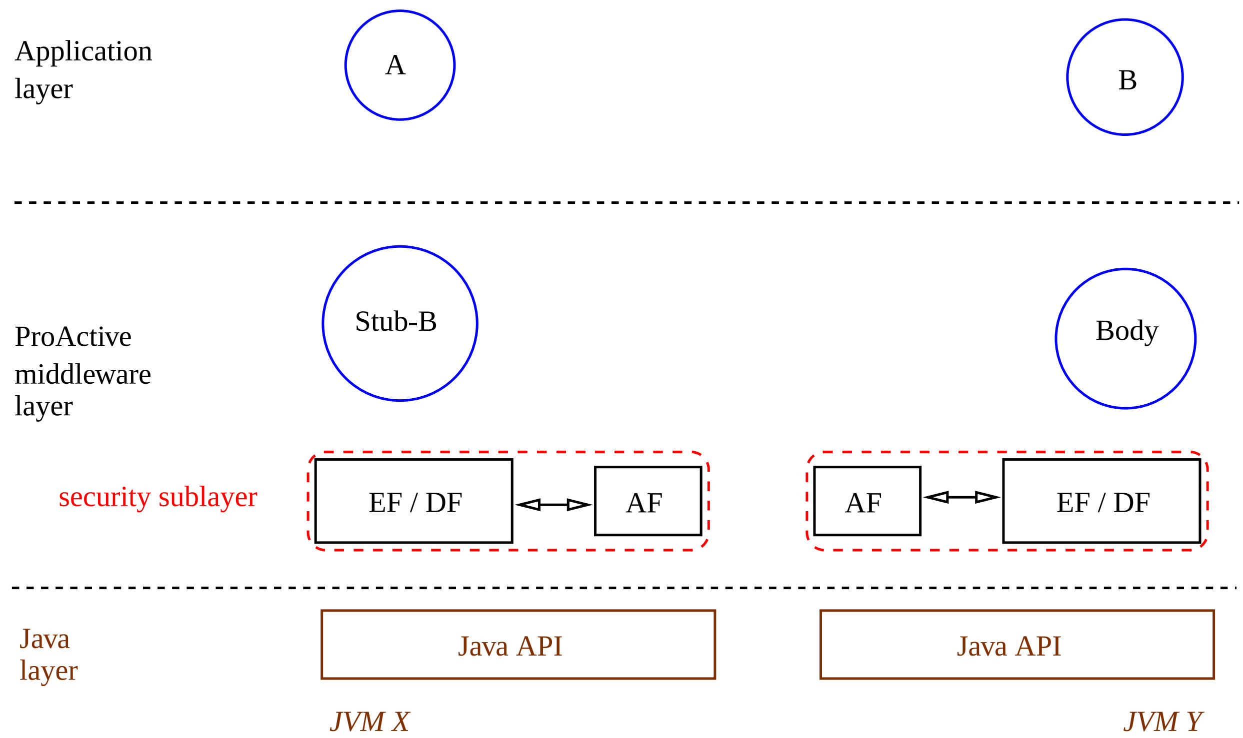

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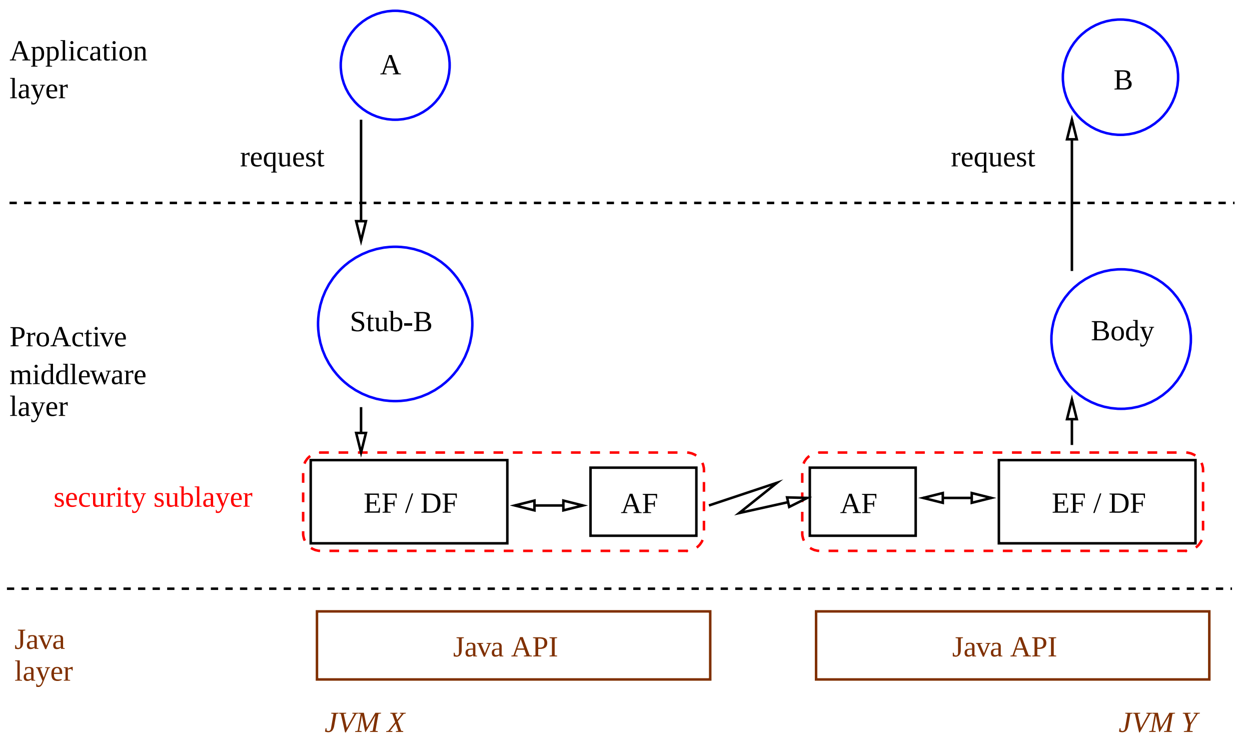

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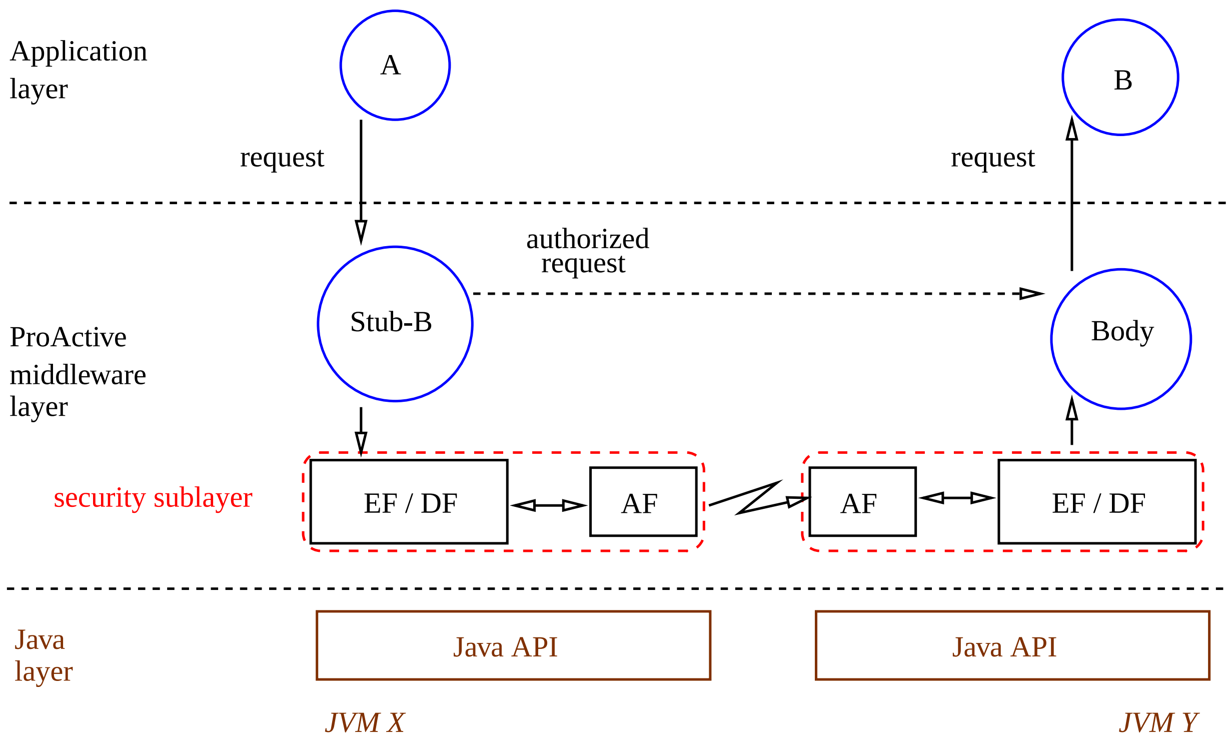

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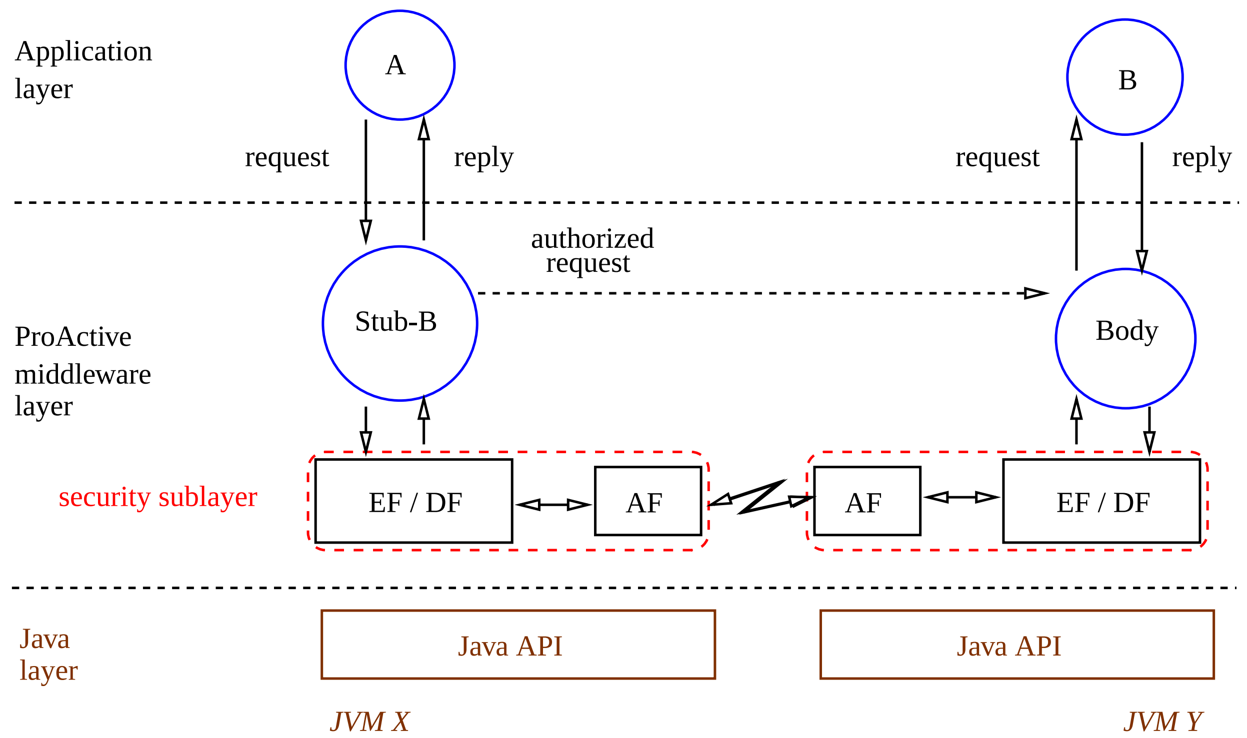

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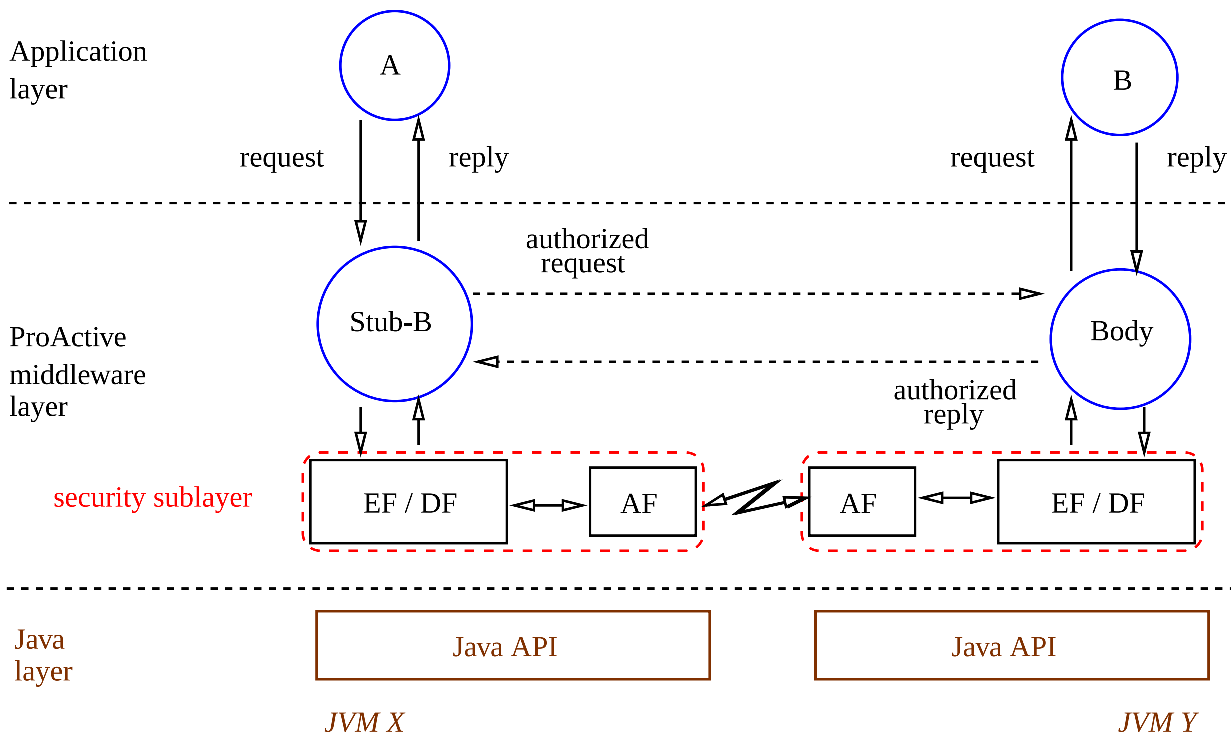

Implementation of the Security Model *(contd.)*

Agenda

Detailed Security sub-layer

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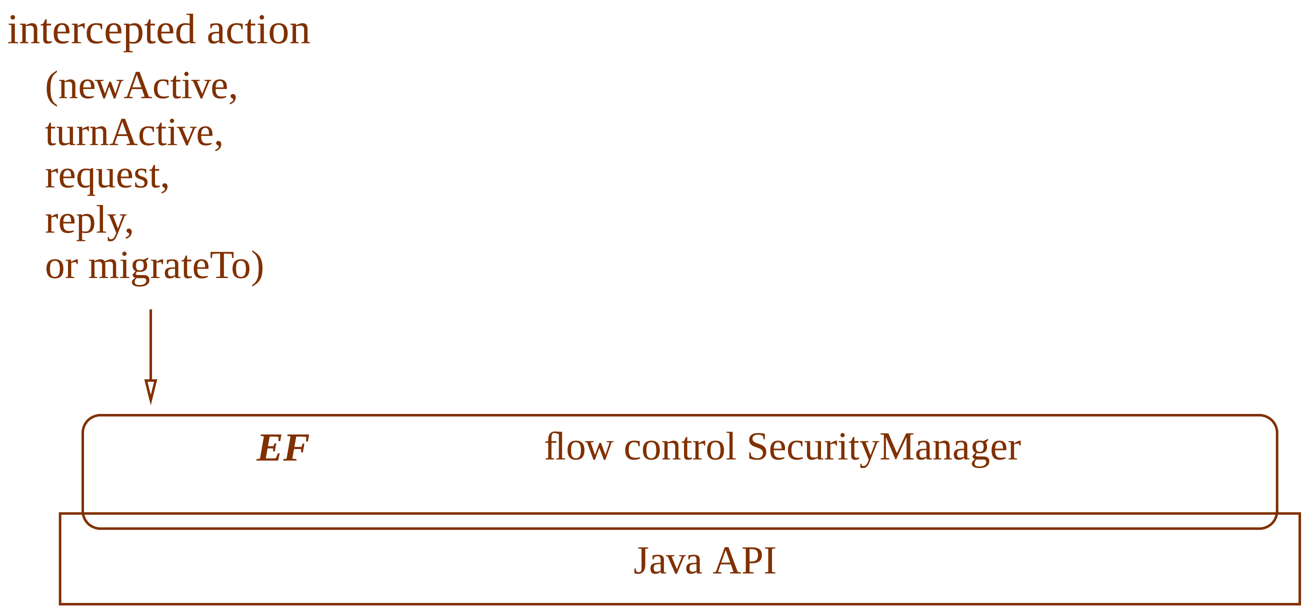

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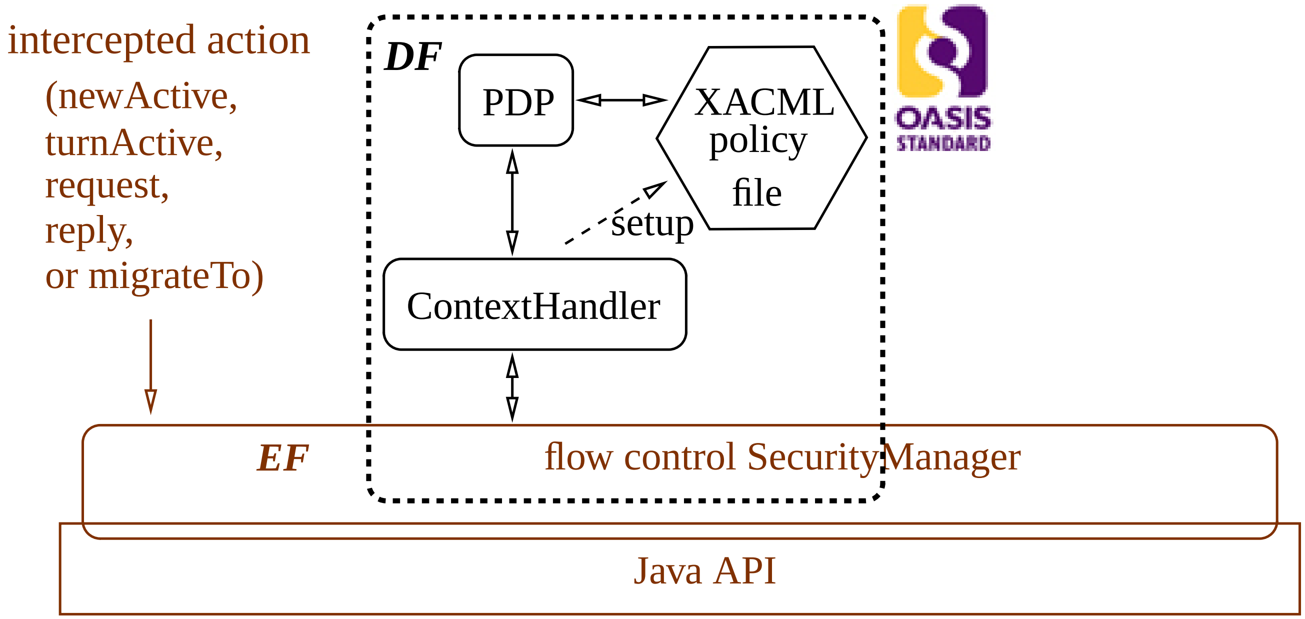
Implementation of the Security Model *(contd.)*

Detailed Security sub-layer



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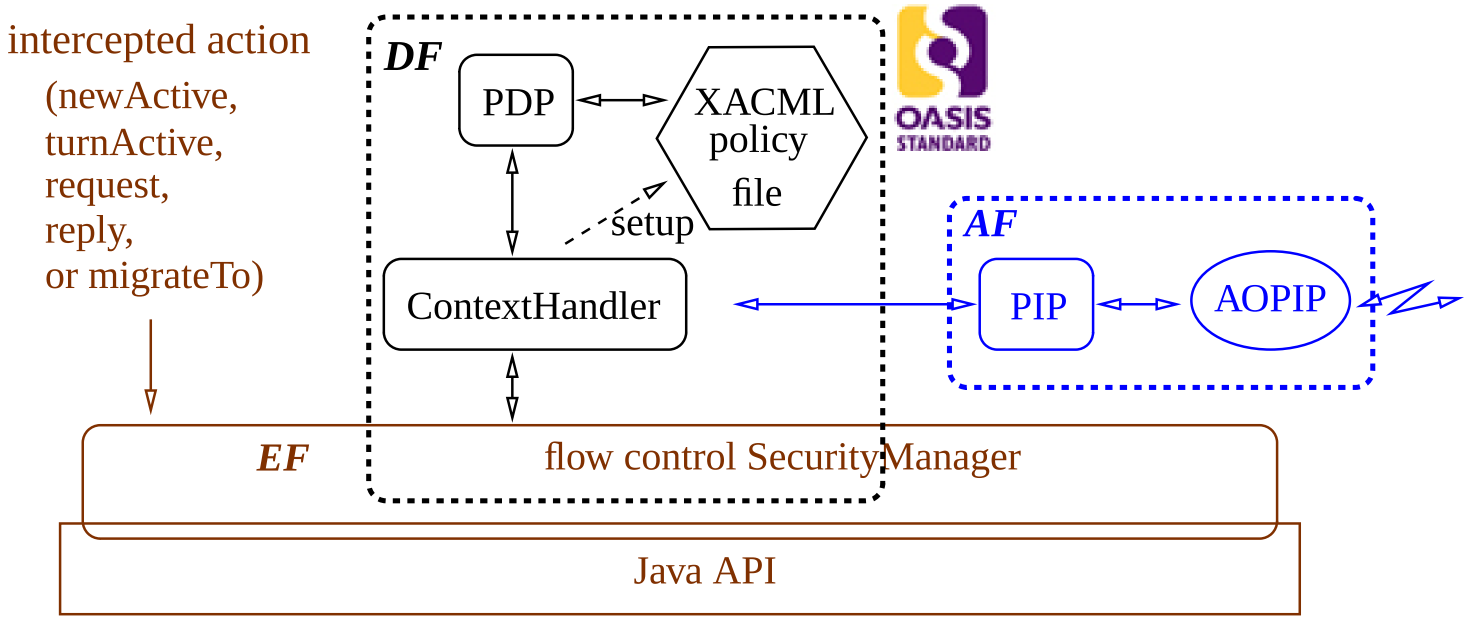
Implementation of the Security Model *(contd.)*

Agenda

Detailed Security sub-layer



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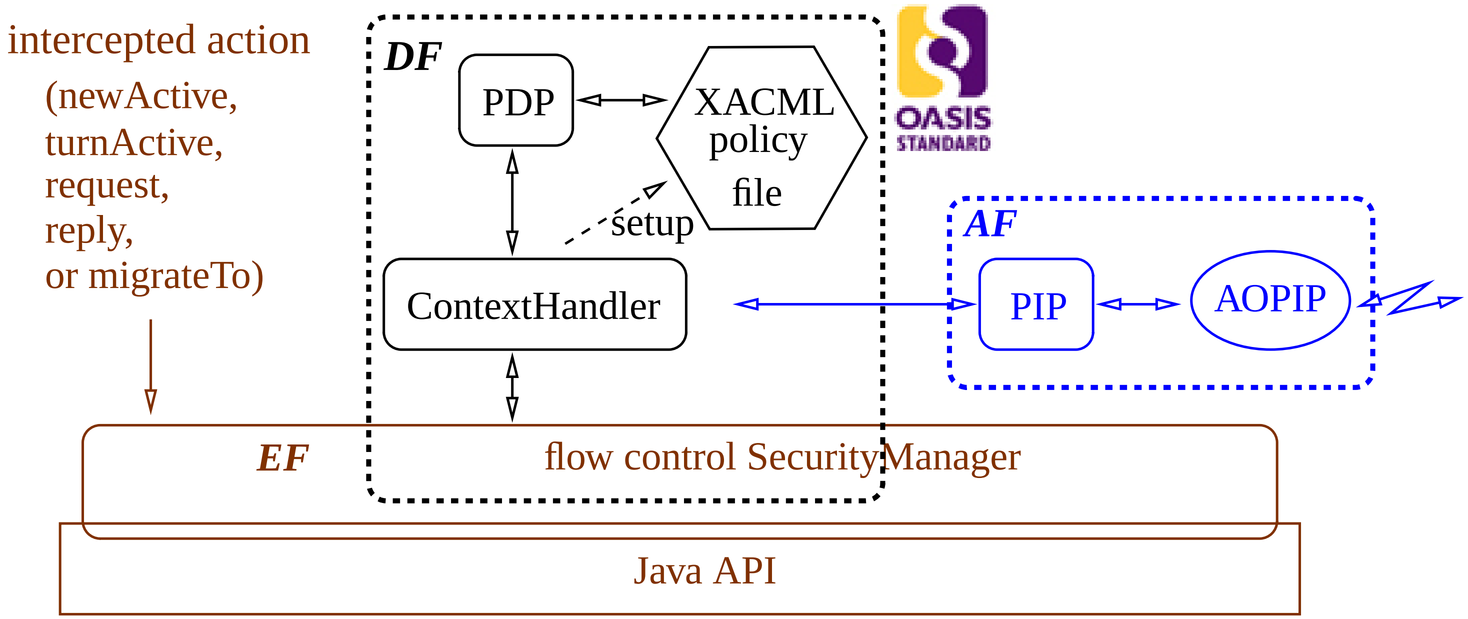

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- Scalability:
  - Dynamic checks performed only at activity creation, and inter-activity communications
- Extendable:
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Perspectives

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- The security mechanism can be applied to the Components paradigm

Q&A

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Questions ?

Thank you for your attention

Q&A

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