Formalization of security requirements

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Journée Langages - 17 Mars 2016

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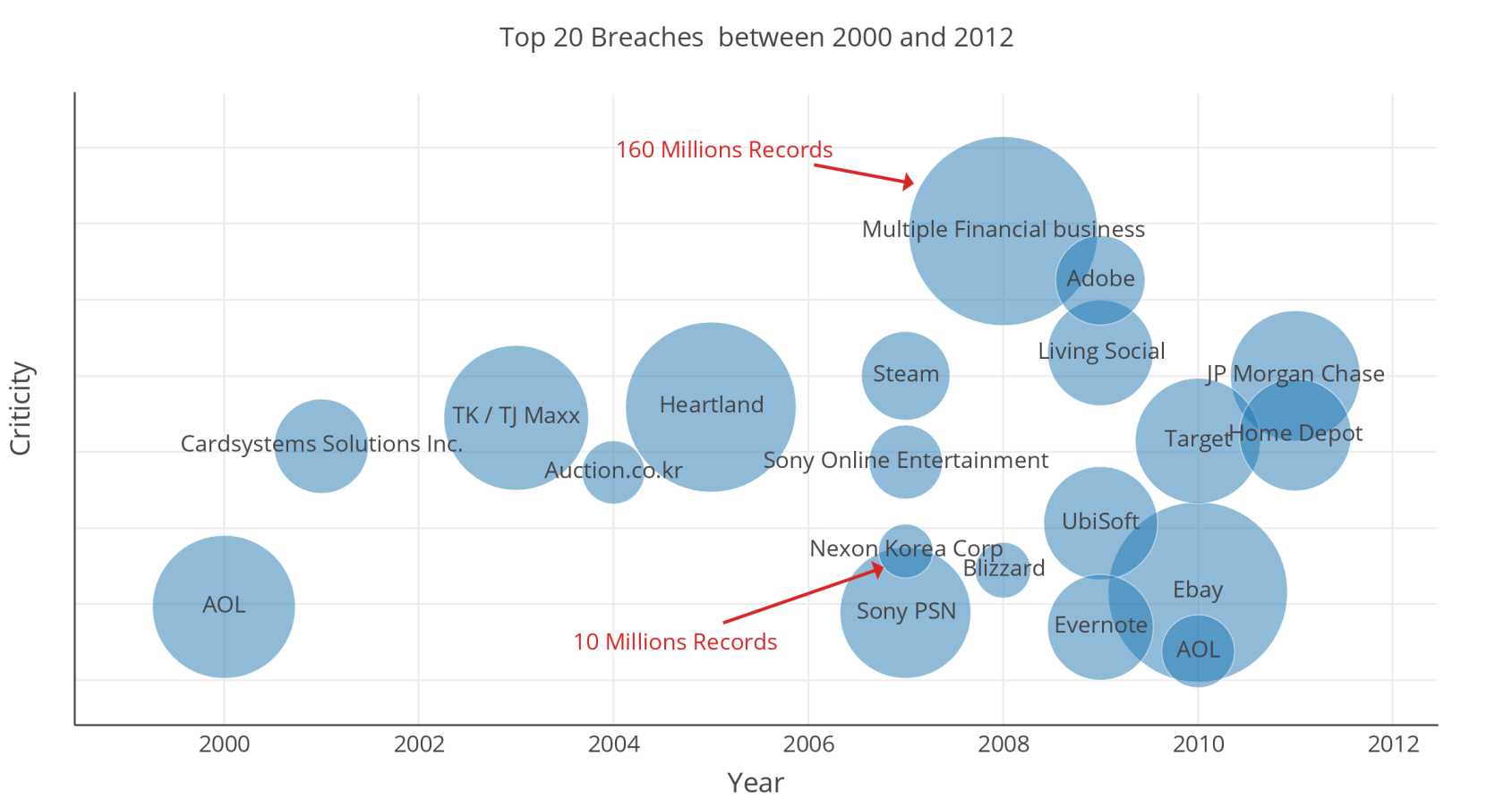
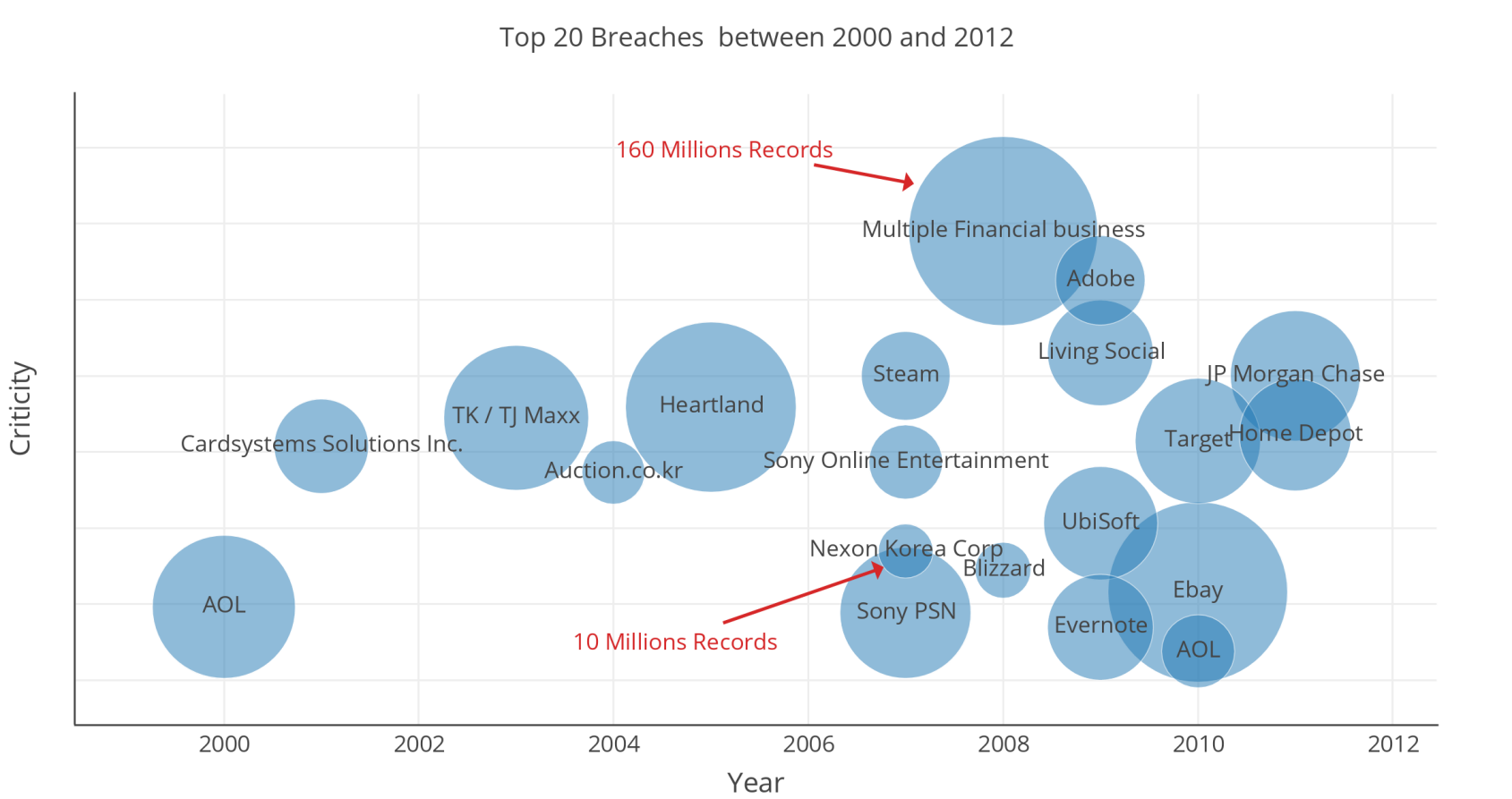
Growing security breaches



Growing security breaches



2015 Average cost per breach: **$3.79 million**

2015 Average cost per stolen record: $154

Current practices: Manual security

An IT managing security “by hand” (configuration, etc.)

Cumbersome Security

- Lack of usability: Complex security mechanisms
- Lack of expertise: Misconfiguration
- Lack of formalism: Requirements in natural language

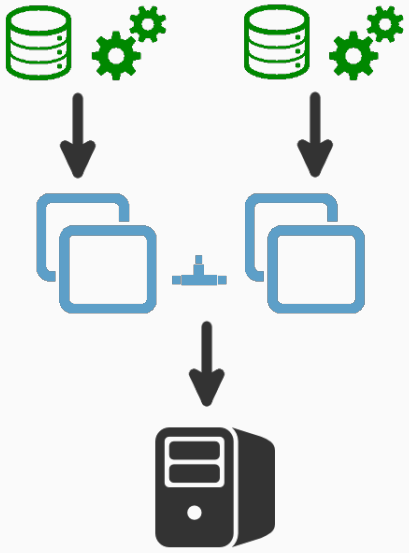
Security Composability

The sum of locally secure systems **does not imply** a globally secure system

What to Secure?

Virtualized Distributed Systems

- Data
- Processes/Services
- VM
- Network



Trends

- Complexification of distributed systems
- Outsourcing and Cloud adoption
- Mutualization of resources: Multitenancy

Global Problem Statement

Problem

How to provide global security of large scale virtualized distributed systems ?

- Usability: ability for a user to specify security requirements.
- Scalability: no centralized system or single point of failure.
- Provability: Guarantee the global enforcement.
- Applicability: security enforcement doable for heterogeneous environments.

Model-based Automatic Security Enforcement

- **Usability: high-level security language to specify requirements.**
- Scalability: Distribute global properties locally on each node.
- **Provability: Proof-based global to local transformations.**
- Applicability: local enforcement based on existing security mechanisms.

What is Security ?

Identification

Authentication

Authorization

What is Security ?

Security Policy

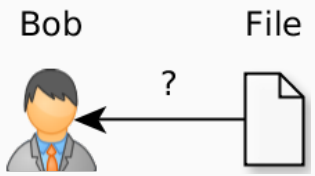
What it means to be secure. Defined by **security properties**

Security Properties

- Confidentiality: Absence of unauthorized disclosure
- Integrity: Absence of unauthorized alteration
- Isolation: Confidentiality + Integrity
- Availability: Absence of denial of use

What Security Model?

Q. Can I read document File?



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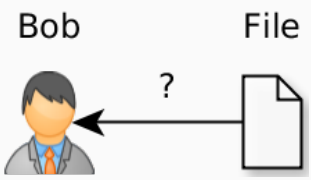
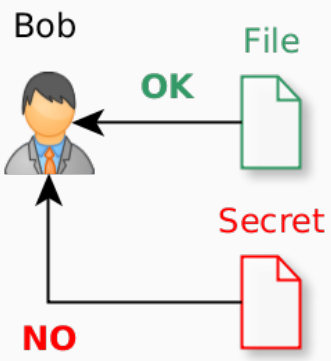


Access Control

Explicit perms., implicit flows

A. *Yes, access is granted.*



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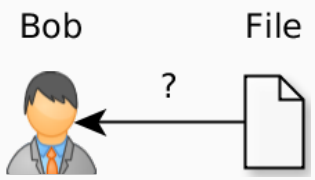


Access Control

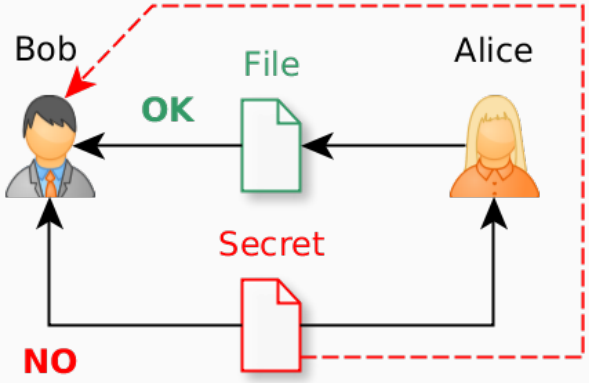
Explicit perms., implicit flows

A. *Yes, access is granted.*

Information Flow Control

Implicit perms., explicit flows

A. *Depends on previous flows.*



Access Control checks place restrictions on the release of information **but not its propagation**.

Existing models – Nguyen *et al.* [APSEC2013]

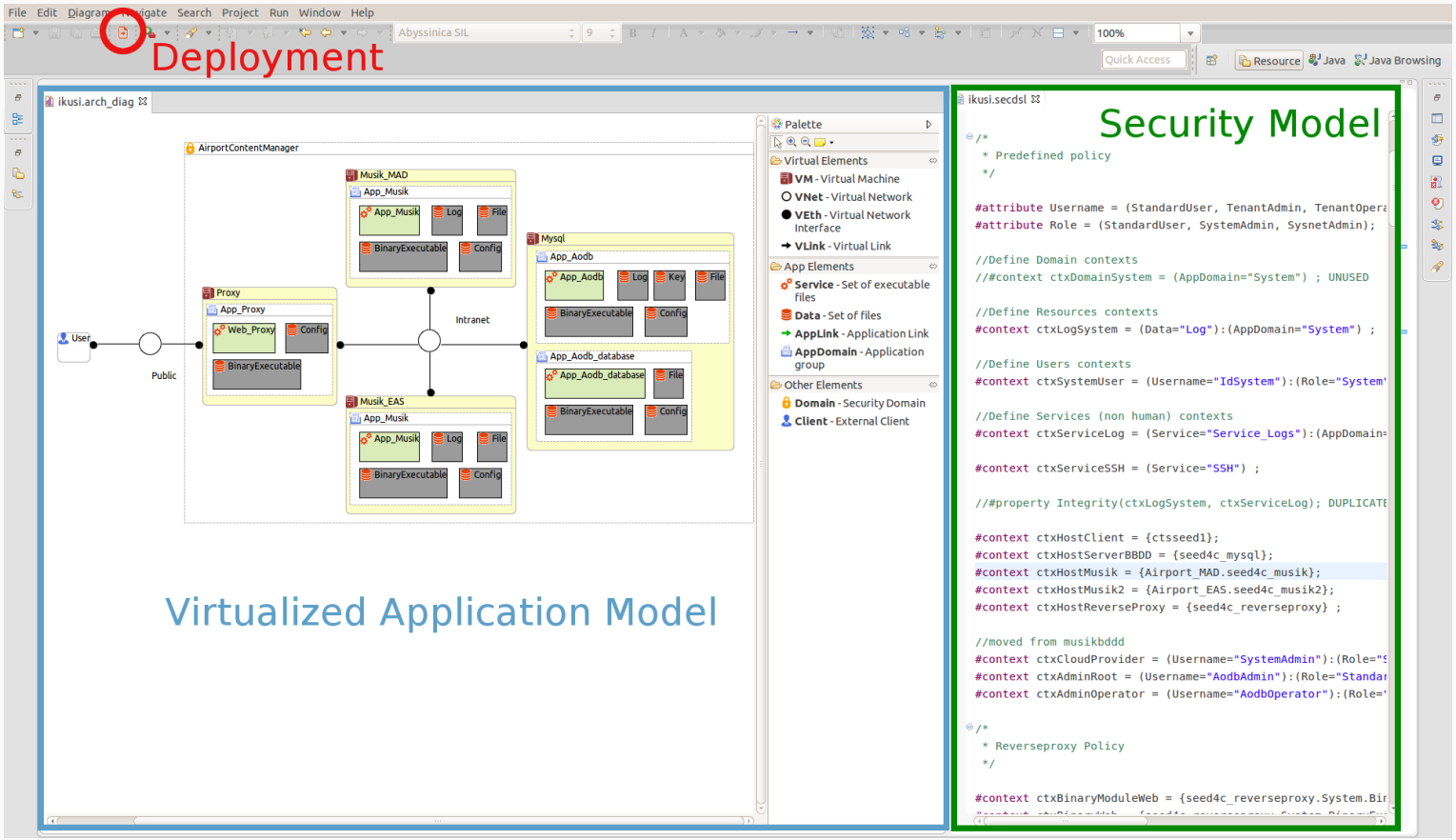
- Specific isolated security concerns (Not all security properties)
- Lack of formality
- Incomplete integrated approach (automation, process-integration, etc.)

Problem

No Models for **Information Flow Properties** on **Virtualized Distributed Systems**

Solution

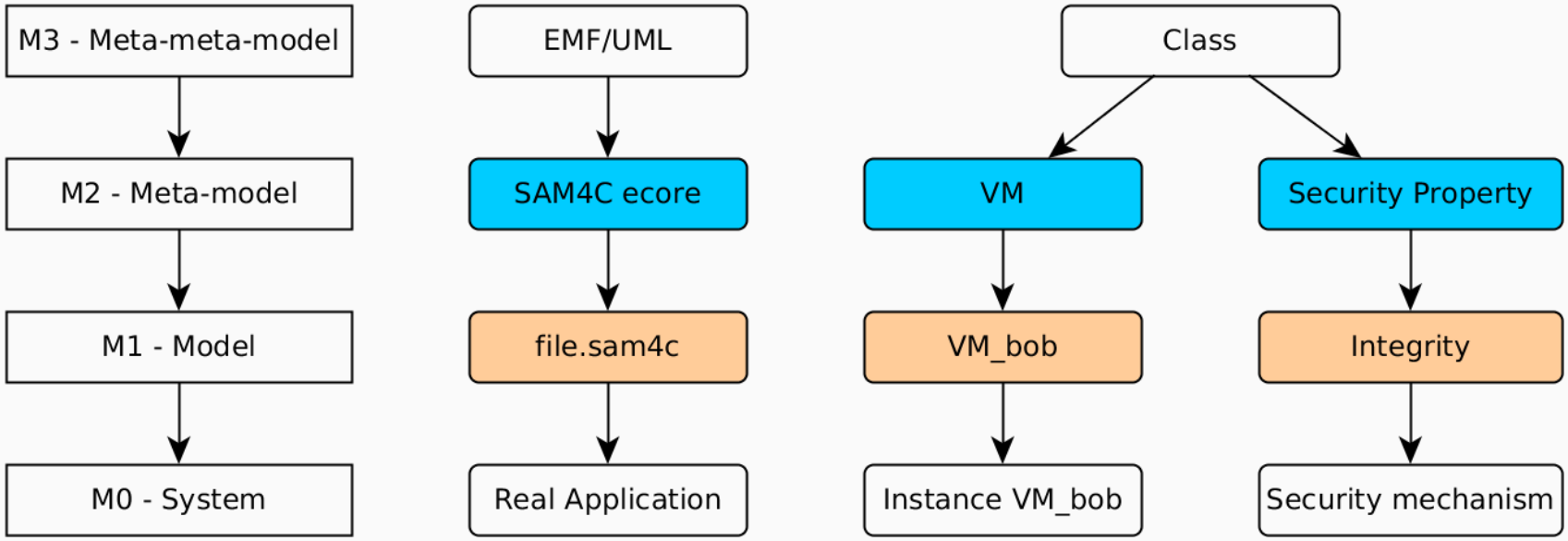
A unified security-aware metamodel: Sam4C



Metamodel (Model of models)

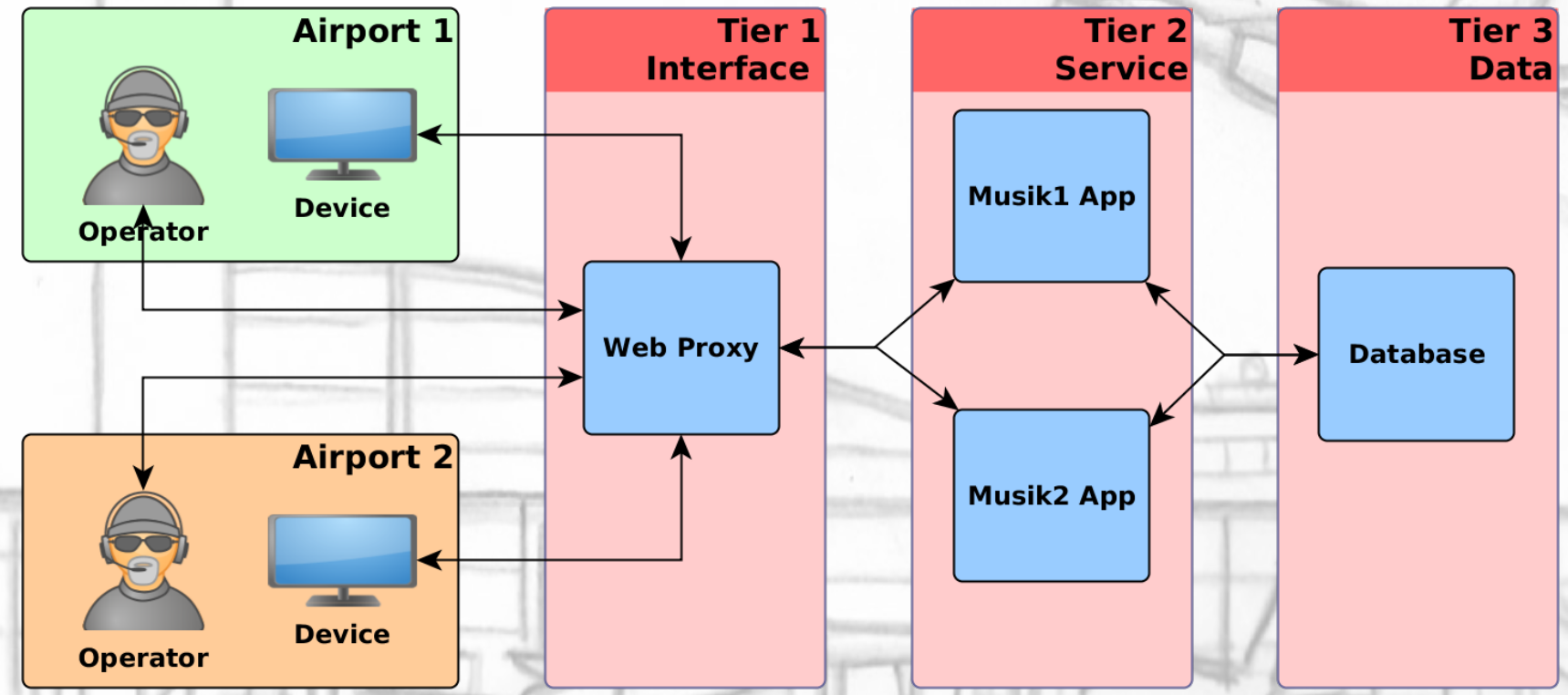
Reducing complex programming tasks by:

- abstracting system-specific constraints
- providing automatic transformation



UseCase: Airport Management

- Industrial UseCase (Ikusi Company)
- *n*-tier application (Standard for building enterprise software)



Integrity Property

`Musik MAD application logs` can only be **modified** by the `Musik MAD service`.

Isolation Property

The whole `AirportContentManager` framework is **isolated** from any other tenant in the hosting virtualized infrastructure.

Context

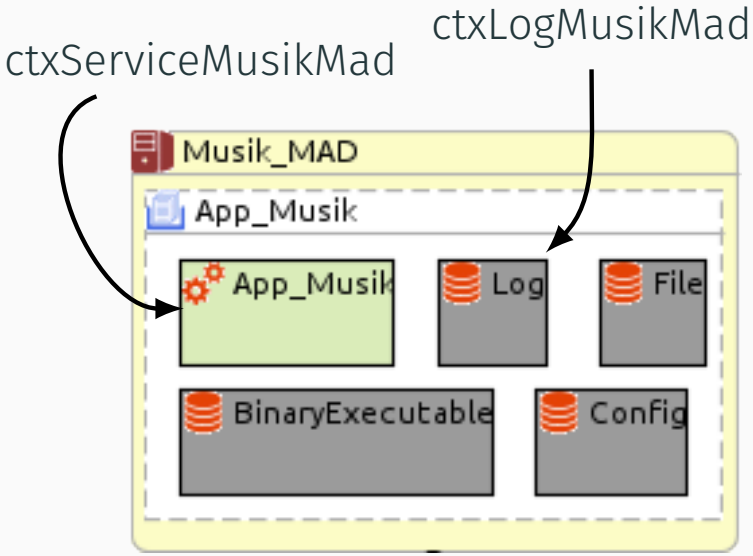
Identifier referring to a (single or) group of entities represented by a list of attributes

Integrity Property

Secured [, Authorized]

Isolation Property

Secured [, Authorized]



`Integrity(ctxLogMusikMAD,ctxServiceMusikMAD)`

`Isolation({AirportContentManager})`

Problem

- What is the definition/interpretation of security properties? (*e.g.*, Integrity)
- How to guarantee that $\sum localConfigs \equiv globalProperty$? (*e.g.*, Isolation)

Security Properties Interpretation

Problem

- What is the definition/interpretation of security properties? (*e.g.*, Integrity)
- How to guarantee that $\sum localConfigs \equiv globalProperty$? (*e.g.*, Isolation)

Solution

Use a formal language: Logic

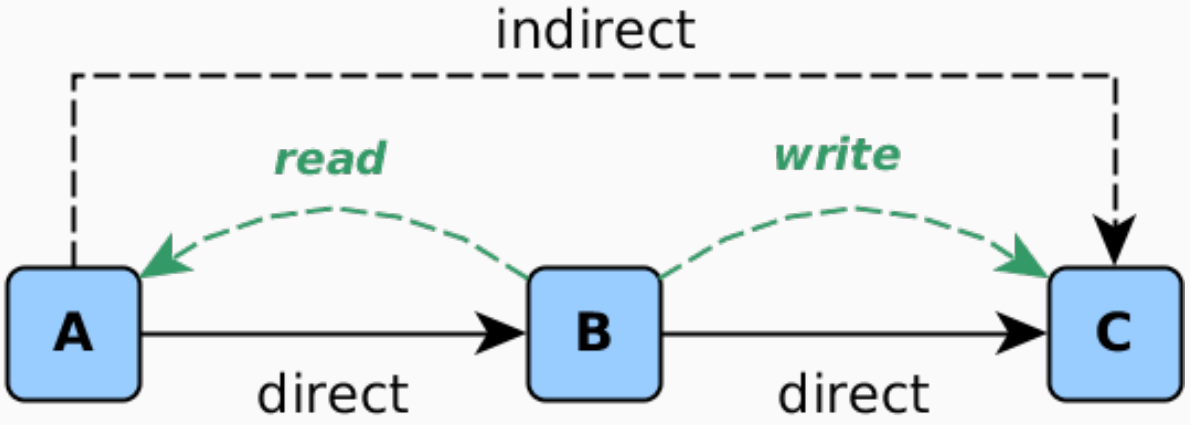
- Unique interpretation
- Proof of equivalences (global/local)

Flows

- B read A = $(A > B)$
- B write C = $(B > C)$

Types of Flows

- Direct (*e.g.*, $A > B$)
- Indirect (*e.g.*, $A \gg C$)



Existing Logics not suitable

- Focus on Access Control (and not Information Flow Control)
- Do not tackle Indirect Flows (Transitive Closure)

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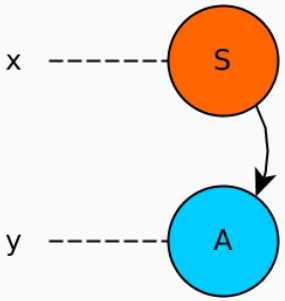
IF-PLTL: a many-sorted first-order temporal logic

- **first-order**, Exists/Forall
- **temporal**, Condition(s) on past actions
- **many-sorted**, 2 sorts: `Context` (*e.g.*, Alice, File) and `Domain` (*e.g.*, Admins, Madrid)

Confidentiality, Integrity and Isolation Definitions

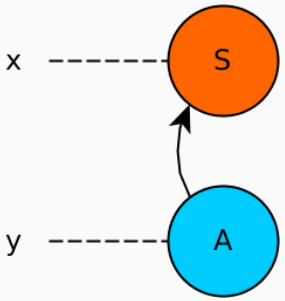
Confidentiality (S,A)

$(\forall_{ctx} x \in S)(\forall_{ctx} y)(x > y) \rightarrow (y \in S \cup A)$



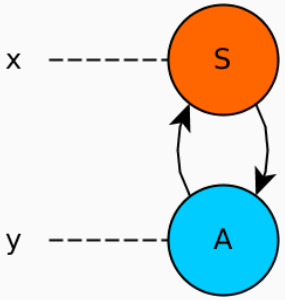
Integrity (S,A)

$(\forall_{ctx} x \in S)(\forall_{ctx} y)(x < y) \rightarrow (y \in S \cup A)$



Isolation (S,A)

$confidentiality(S, A) \wedge integrity(S, A)$

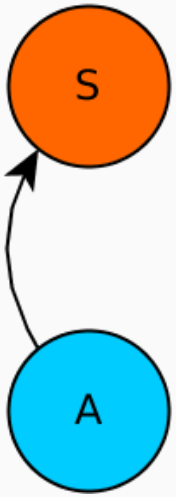


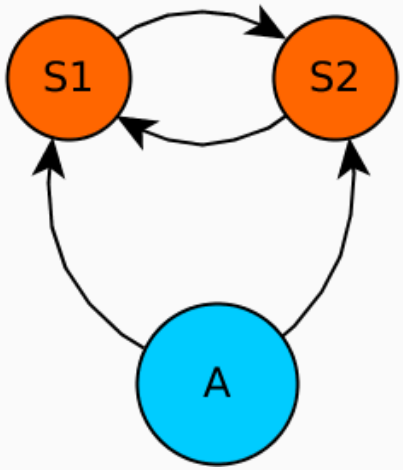
Integrity(S, A)

$$(\forall_{ctx} x \in S)(\forall_{ctx} y)(x > y) \rightarrow (y \in S \cup A)$$

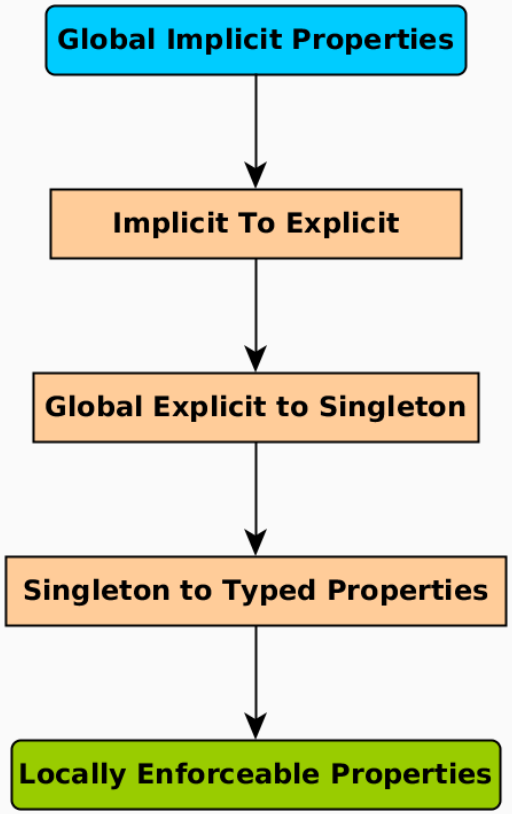
Given $S = S_1 \cup S_2$

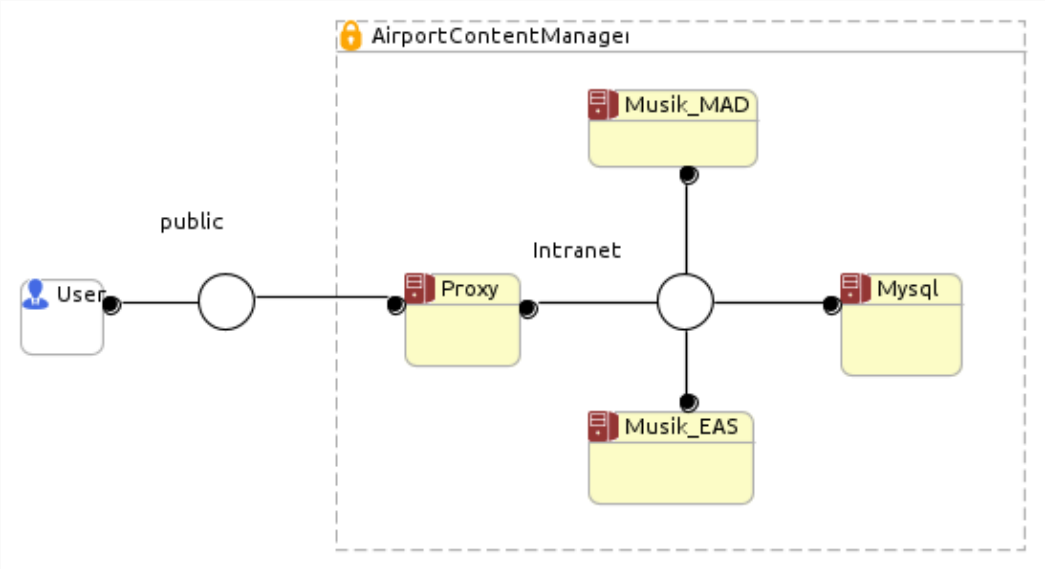
$$Integrity(S, A) \equiv Integrity(S_1, A \cup S_2) \wedge Integrity(S_2, A \cup S_1)$$





Global to local transformation





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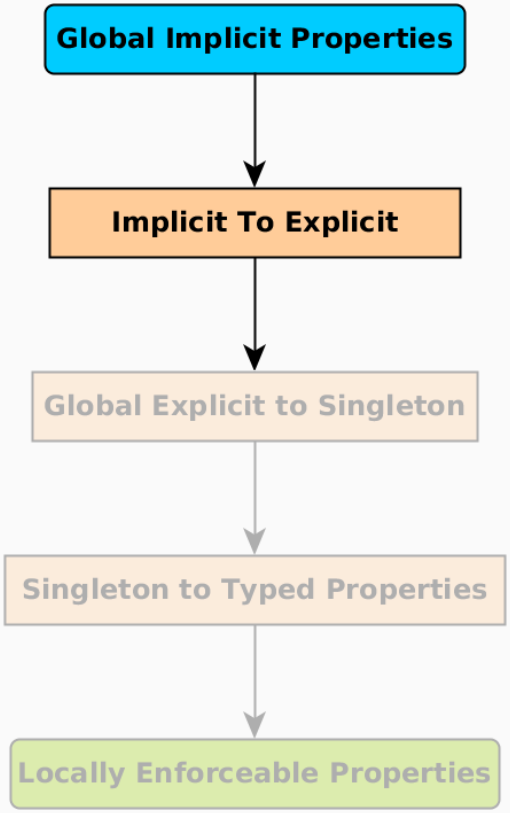
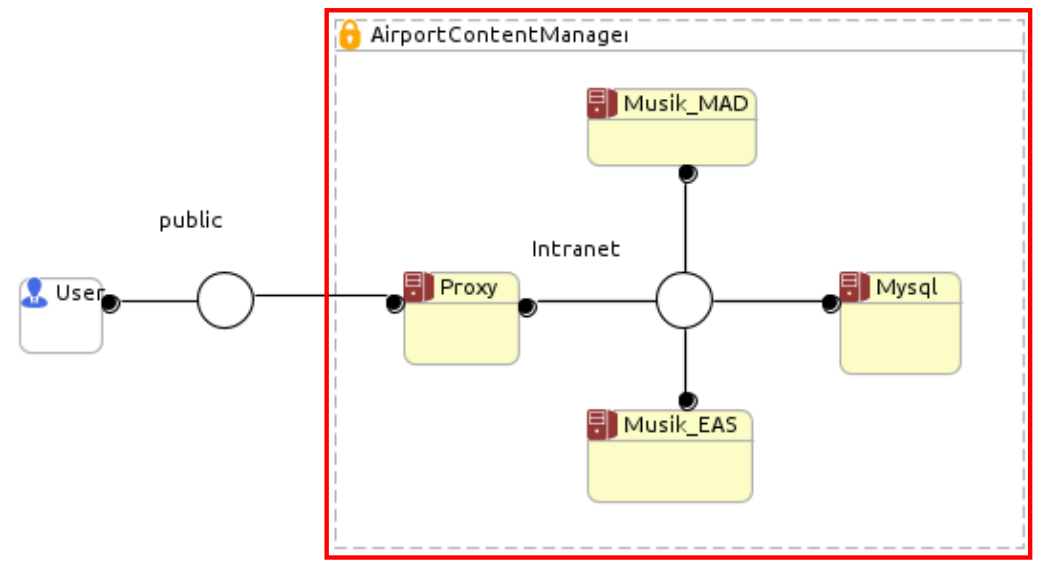




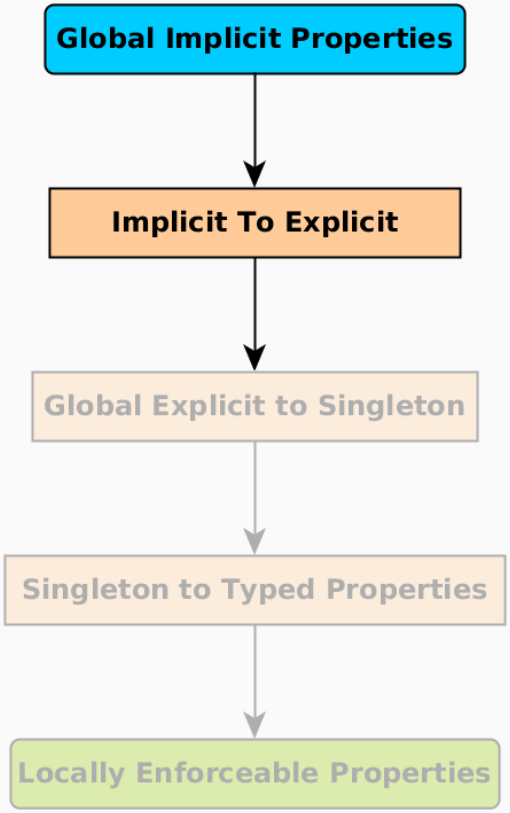
Tenant Input

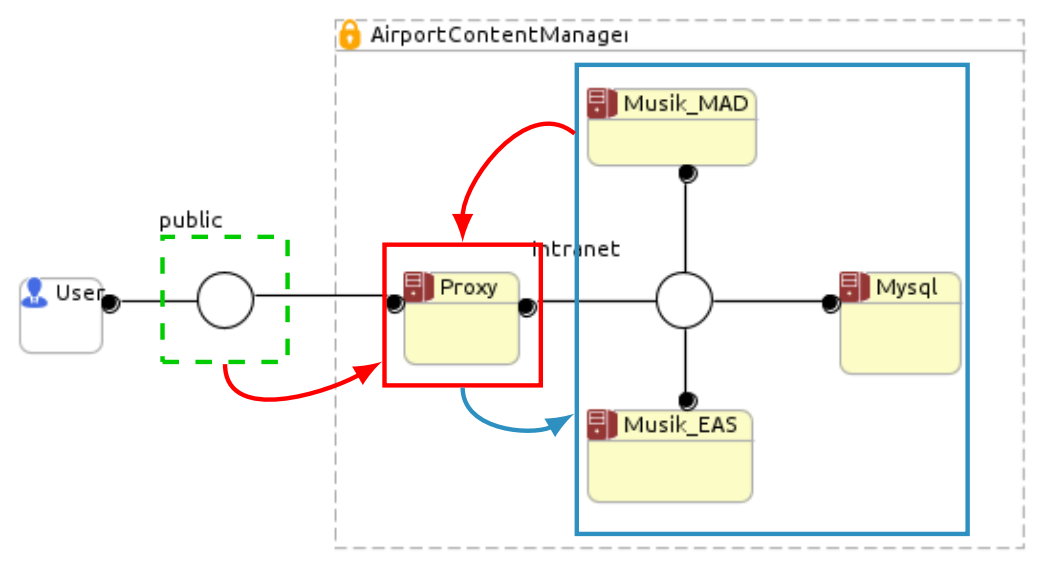
1 global implicit property: `Isolation`

Problem

`Public` should access `Proxy`

Global to local transformation





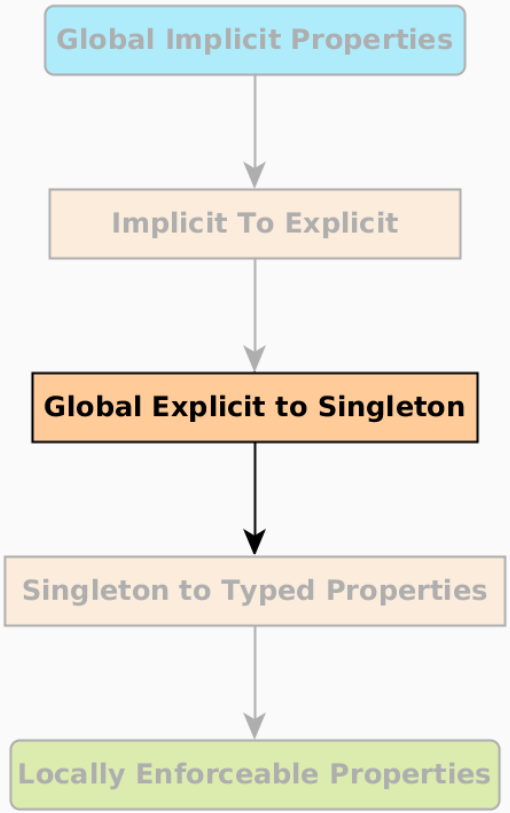
Solution

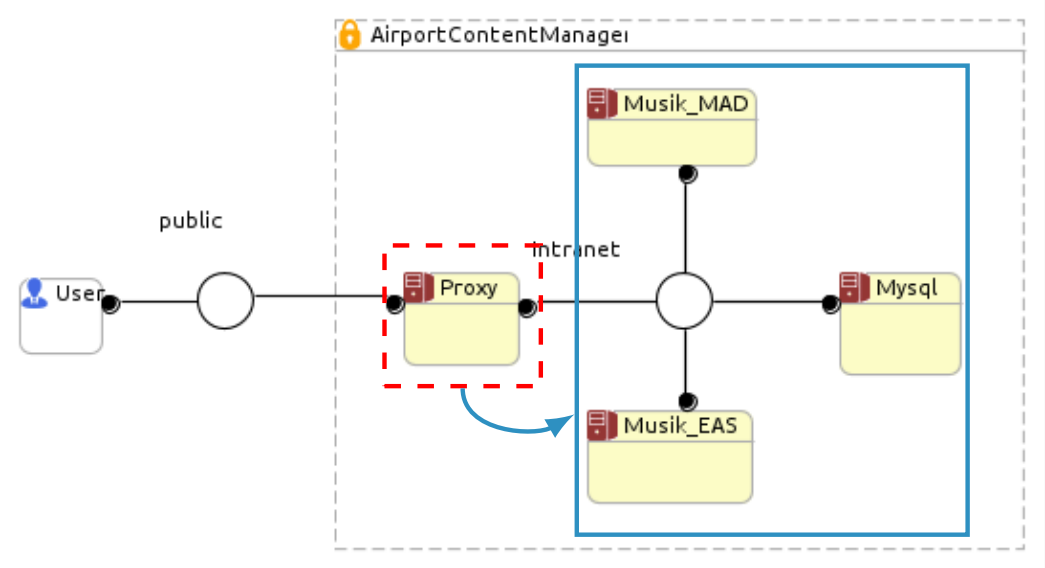
Use graph connectivity

Result

2 Explicit `Isolation` Properties

Global to local transformation





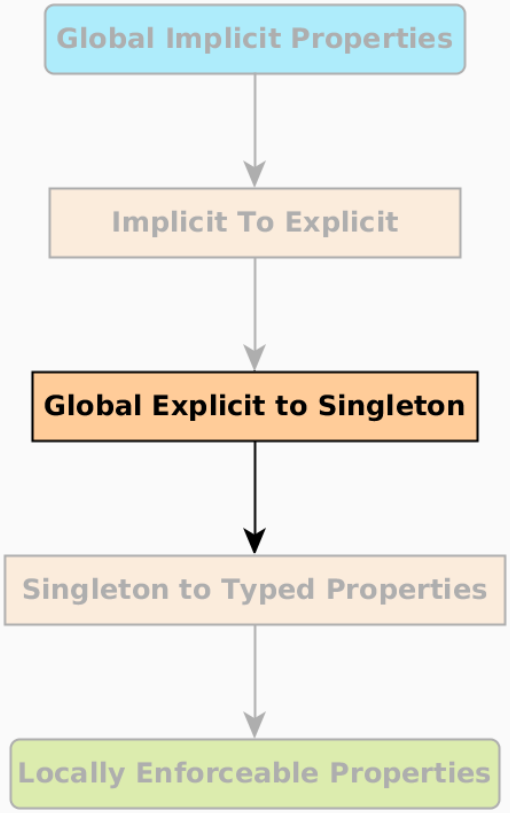
Input

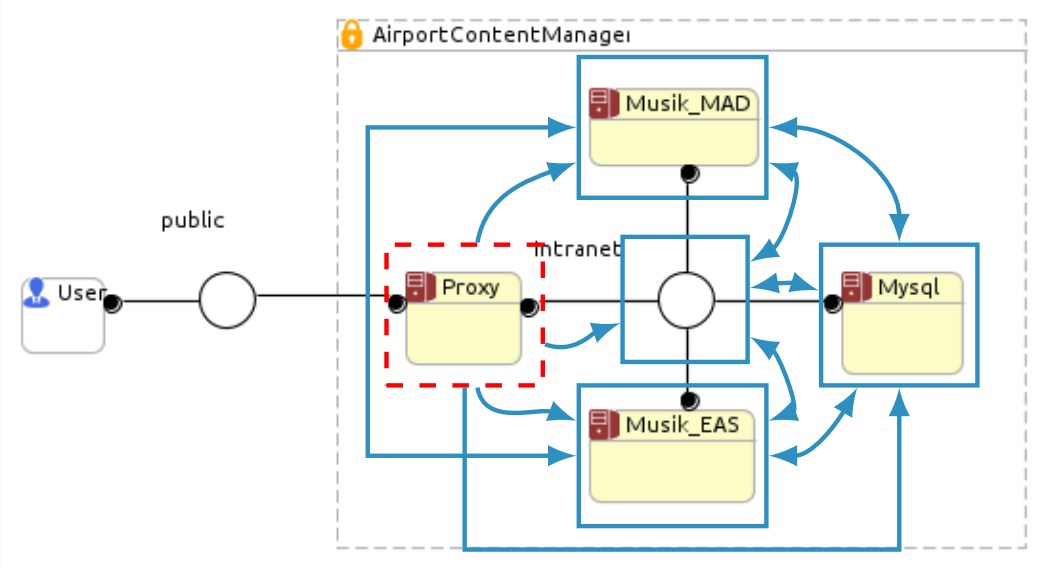
1 global explicit property: `Isolation`

Problem

No solution for `Musik_MAD, …, Intranet`.

Global to local transformation





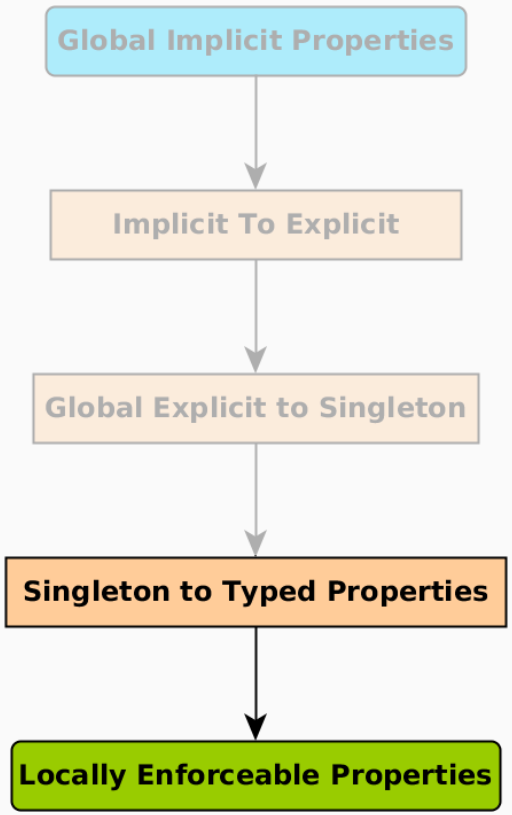
Solution

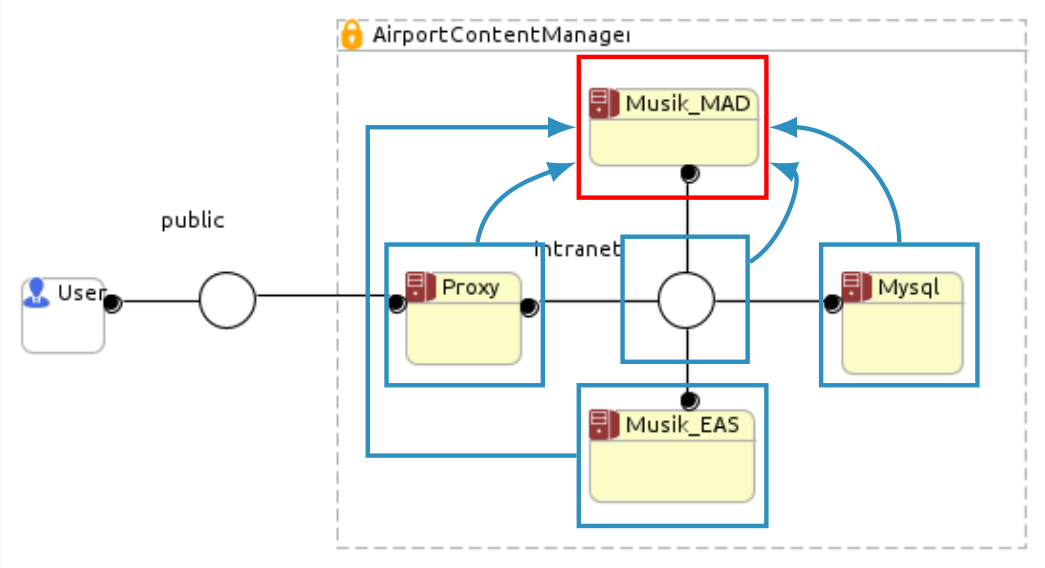
Use global/local equivalences

Result

4 singleton explicit properties

Global to local transformation





Input

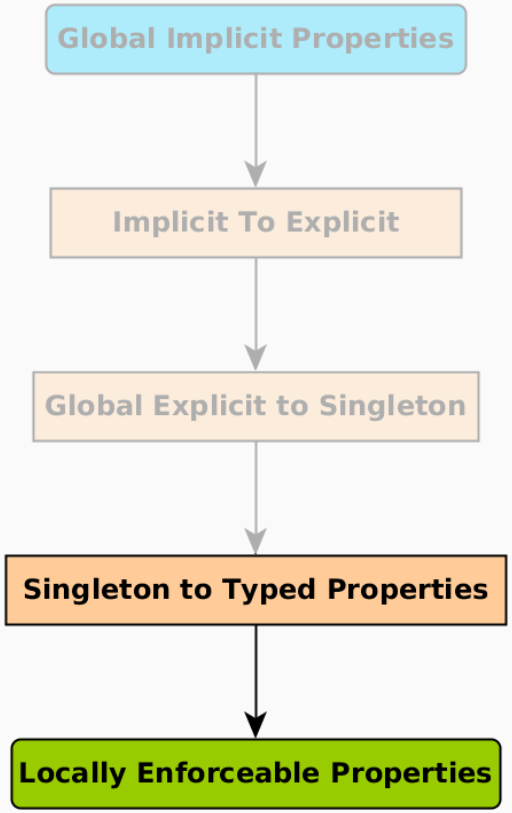
1 singleton explicit properties

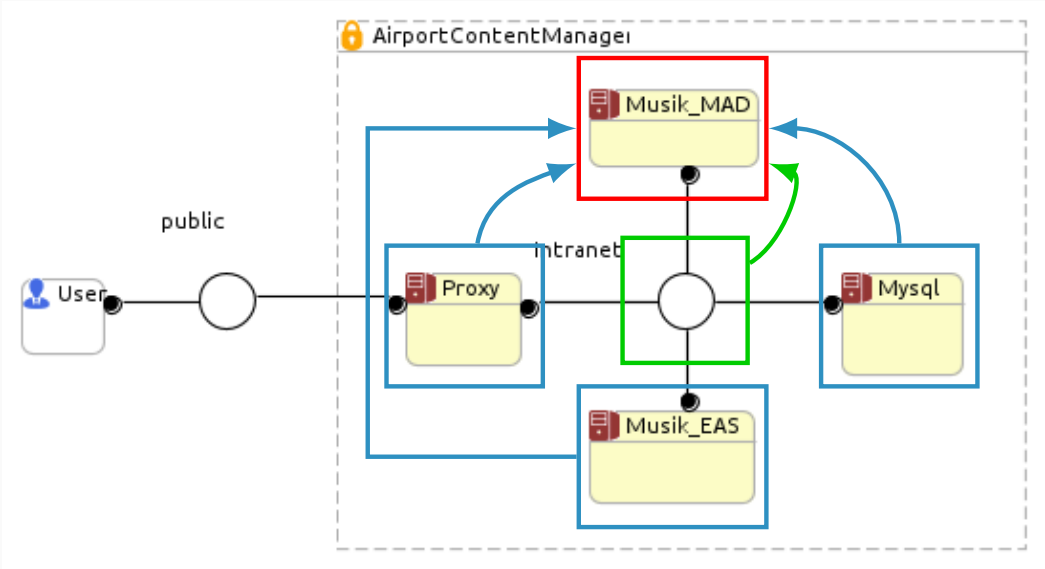
Problem

No isolation mechanism for mixed VM/VNet

e.g., `Mysql, Intranet`

Global to local transformation





Solution

Use typed equivalences

Result

1 Explicit Property = 2 Typed Properties

IsolationVM and IsolationVNET

Problem summary

How to provide global security of large scale virtualized distributed systems ?

- Usability
- Scalability
- Provability
- Applicability

Presented solution

Model-based Automatic Security Enforcement

- Focus: **IFPLTL**, a logic suitable for information flow properties

Open research problems

- Modelization: Elastic apps, reconfiguration at runtime
- Formalization: General equivalences, coherence verification
- Security: distributed reference monitor, autonomic security

Research Agenda at Qirinus

Toward a unified language/model to specify and automate all security aspects

- Network-based security
- Host-based security
- Application Hardening
- Fault-tolerance

Qirinus