A Normative Model to Adapt the Regulation Management of Multi-Agent Systems

Elena Yan* Luis G. Nardin* Olivier Boissier* Jaime S. Sichman***

*Mines Saint-Etienne, Univ Clermont Auvergne, INP Clermont Auvergne, CNRS, UMR 6158 LIMOS, F-42023 Saint-Etienne France
**Laboratório de Técnicas Inteligentes (LTI), Escola Politécnica (EP), Universidade de São Paulo (USP), São Paulo, Brazil

elena.yan@emse.fr

SeReCo Workshop
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Next in Line...

1. Context & Motivations
2. A Normative Model for the Regulation Management of MAS
3. Adapting the Regulation Management of MAS
4. Conclusion

Context

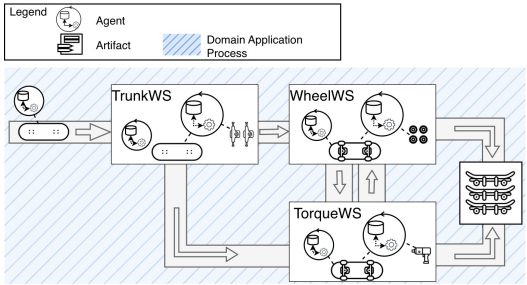
→ Cyber-Physical Systems

- Physical system (e.g., industry)
- Cyber system (e.g., *Multi-Agent System* (MAS) with *agents* and *artifacts*)

Example

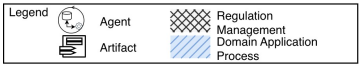
Skateboard assembly line controlled by MAS

- product-centric agents that handle customized skateboard orders
- assembly-process agents that operate on the workstations using artifacts



Fábrica do Futuro, University of São Paulo `https://sites.usp.br/fabricadofuturo/`

Aim: Resilience and Flexibility

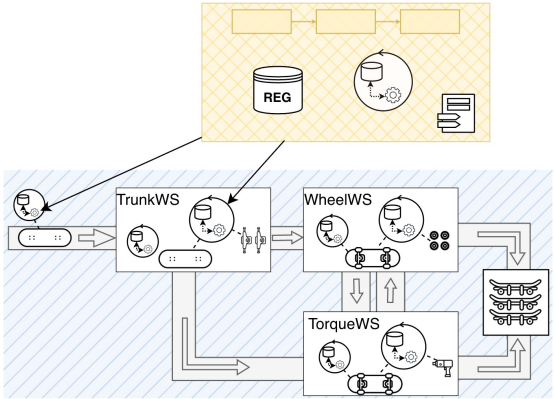


→ Cyber-Physical Social Systems

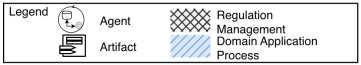
Regulation management system can be integrated into MAS to guide agents' behaviors

Example

- guide product-centric agents in specifying the admissible next steps to be performed
- guide assembly-process agents in performing the required operations at each workstation



Challenge

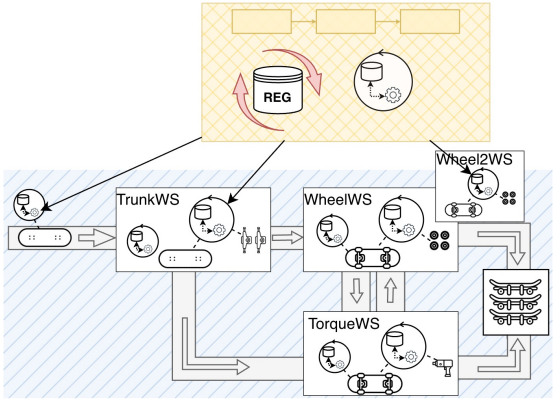


Adapt the regulations to cope with changing

- Contextual Requirements

Example

→ Adapt the **Regulations Representation** to incorporate new operations and workstations



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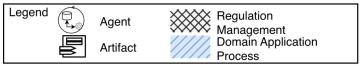
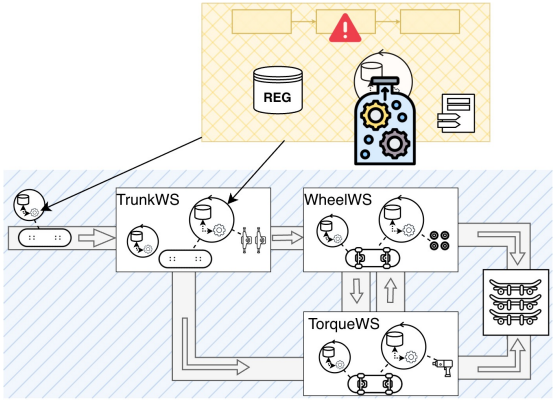


Adapt the regulations to cope with changing

- Contextual Requirements
- Functional Requirements
- Non-Functional Requirements

Example

In case of *bottleneck* in the regulation management



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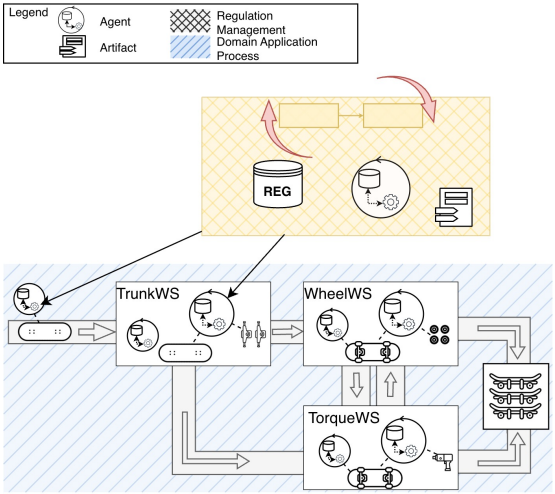
In case of *bottleneck* in the regulation management
→ Adapt the:

1. **Regulation Process**, e.g., simplifying the process of the regulation management



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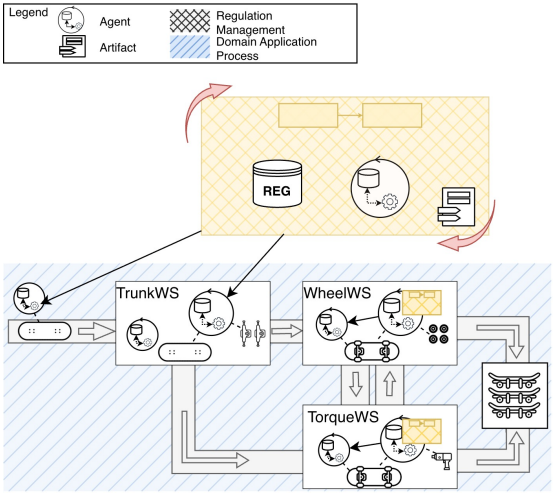
In case of *bottleneck* in the regulation management
→ Adapt the:

1. **Regulation Process**, e.g., simplifying the process of the regulation management
2. **Regulation Architecture**, e.g., distributing the regulation management to assembly-process agents



Challenge

Adapt the regulations to cope with changing

- Contextual Requirements → *main focus of the existing adaptation models*
- Functional Requirements
- Non-Functional Requirements

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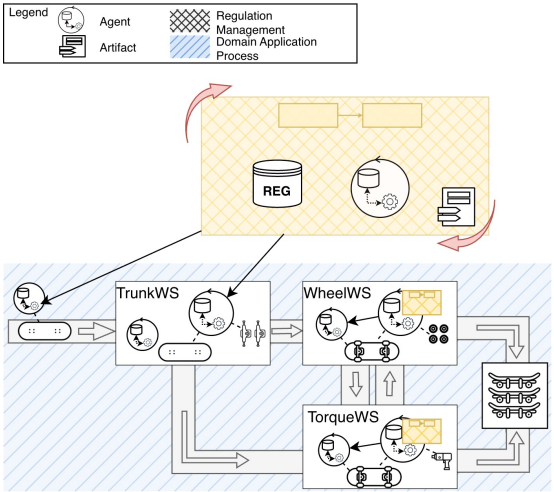

Yan, E., Nardin, L., Boissier, O., & Sichman, J. A regulation adaptation model for multi-agent systems. ECAI 2025

Challenge

Adapt the regulations to cope with changing

- Contextual Requirements → *main focus of the existing adaptation models*
- Functional Requirements → *no existing work*
- Non-Functional Requirements → *no existing work*

Example

In case of *bottleneck* in the regulation management
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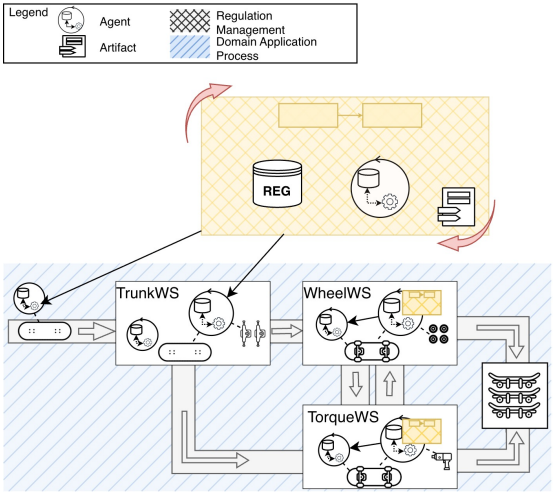

Objective

Objective

Design a normative model to adapt the regulation management of MAS

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Design a normative model to adapt the regulation management of MAS

Adaptation of:

→ *Regulation Process*

→ *Regulation Architecture*

Research Questions

RQ1 What are the core elements of the *normative model* for the regulation management of MAS?

RQ2 How to design a normative model enabling the *adaptation* of the regulation management of MAS?

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Regulations Representation

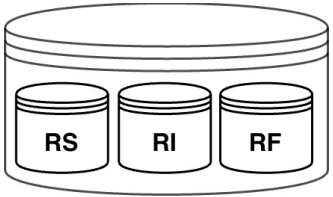
Types of regulations:

- Constitutive Norms
  $cns ::= \langle \texttt{constitutive}, condition, brute, institutional \rangle$
- Regulative Norms
  $rns ::= \langle \texttt{regulative}, condition, subject, modality, object \rangle$
- Sanction Rules
  $srs ::= \langle \texttt{sanction}, condition, subject, \{\langle s\text{-}reg, status \rangle\}, content \rangle$

Explicit *regulations representation* in terms of

- Regulation Specification *RS*
- Regulation Instance *RI*
- Regulation Fact *RF*

$\rightarrow REG = \langle RS, RI, RF \rangle$

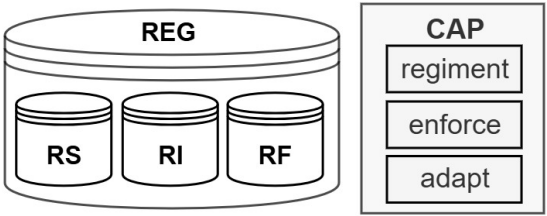


Regulation Capability

A *regulation capability* *cap* denotes the procedural or declarative definitions of the functions to manage *REG*

$CAP \subseteq \{regiment, enforce, adapt\}$

- *regiment*
- *enforce*
  - *detect*
  - *evaluate*
  - *execute*
- *adapt*
  - *detect*
  - *design*
  - *execute*

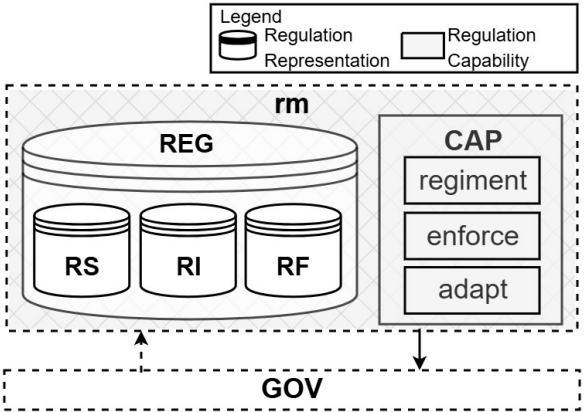


Regulation Management Element

A *regulation management element* is
$rm = \langle REG, CAP, GOV \rangle$

- *REG* Regulations Representation
- *CAP* Regulation Capabilities

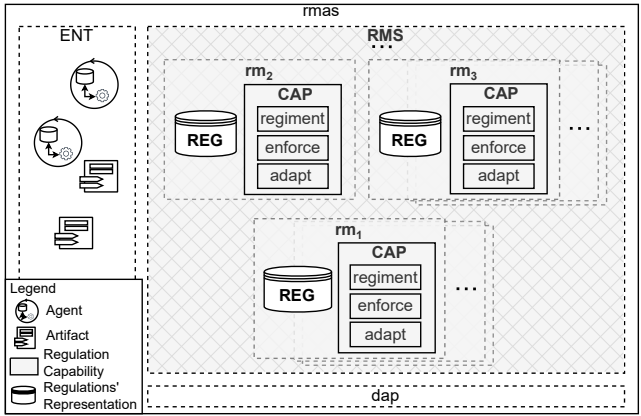
that are used by some entities to govern the entities managing the process *GOV*



Regulation Management System

Regulated MAS $rmas ::= \langle ENT, RMS, dap \rangle$

- $ENT = \langle AG, ART \rangle$ MAS Entities
- $RMS = \{rm_1, ..., rm_n\}$ Regulation Management System
- *dap* domain application process



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Adapting the Regulation Management: Approach

We define dedicated *Regulation Management Elements* to govern and adapt the deployment of the regulation process and regulation architecture together with

1. **Representations** of the regulation process and regulation architecture
2. **Language Constructs** to express their deployment

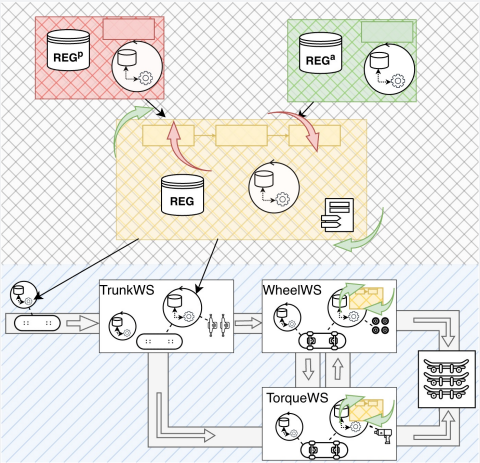
3. **Regulations Representation** to govern their deployment
4. **Adapt Capabilities** to adapt their deployment at runtime

Process and Architecture Regulation Management Elements

A *process regulation management element* that governs the deployment of the regulation process

An *architecture regulation management element* that governs the deployment of the regulation architecture

Example

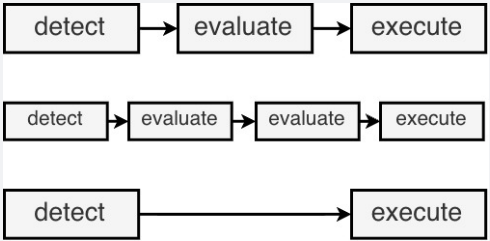


Representing the Regulation Process

The *regulation process* $proc ::= \langle sub_1^{cap}, ..., sub_n^{cap} \rangle$ denotes the sequence of execution of the sub-capabilities of a regulation capability *cap*

Example

Possible regulation processes of the `enforce` capability



Representing the Regulation Architecture

The *regulation architecture* is a combination of $arc ::= \langle FUN, con \rangle$

- Functional Structure $FUN \subseteq \{\texttt{acr}, \texttt{ecr}, \texttt{icr}, \texttt{ocr}\}$
  - `acr` agent-centric regulation
  - `ecr` environment-centric regulation
  - `icr` interaction-centric regulation
  - `ocr` organization-centric regulation
- Control Structure $con \in \{\texttt{fcr}, \texttt{scr}, \texttt{sdr}, \texttt{fdr}\}$
  - `fcr` fully-centralized regulation
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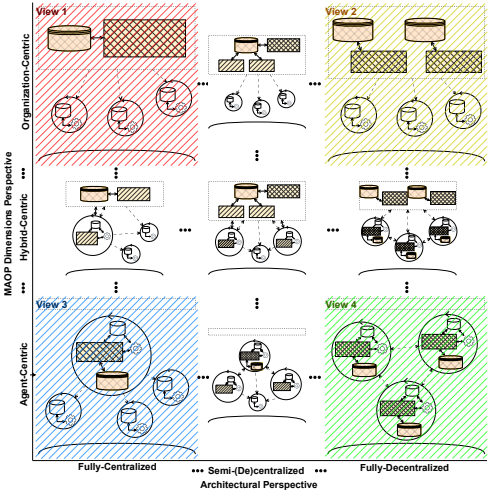
  - `fdr` fully-decentralized regulation



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Language Constructs for an Adaptation Requirement

Language construct to denote a *requirement* of an adaptation of a

→ new regulation process *proc* in a regulation capability *cap*:

- `required`$(\langle proc, cap \rangle)$

→ new regulation architecture:

- `required`(arc)

Language Constructs for Adaptation Deployment

Language constructs to denote the *deployment* of a

→ regulation process *proc*:

- `realized`($\langle proc, cap \rangle$)
- `managed`($\langle proc, cap \rangle$)

→ regulation architecture *arc*:

- `realized`(arc)
- `represented`(REG)
- `managed`(CAP)

or delegate the deployment to another entity: `deployed`($x, entity$)

Regulations Representation for Specifying the Requirement of Adaptations

Constitutive norms for stating an adaptation requirement based on *brute* facts under some *conditions*

Example (a bottleneck count-as required a new regulation process)

$$\begin{aligned}\mathrm{cns}_1 = \langle &\texttt{constitutive}, \texttt{timeCritical} \wedge \langle\langle \texttt{detect}, \texttt{evaluate}, \texttt{execute}\rangle, \texttt{enforce}\rangle,\\ &\texttt{bottleneck},\\ &\textbf{required}(\langle\langle \texttt{detect}, \texttt{execute}\rangle, \texttt{enforce}\rangle)\rangle\end{aligned}$$

Example (a bottleneck count-as required a new regulation architecture)

$$\begin{aligned}\mathrm{cns}_1 = \langle &\texttt{constitutive}, \texttt{highLoad} \wedge \langle \{\texttt{ocr}\}, \texttt{fcr}\rangle,\\ &\texttt{bottleneck},\\ &\textbf{required}(\langle \{\texttt{ocr}, \texttt{acr}\}, \texttt{sdr}\rangle)\rangle\end{aligned}$$

Regulations Representation for Specifying the Realization of Adaptations

Regulative norms for guiding agents in the deployment of the required adaptation

Example (*skGovernor* agent is obliged to realize the required regulation process)

$$\begin{aligned}\mathrm{rns}_2 = \langle &\texttt{regulative}, \texttt{required}(\langle\langle \text{detect}, \text{execute}\rangle, \texttt{enforce}\rangle\rangle,\\ &\texttt{skGovernor},\\ &\texttt{obligation}, \textbf{realized}(\langle\langle \text{detect}, \text{execute}\rangle, \texttt{enforce}\rangle)\end{aligned}$$

Example (*skGovernor* is obliged to realize the required regulation architecture)

$$\begin{aligned}\mathrm{rns}_1 = \langle &\texttt{regulative}, \texttt{required}(\langle\{\texttt{ocr}, \texttt{acr}, \texttt{sdr}\}\rangle),\\ &\texttt{skGovernor},\\ &\texttt{obligation}, \textbf{realized}(\langle\{\texttt{ocr}, \texttt{acr}\}, \texttt{sdr}\rangle)\rangle\end{aligned}$$

Regulations Representation for Specifying the Realization of Adaptations

Regulative norms for guiding agents in the deployment of the required adaptation

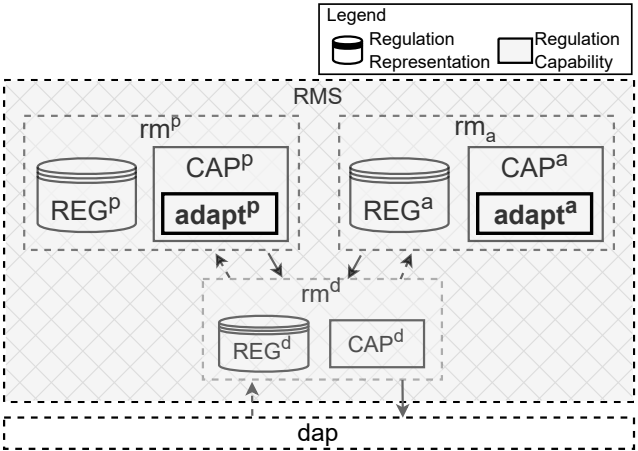
Example (*wkHandler* is obliged to manage the enforce capability)

$$\begin{aligned} \mathrm{rns}_1 = \langle & \texttt{regulative}, \texttt{required}(\langle\{\texttt{ocr}, \texttt{acr}, \texttt{sdr}\}\rangle), \\ & \texttt{wkHandler}, \\ & \texttt{obligation}, \textbf{managed}(\texttt{enforce})\rangle \end{aligned}$$

Example (*skGovernor* is obliged to deploy the representation to *boardArt*)

$$\begin{aligned} \mathrm{rns}_1 = \langle & \texttt{regulative}, \texttt{required}(\langle\{\texttt{ocr}, \texttt{acr}, \texttt{sdr}\}\rangle), \\ & \texttt{skGovernor}, \\ & \texttt{obligation}, \textbf{deployed}(\texttt{represented}(\texttt{skREG}), \texttt{boardArt}\rangle \end{aligned}$$

Adapting the Regulation Process and Regulation Architecture



Adapting the Regulation Process and Regulation Architecture

Example

Prototype implementation of the Skateboard case study using

- *JaCaMo* [Boissier et al., 2020] MAS platform
- *NPL(s)* [Yan et al., 2025c] and *SAI* [de Brito et al., 2019] for the adaptive regulation management system

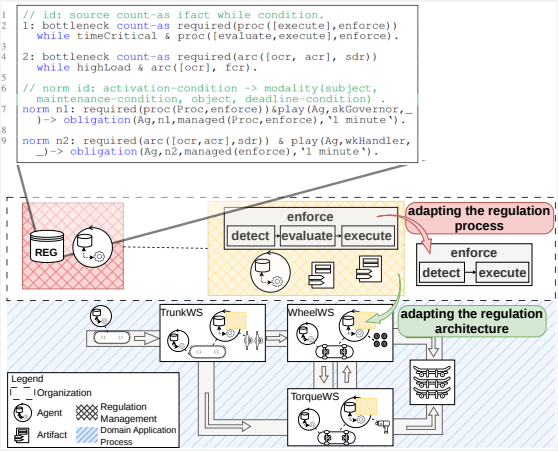
→ `https://gitlab.emse.fr/naiman/skateboard-adaptive-rms`

```
// id: source count-as ifact while condition.
1: bottleneck count-as required(proc([execute],enforce))
   while timeCritical & proc([evaluate,execute],enforce).

2: bottleneck count-as required(arc([ocr, acr], sdr))
   while highLoad & arc([ocr], fcr).

// norm id: activation-condition -> modality(subject,
   maintenance-condition, object, deadline-condition) .
norm n1: required(proc(Proc,enforce))&play(Ag,skGovernor,_
   )-> obligation(Ag,n1,managed(Proc,enforce),'1 minute').

norm n2: required(arc([ocr,acr],sdr)) & play(Ag,wkHandler,
   _)-> obligation(Ag,n2,managed(enforce),'1 minute').
```



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Conclusions

RQ1 What are the core elements for the *regulation management* of MAS?
→ *Regulation Management System*
- *Regulation Management Element*
  - Regulations Representation
  - Regulation Capabilities

RQ2 What are the core elements for *adapting* the regulation management?
→ *Process and Architecture Regulation Management Elements*
- *Process and Architecture Regulations Representation* expressed with
  - Regulation Process and Architecture Representations
  - Regulation Process and Architecture Language Constructs
- *Regulation Process and Architecture Adapt Capabilities*

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Thank you for your attention!

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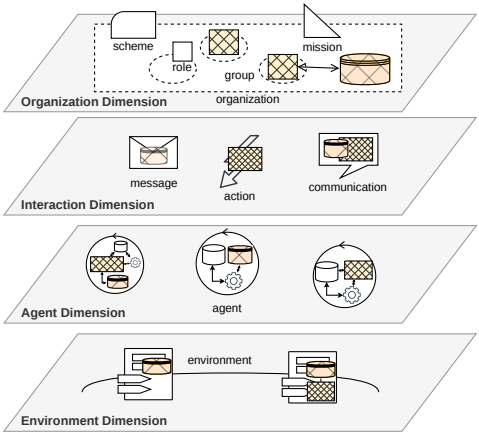

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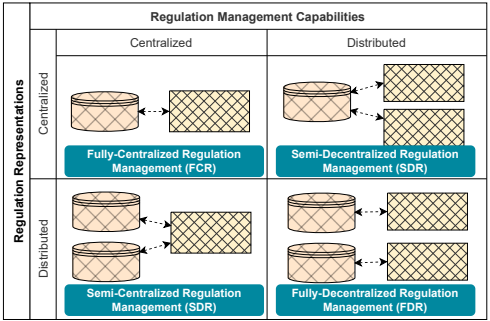

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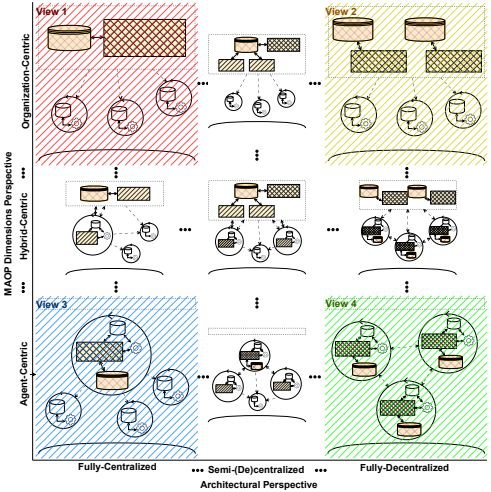
Regulation Architecture $arc ::= \langle FUN, con \rangle$



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