Università degli Studi di Torino
Computer Science Department
Ph.D. Program in Computer Science
Cycle XXXIII

Exception Handling for Robust Multi-Agent Systems

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October 15th, 2021

Outline

Introduction

What is this presentation about?

We outline a vision of how **robustness** in Multi-Agent Systems (MAS) can be granted as a design property

We present a model for MAS **organizations** explicitly encompassing the notion of **exception**
→ **Exception handling** is grafted inside the normative system of the organization

The mechanism relies on abstractions that are seamlessly integrated with organizational concepts:

- **Responsibilities**
- **Goals**
- **Norms**

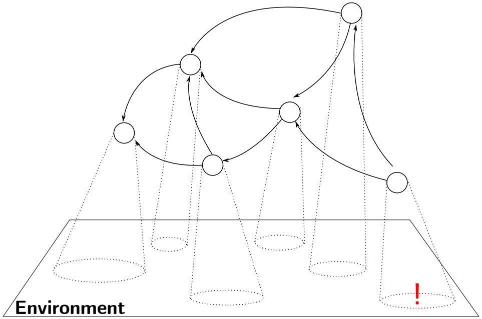
We exemplify our vision on the **JaCaMo**[1] multi-agent platform

[1] Olivier Boissier et al. *Multi-agent oriented programming: programming multi-agent systems using JaCaMo*. MIT Press, 2020.

Motivation

In a MAS, the agent detecting a **perturbation**:

1. May not be equipped with the means to handle it
2. May not be able to determine its impact over the overall distributed execution



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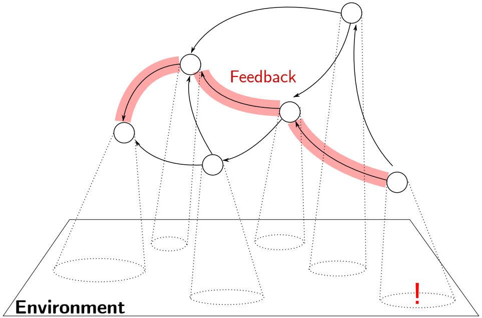

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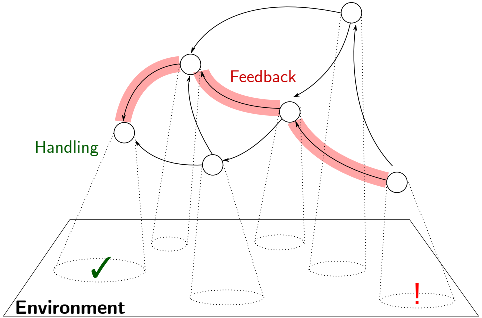

→ No structured way for collecting and propagating **feedback** about encountered situations

→ No clear **distribution of responsibilities** concerning the handling of perturbations

Robustness and Exception Handling

Robustness

The degree to which a system or component can function correctly in the presence of invalid inputs or stressful environmental conditions[2]

[2] "ISO/IEC/IEEE International Standard - Systems and software engineering – Vocabulary". In: *ISO/IEC/IEEE 24765:2010(E)* (2010), pp. 1–418.

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One mechanism that supports robustness is **exception handling**

→ Equipping the system with the capabilities to tackle classes of abnormal situations

→ Benefits in terms of **modularity** and **decoupling**

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Current MAS architectures fall short in addressing robustness in a systematic way

→ No mechanisms for exception handling, as for **programming languages** or the **actor model**

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Exception Handling in MAS

Research Objective

To present an **exception handling** mechanism for use in **multi-agent systems**, encompassing exceptions as first-class elements, and based on the notions of **responsibility** and **feedback**

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MAS organizations are built upon **responsibilities**
→ Naturally suited to encompass an exception handling mechanism

Proposal

When joining an organization, agents will be asked to take on the **responsibilities**:

1. For **providing feedback** about the context where exceptions are detected
2. If appointed, for **handling** such exceptions once the needed information is available

Background

Exception Handling in Programming Languages

Among the first to address explicitly
the concern of exception handling[3]

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Dedicated **language constructs** enable a **systematic treatment** of perturbations

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public static void m1(...) throws Exception {
    if(...) throw new Exception(...);
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The search for a suitable handler follows the program **call stack**

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All computational entities are modeled as independent **actors**

→ Communication through **message passing**

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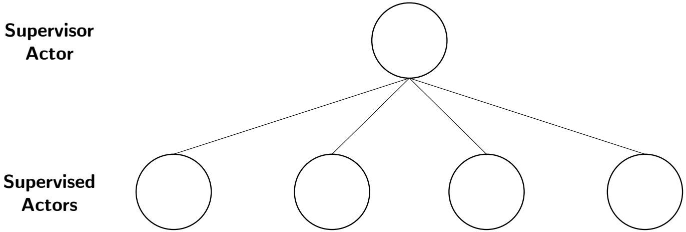

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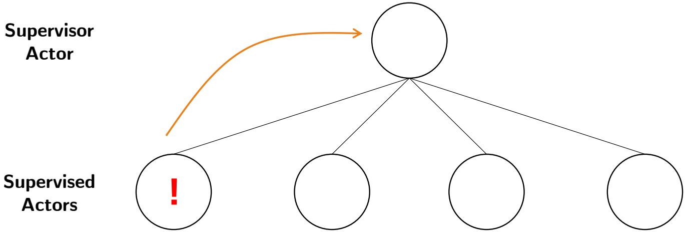

Actors can notify **exceptions** to their parent actor

The parent should implement a suitable **supervision strategy** (or escalate the exception)

Business Process

A set of activities that are performed in coordination in an organizational and technical environment. These activities jointly realize a business goal.[4]

[4] Mathias Weske. *Business Process Management: Concepts, Languages, Architectures*. Springer, 2007.

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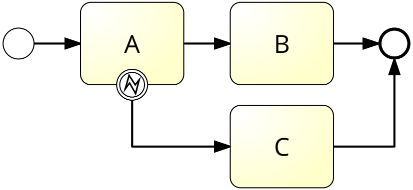
Error events model the occurrence of errors during the execution of an activity



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Exception Handling in the MAS research

Multiple approaches have been proposed, but **without clear consensus**

- Guardian[6]
- Sentinels[7]
- Exceptions in the agent execution model[8]
- Failures events in SARL
- Contingency plans in Jason

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Main difficulty → Conjugate exception handling with the peculiarities of the agent paradigm

- **Autonomy**
- **Heterogeneity**
- **Openness**
- **Distribution**
- **Situatedness**

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A Proposal for Exception Handling in Multi-Agent Systems

Responsibility and Feedback in Exception Handling

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Exception handling is in essence a matter of **responsibility distribution**

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Exception handling is in essence a matter of **responsibility distribution**

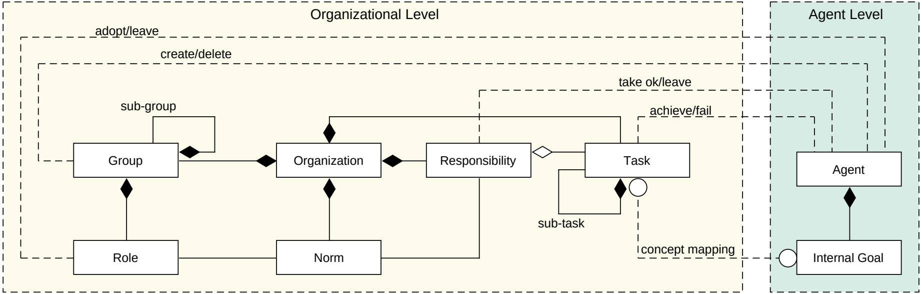
Multi-agent organizations are built upon responsibility

MAS Organizations

Key features of many organizational models:

- Decomposition of the **organizational task**
- **Normative system**

Norms shape the scope of the responsibilities that agents take when joining the organization
→ What agents should do to contribute to the achievement of the organizational task



Introducing Exceptions

Main idea → Review the basic mechanism of exception handling in terms of responsibilities

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When joining an organization, agents are asked to take on the **responsibilities** not only for organizational tasks, but also:

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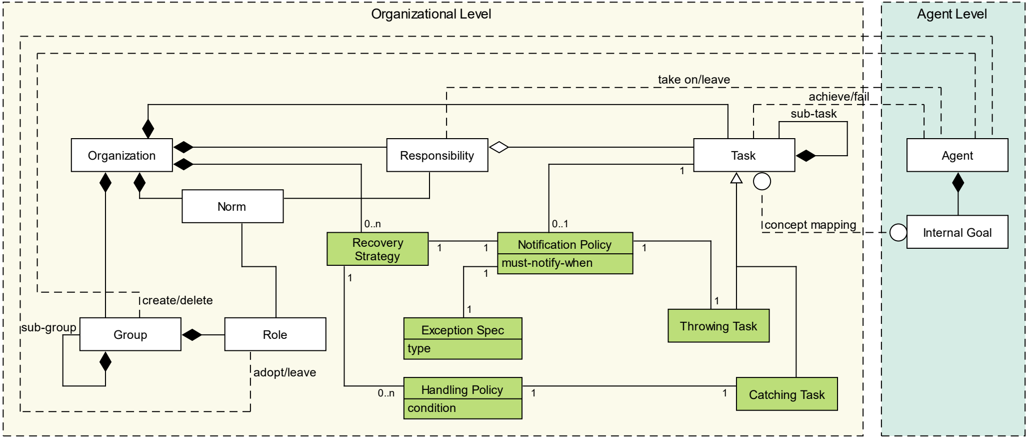
2. For **handling** some of the exceptions raised from others

Norms govern these additional **responsibilities**, as well
→ **Obligations** issued when necessary

Exception Handling Model



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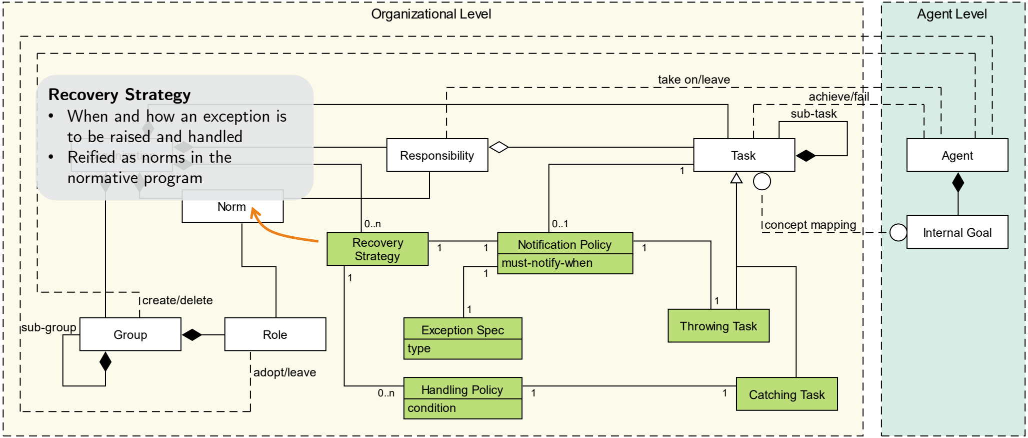

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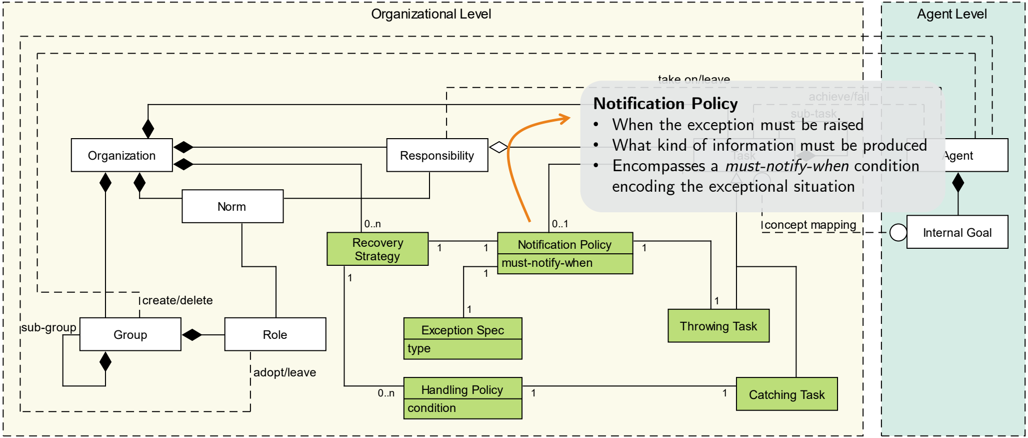
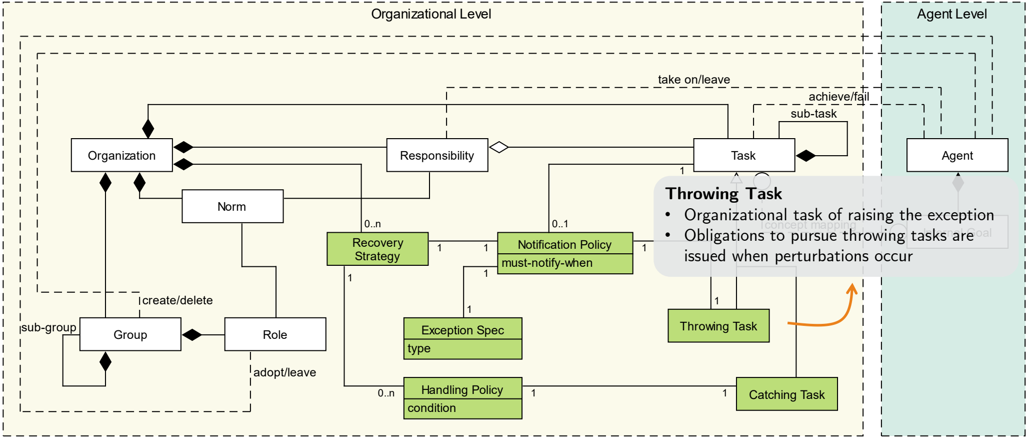


Notification Policy

- When the exception must be raised
- What kind of information must be produced
- Encompasses a *must-notify-when* condition encoding the exceptional situation

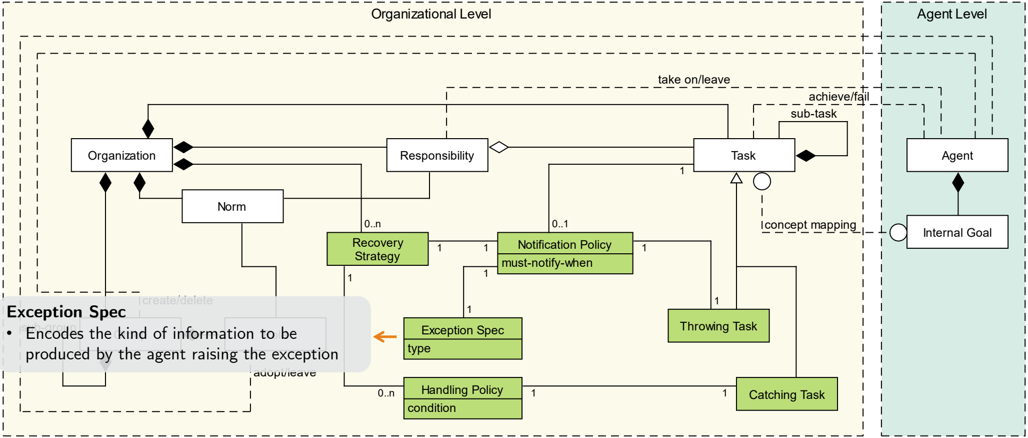
Exception Handling Model



Throwing Task

- Organizational task of raising the exception
- Obligations to pursue throwing tasks are issued when perturbations occur

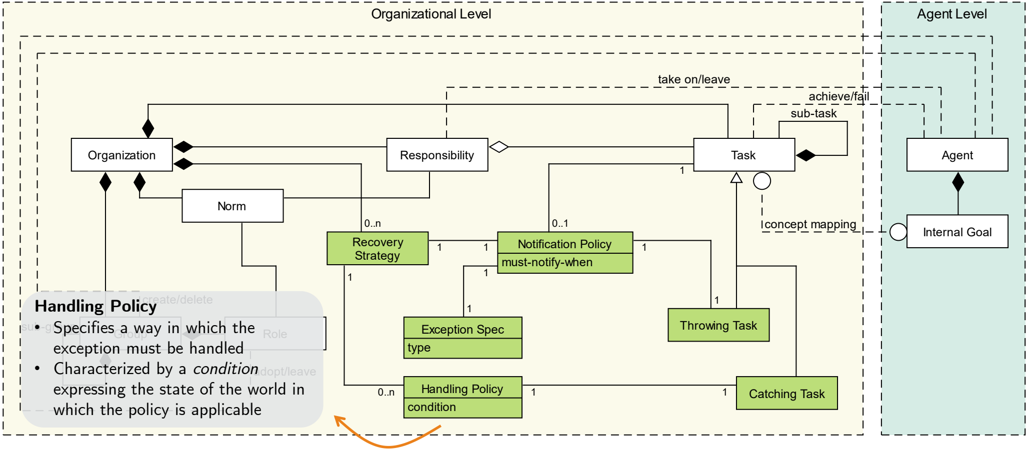
Exception Handling Model



Exception Spec

- Encodes the kind of information to be produced by the agent raising the exception

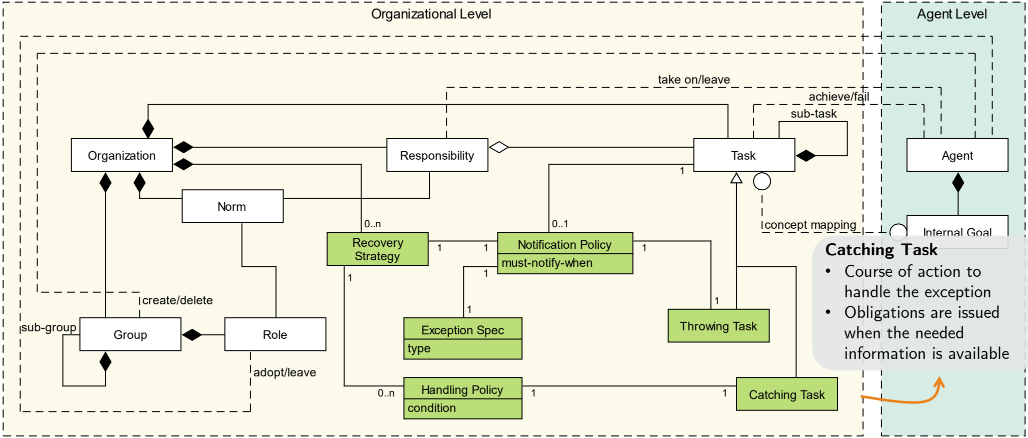
Exception Handling Model



Handling Policy

- Specifies a way in which the exception must be handled
- Characterized by a *condition* expressing the state of the world in which the policy is applicable

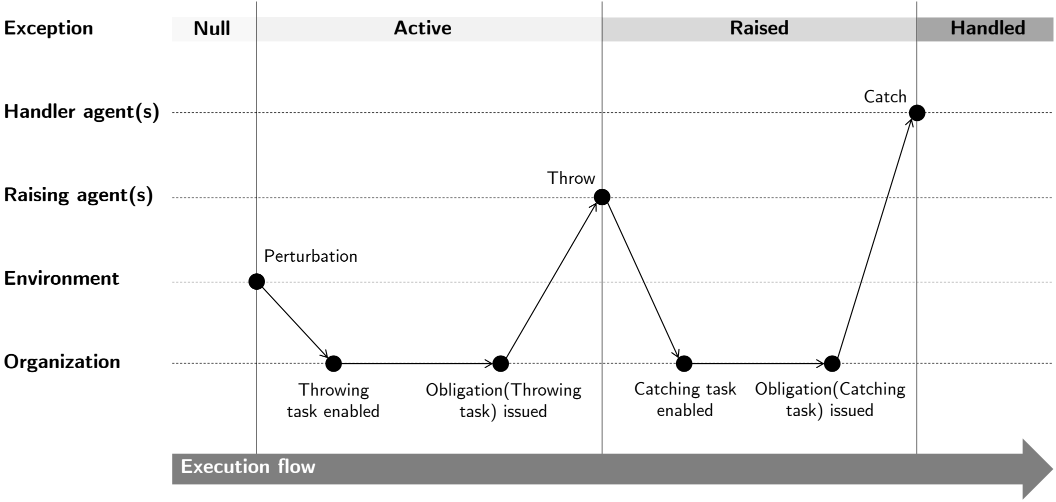
Exception Handling Model



Catching Task

- Course of action to handle the exception
- Obligations are issued when the needed information is available

Exception Lifecycle



Exception Handling in JaCaMo

JaCaMo Basics

JaCaMo is a well-known framework for the development of multi-agent organizations

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Its organizational model does not include any mechanism for exception handling

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Jason, CArtAgO and Moise

```
happy(bob).

!say(hello).

+!say(X)
     : happy(bob)
    <- .print(X).

// ...
```

Sample Jason agent

```
public class Counter extends Artifact {
    void init(int initialValue) {
        defineObsProperty("count",
                          initialValue);
    }

    @OPERATION
    void inc() {
        ObsProperty prop =
                getObsProperty("count");
        prop.updateValue(prop.intValue()+1);
    }
}
```

Sample artifact in CArtAgO

```
<organisational-specification ...>
    <structural-specification>
        <role-definitions>
            ...
        </role-definitions>
        <group-specification id="...">
            ...
        </group-specification>
    </structural-specification>

    <functional-specification>
        <scheme id="...">
            <goal id="...">
                ...
            </goal>
            <mission id="...">
                ...
            </mission>
        </scheme>
    </functional-specification>

    <normative-specification>
        <norm ... />
        ...
    </normative-specification>
</organisational-specification>
```

Sample org. spec. in Moise

Extending JaCaMo for Exception Handling

- The extension mostly concerns the **organizational dimension**
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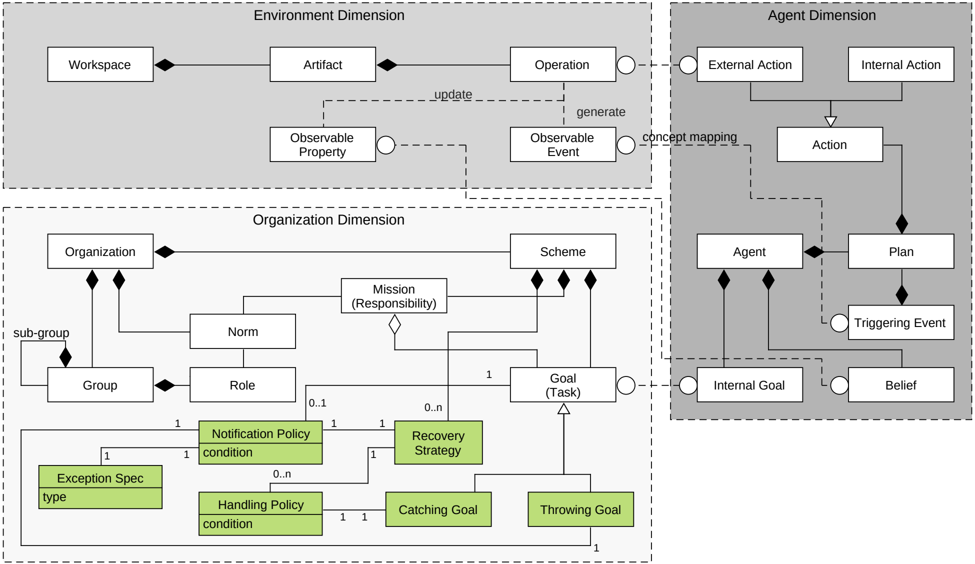
- We satisfy three needs
  → **Specify recovery strategies** within an organization
  → Translate recovery strategies into a **corresponding body of norms**
  → Give agents the capability of **throwing exceptions** and **marking goals** not only as achieved, but also as **failed** or **released**

JaCaMo Metamodel Extended



Generating norms from recovery strategies

Recovery are strategies reified as norms in JaCaMo's normative program

Exception Handling Infrastructure

Generating norms from recovery strategies

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New **normative facts**, such as:

- notificationPolicy(NP,Condition)
- handlingPolicy(HP,Condition)
- policy_goal(P,G)
- exceptionArgument(E,ArgFunctor,ArgArity)
- failed(S,G)
- thrown(S,E,Ag,Args)

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New **rules** and **norms**, like:

```
enabled(S,TG) :-
        policy_goal(P,TG) & notificationPolicy(P,Condition) & Condition &
        goal(_, TG, Dep, _, NP, _) & NP \== 0 &
        ((Dep = dep(or,PCG) & (any_satisfied(S,PCG) | all_released(S,PCG))) |
        (Dep = dep(and,PCG) & all_satisfied_released(S,PCG))).
```

Exception Handling Infrastructure

Extending the organizational artifacts

Agents commit to missions encompassing standard goals, as well as throwing and catching ones
→ Obligations for **throwing goals** issued when perturbations occur
→ Obligations for **catching goals** issued when an **exception** has been thrown

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New operations are made available to the agents:

- goalFailed(G)
- throwException(S,E,Ag,Args)
- goalReleased(G)

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- goalFailed(G)
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- goalReleased(G)

Exceptions are made available as artifact's **observable properties**

Agent Programming with Exceptions

```
+obligation(Ag,_,done(_,SOME_GOAL,Ag),_)
    : my_name(Ag)
   <- !SOME_GOAL;
      goalAchieved(SOME_GOAL).

+!SOME_GOAL
   <- // do something to achieve the goal

-!SOME_GOAL
   <- goalFailed(SOME_GOAL);
      .fail.

+obligation(Ag,_,done(_,THROWING_GOAL,Ag),_)
    : my_name(Ag)
   <- throwException(E,[arg1(A1),...,argN(AN)]);
      goalAchieved(THROWING_GOAL).
```

Raising agent

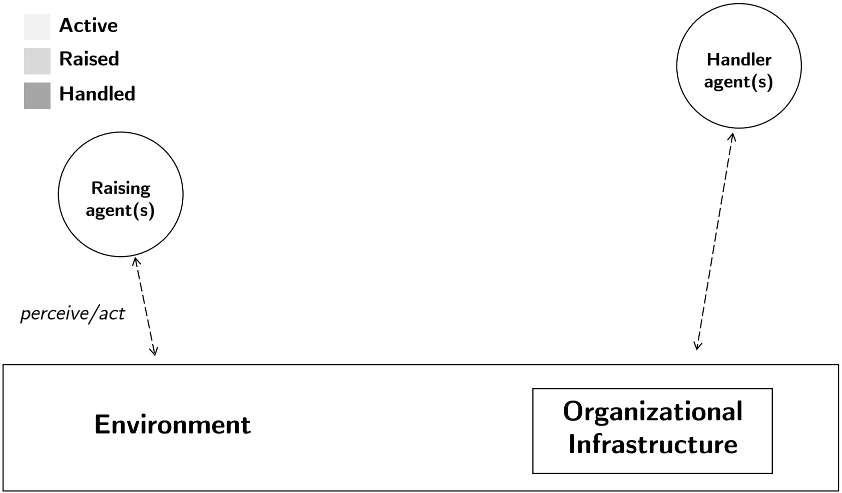
```
+obligation(Ag,_,done(_,CATCHING_GOAL,Ag),_)
    : my_name(Ag) &
      exceptionArgument(_,E,arg1(A1)) & ... &
      exceptionArgument(_,E,arg1(AN))
   <- // do something to handle the exception
      goalReleased(SOME_GOAL);
      // or resetGoal(SOME_GOAL);
      goalAchieved(CATCHING_GOAL).
```

Handler agent

```
<recovery-strategy id="...">
  <notification-policy id="...">
    <condition type="goal-failure">
      <condition-argument id="target" value="SOME_GOAL" />
    </condition>
    <exception-spec id="E">
      <exception-argument id="arg1" arity="..." />
      ...
      <exception-argument id="argN" arity="..." />
    </exception-spec>
    <goal id="THROWING_GOAL" />
  </notification-policy>
  <handling-policy id="...">
    <condition type="always" />
    <goal id="CATCHING_GOAL" />
  </handling-policy>
</recovery-strategy>
```

Recovery strategy

Exception Handling in Operation



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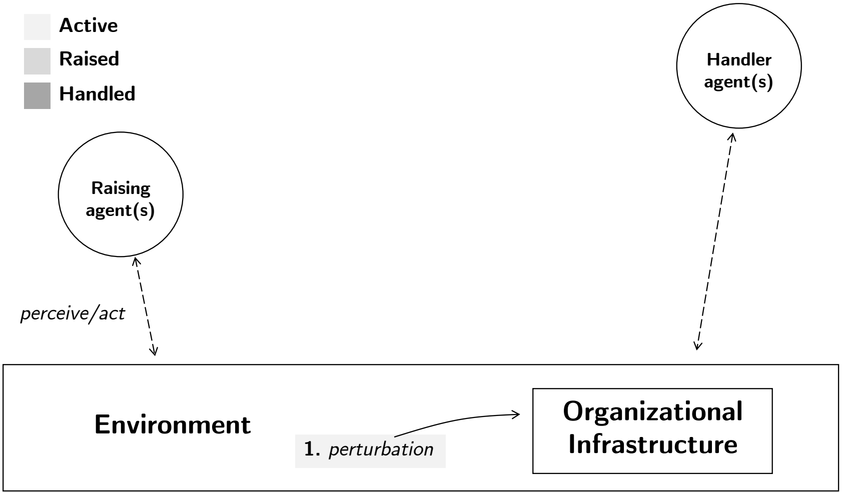

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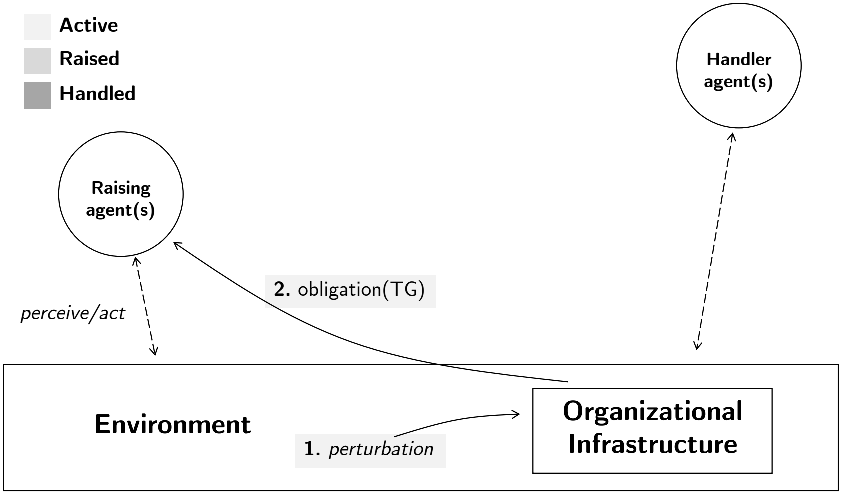
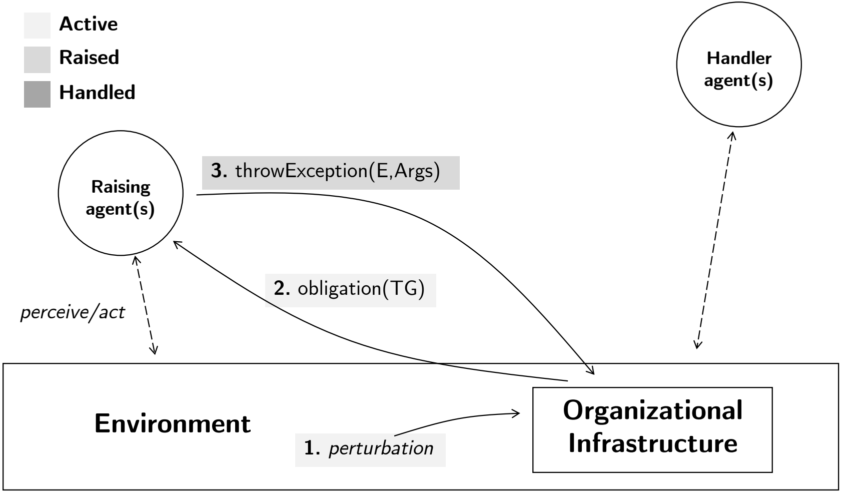


Exception Handling in Operation



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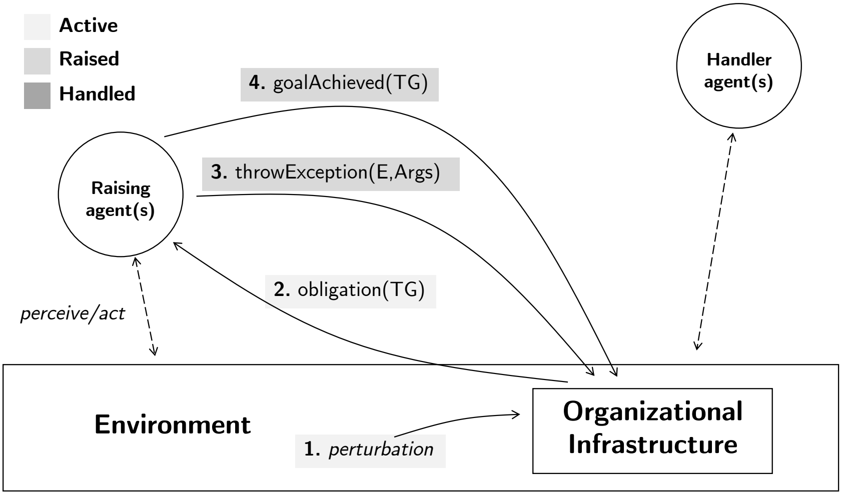

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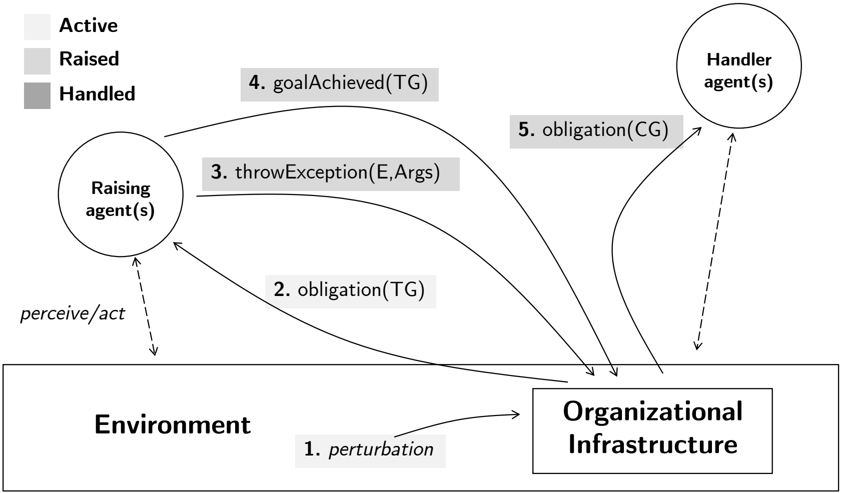

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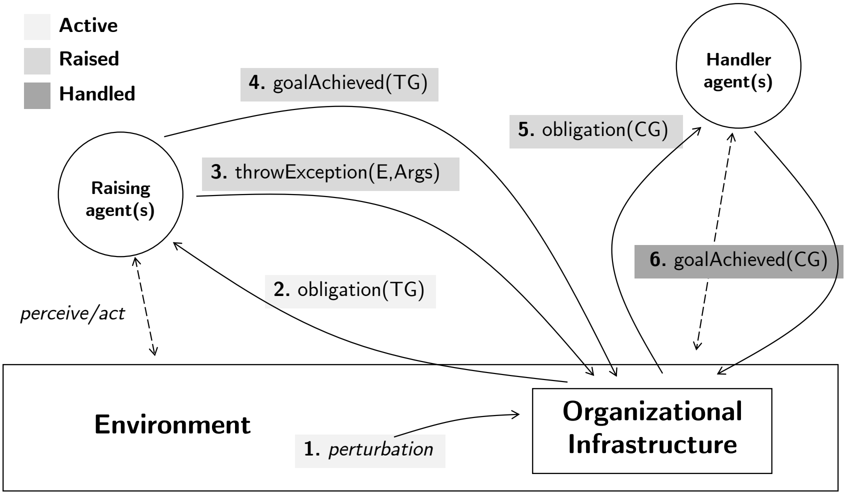
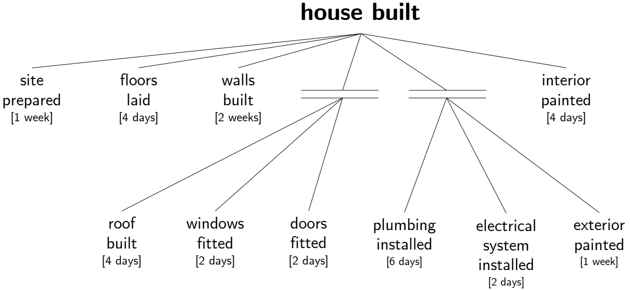


Example: House Building

- The organizational goal is to build a house on a plot
- Site preparation must be completed before any other step; should a failure occur, the whole construction could not proceed



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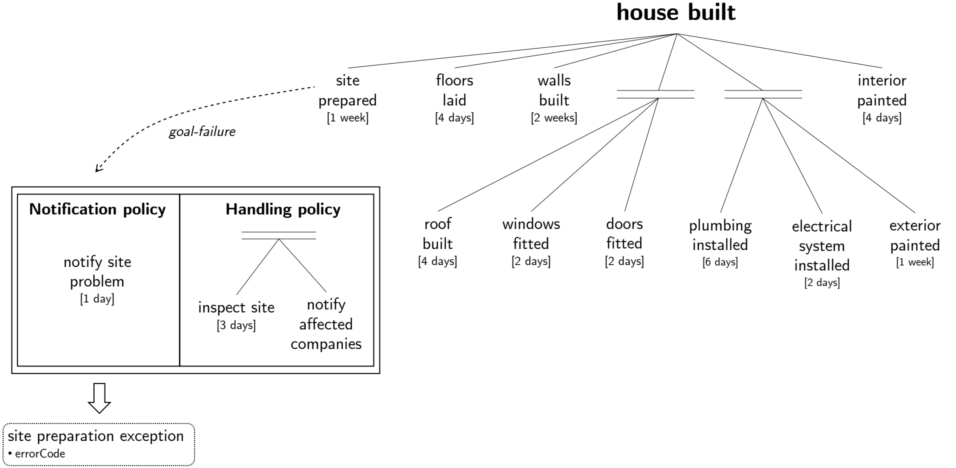

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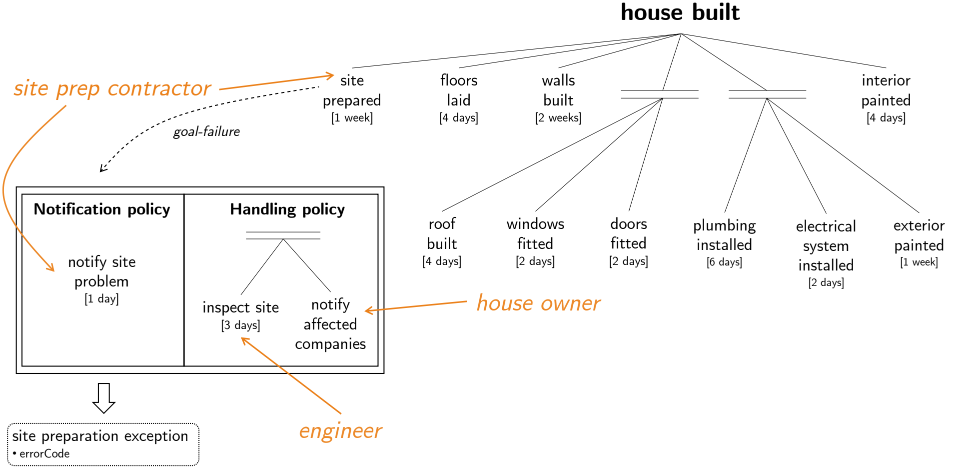

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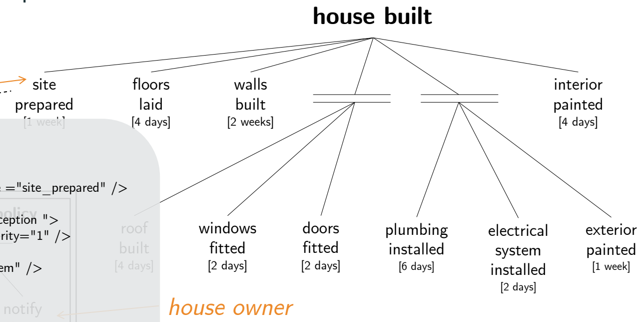


```xml
<recovery-strategy id="rsSitePreparation ">
  <notification-policy id="np1">
    <condition type="goal-failure">
      <condition-argument id="target" value ="site_prepared" />
    </condition>
    <exception-spec id="site_preparation_exception ">
      <exception-argument id="errorCode" arity="1" />
    </exception-spec>
    <goal id="notify_site_preparation_problem" />
  </notification-policy>
  <handling-policy id="hp1">
    <condition type="always" />
    <goal id="handle_site_problem">
      <plan operator="parallel">
        <goal id="inspect_site" />
        <goal id="notify_affected_companies" />
      </plan>
    </goa >
  </handling-policy>
</recovery-strategy>
```

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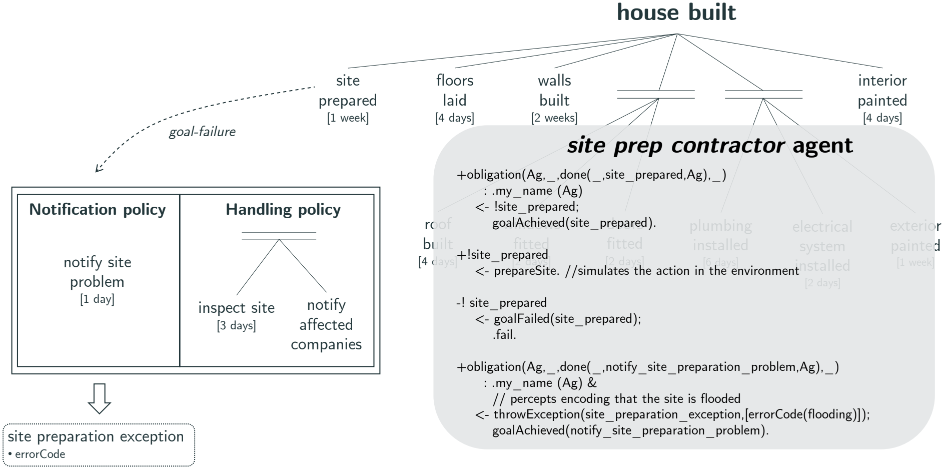


```
+obligation(Ag,_,done(_,site_prepared,Ag),_)
    : .my_name (Ag)
   <- !site_prepared;
      goalAchieved(site_prepared).

+!site_prepared
   <- prepareSite. //simulates the action in the environment

-! site_prepared
   <- goalFailed(site_prepared);
      .fail.

+obligation(Ag,_,done(_,notify_site_preparation_problem,Ag),_)
    : .my_name (Ag) &
      // percepts encoding that the site is flooded
   <- throwException(site_preparation_exception,[errorCode(flooding)]);
      goalAchieved(notify_site_preparation_problem).
```

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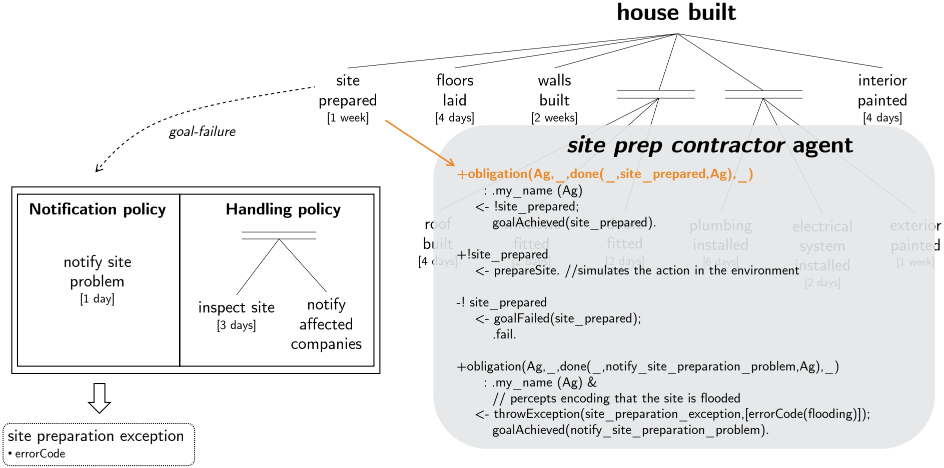

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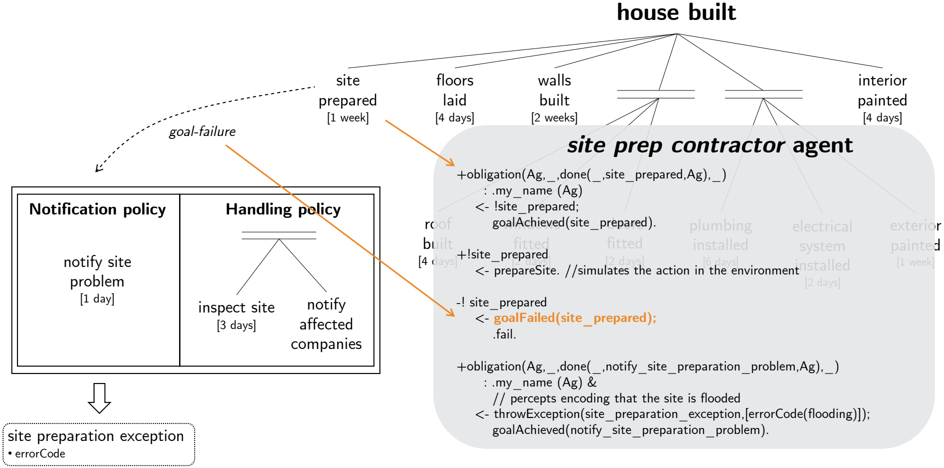

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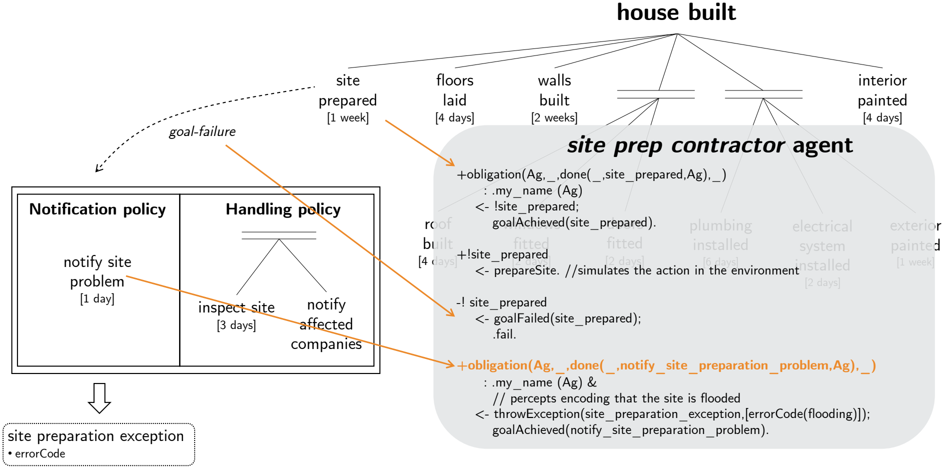

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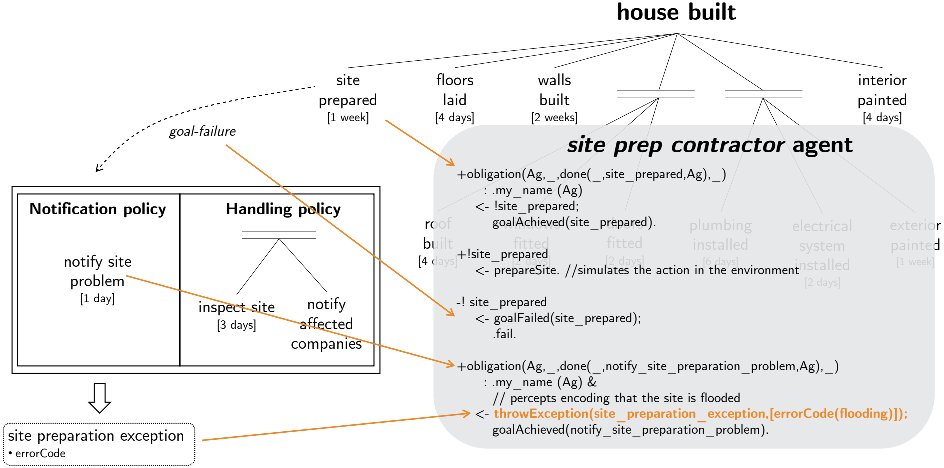

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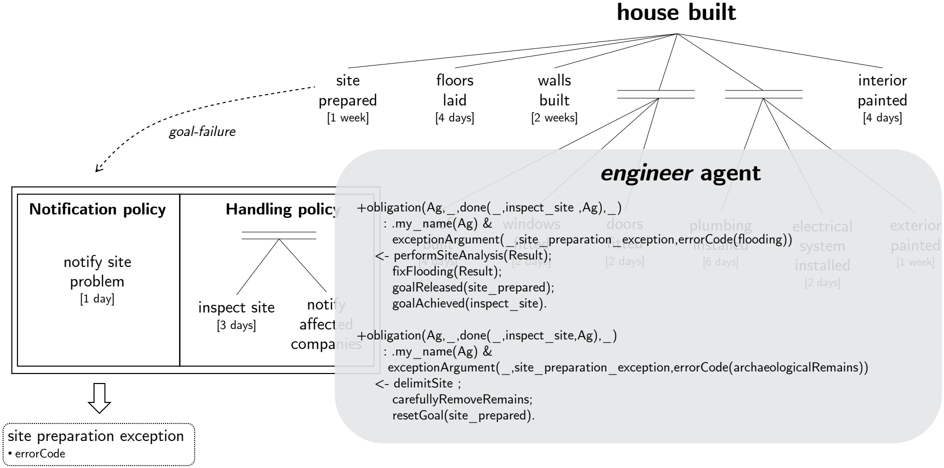

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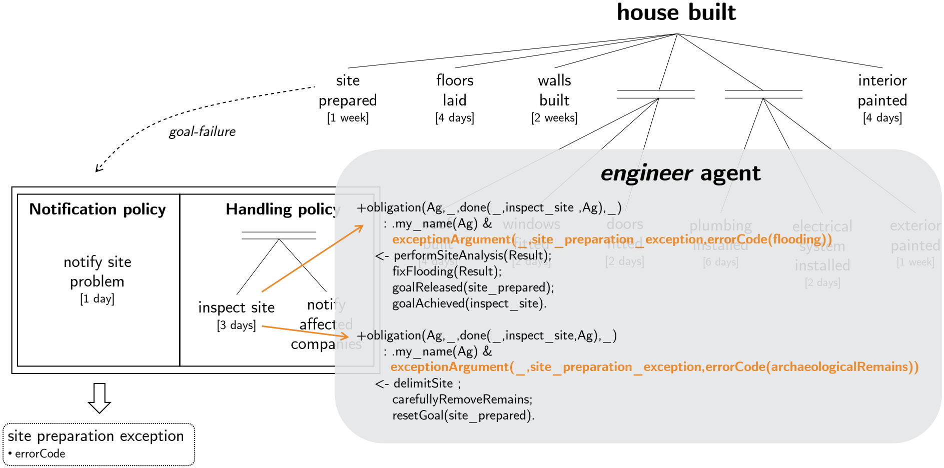

Discussion and Conclusions

Benefits

Five important features of the approach:

- **Autonomy preservation**
- **Decentralization**
- **Responsibility distribution**
- **Reliable feedback**
- **Platform integration**

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Autonomy preservation

Decentralization

Responsibility distribution

Reliable feedback

Platform integration

We can capture a wide range of situations:

- Goal **failures**
- Goal **delays**
- **Custom** perturbations
- Exceptions **raised collectively**
- Exceptions **handled collectively**
- **Recurrent** exception handling
- **Concerted** exceptions
- **BPMN** error events

Exception Handling and Message Passing

Robustness could be achieved by relying on **inter-agent messages**

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Responsibilities concerning the handling of perturbations are not clear
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→ Bad impact in terms of **modularity** and **decoupling**

We rely on the **normative layer** of the organization to encode such responsibilities
→ **No significant increase of computational cost** when exception handling is in place

Modularity through Exception Handling

Exceptions and exception handling are **not only needed to deal with errors**

[12] John B. Goodenough. "Exception Handling: Issues and a Proposed Notation". In: *Communications of the ACM* 18.12 (1975), pp. 683–696.

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Means for enabling **robust software composition**[12]
→ Allow the invoker of an operation to **extend the operation domain or its range**
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MAS bring software modularity and separation of concerns to an extreme

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Channels through which relevant local information (**accounts**) flow from informed sources (**a-givers**) to the agents competent to understand the answer (**a-takers**)

Accountability supports robustness when the account about a perturbation is reported to the agent who is responsible for treating that perturbation

Future Directions

1. **Unexpected** (or unanticipated) **exceptions** → Self-Adaptive Systems

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Accountability as a **framework to exchange reliable feedback** among distributed components in a structured way
→ Support for a wide range of **non-functional requirements**

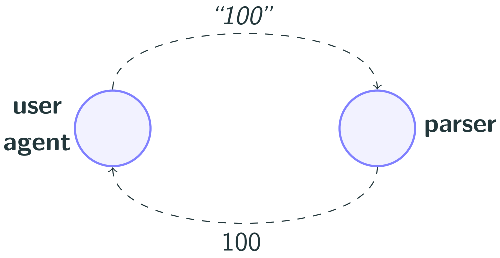
Thank you for your attention!

Questions?

ATM Example

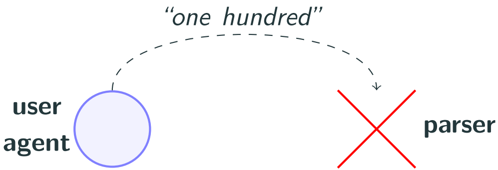
Money withdrawal at an ATM involves two steps:

1. The desired amount is collected from the user by a **user agent** as a string
2. The string is parsed by a **parser** and the amount is given back to the user agent to provide the money



ATM Example

If the string is not a number in digits parsing fails



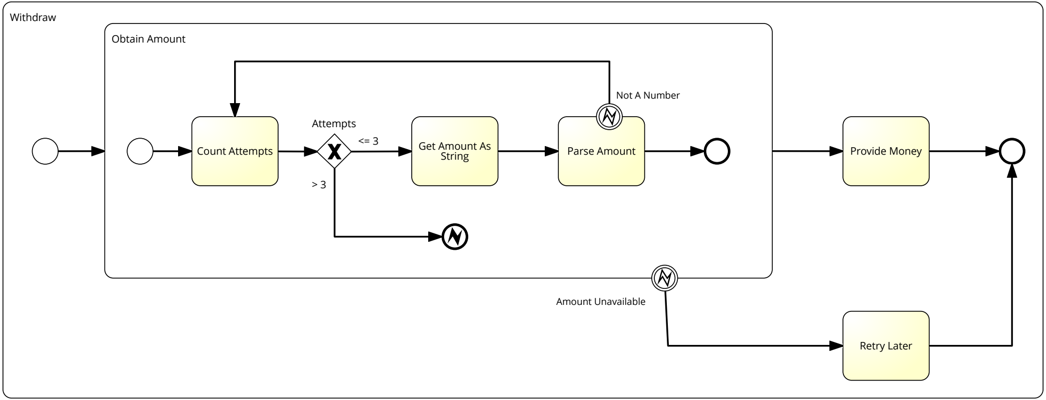
The parser agent has only a **partial view**

→ Unaware of the data source and of the aims for which the parsing is requested

Only the user agent has the necessary **contextual information**

→ A new input must be requested to the user

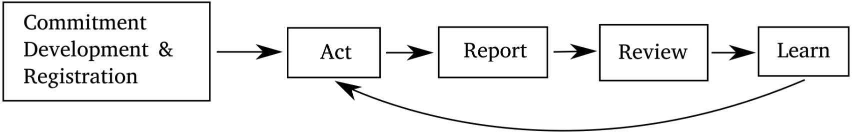
ATM Example in BPMN



Accountability in the Human World

Accountability frameworks describe organization-wide processes for monitoring, analysing, and improving performance in all aspects of an organization[13]

Address recurring and systemic issues to incorporate lessons learned into future activities



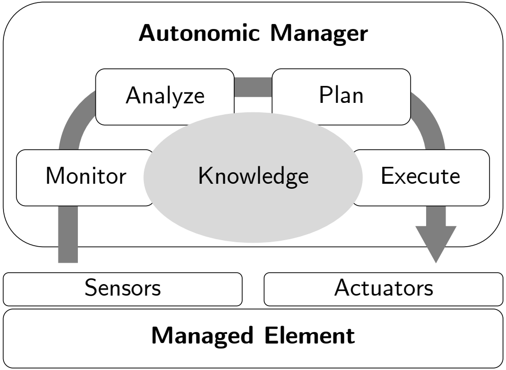
A general schema for accountability frameworks

[13] Executive Board of the United Nations Development Programme and of the United Nations Population Fund. *The UNDP accountability system, Accountability framework and oversight policy*. Tech. rep. DP/2008/16/Rev.1. United Nations, 2008.

Self-Adaptive Systems

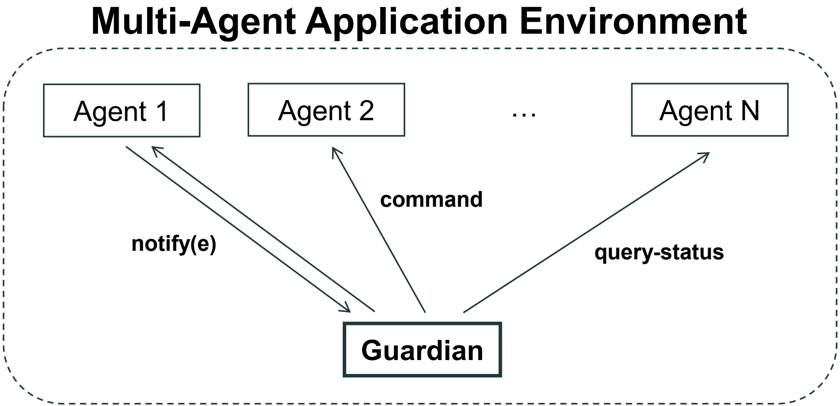
Self-adaptive software aims at **autonomously evaluating and changing its behavior** whenever an evaluation shows that the system is not accomplishing what it was intended to do[14]

Most approaches follow the **MAPE-K loop**[15]



[14] Frank D. Macías-Escrivá et al. "Self-adaptive systems: A survey of current approaches, research challenges and applications". In: *Expert Systems with Applications* 40.18 (2013), pp. 7267–7279.

[15] IBM. *An Architectural Blueprint for Autonomic Computing*. Tech. rep. IBM, 2005.


Multi-Agent Application Environment
Agent 1
Agent 2
…
Agent N
command
notify(e)
query-status
Guardian

Organizational Artifacts in JaCaMo

OrgBoard

- Group Boards
- Scheme Boards
- Org Specification

- createGroup
- removeGroup
- createScheme
- removeScheme

GroupBoard

- Role Players
- Schemes
- Group Specification
- Subgroups
- Parent Group
- Formation Status

- adoptRole
- leaveRole
- addScheme
- removeScheme
- setParentGroup
- destroy

SchemeBoard

- Commitments
- Groups
- Goals States
- Scheme Specification
- Obligations
- Goals Arguments

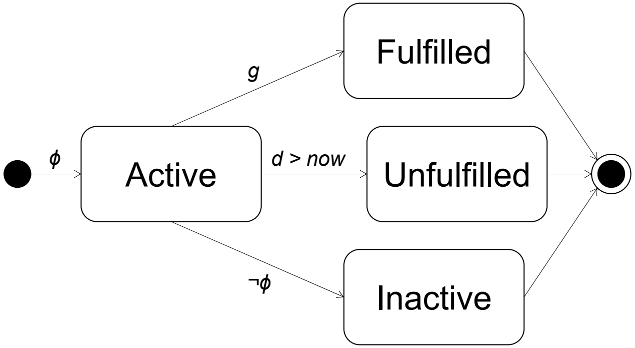
- commitMission
- leaveMission
- goalAchieved
- setArgumentValue
- resetGoal
- destroy

NormativeBoard

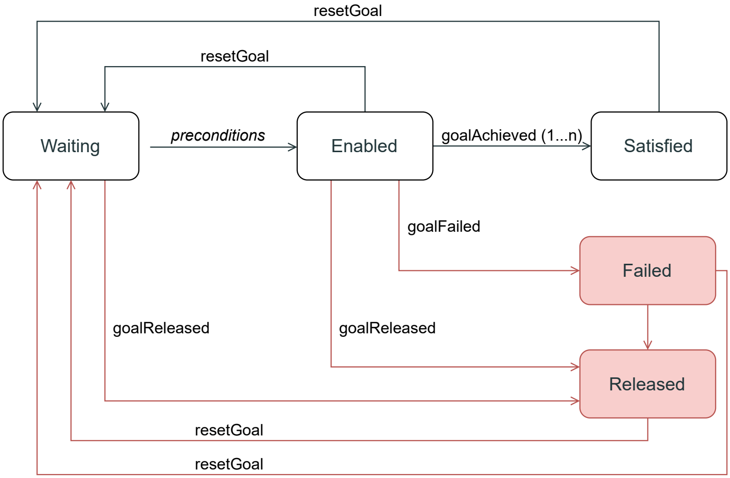
- Obligations

- load
- addFact

State transitions for obligations in JaCaMo



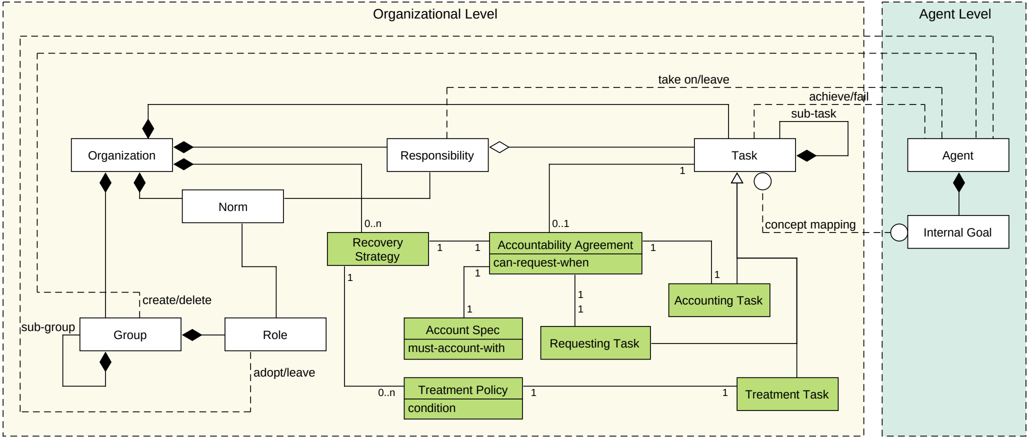
Extended Lifecycle of a JaCaMo Goal



Condition Types for Recovery Strategies

Type	Arguments	Condition formula
always	[]	true
goal-failure	[target]	scheme_id(S) & failed(S,$target)
goal-ttf-expiration	[target]	scheme_id(S) & unfulfilled(obligation(_,_,done(S,$target,_),_))
custom	[formula]	$formula

Accountability Model



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