Precise and Complete Requirements? An Elusive Goal

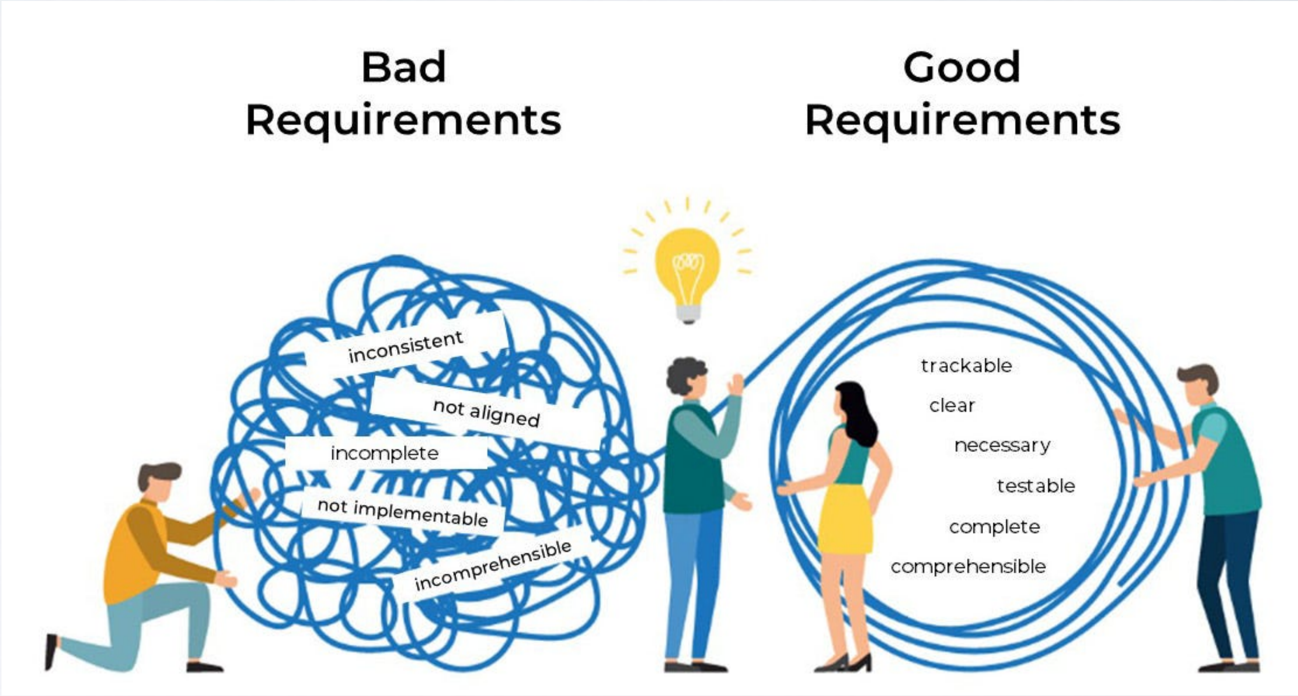
Lionel Briand

MO2RE 2024 Keynote

http://www.lbriand.info

Canada Research Chairs
Chaires de recherche du Canada
Canada

Academic Assumptions



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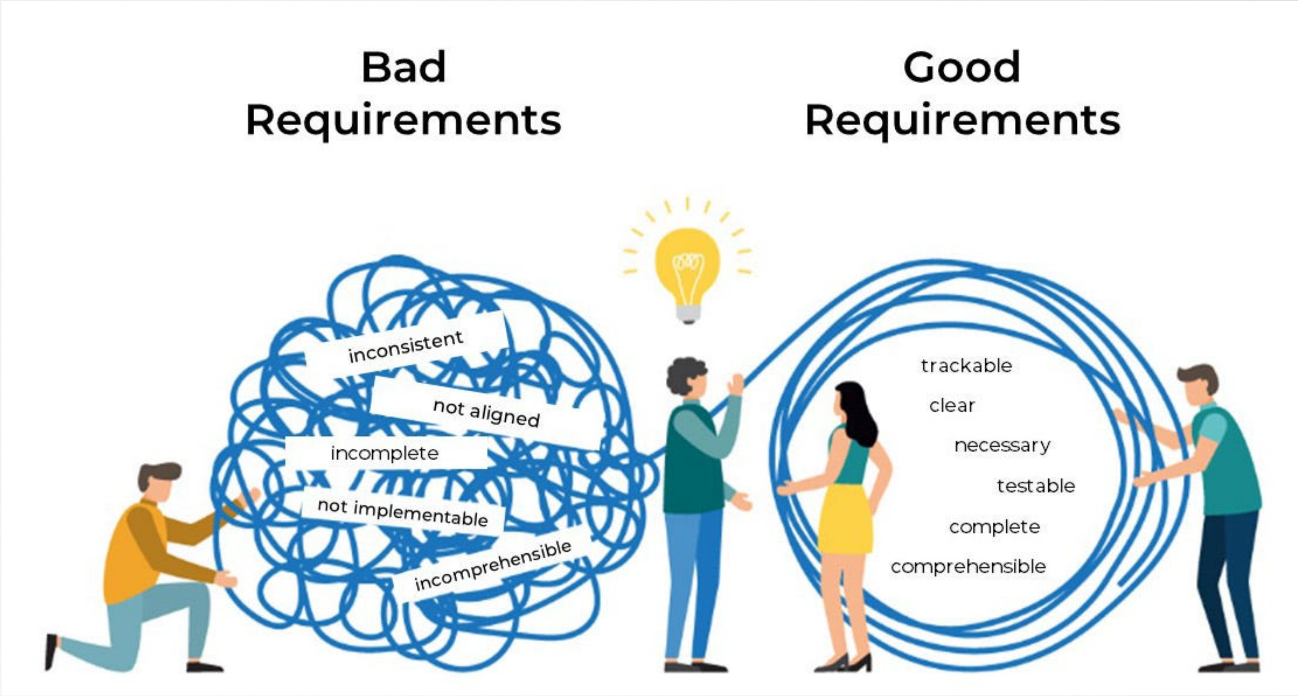

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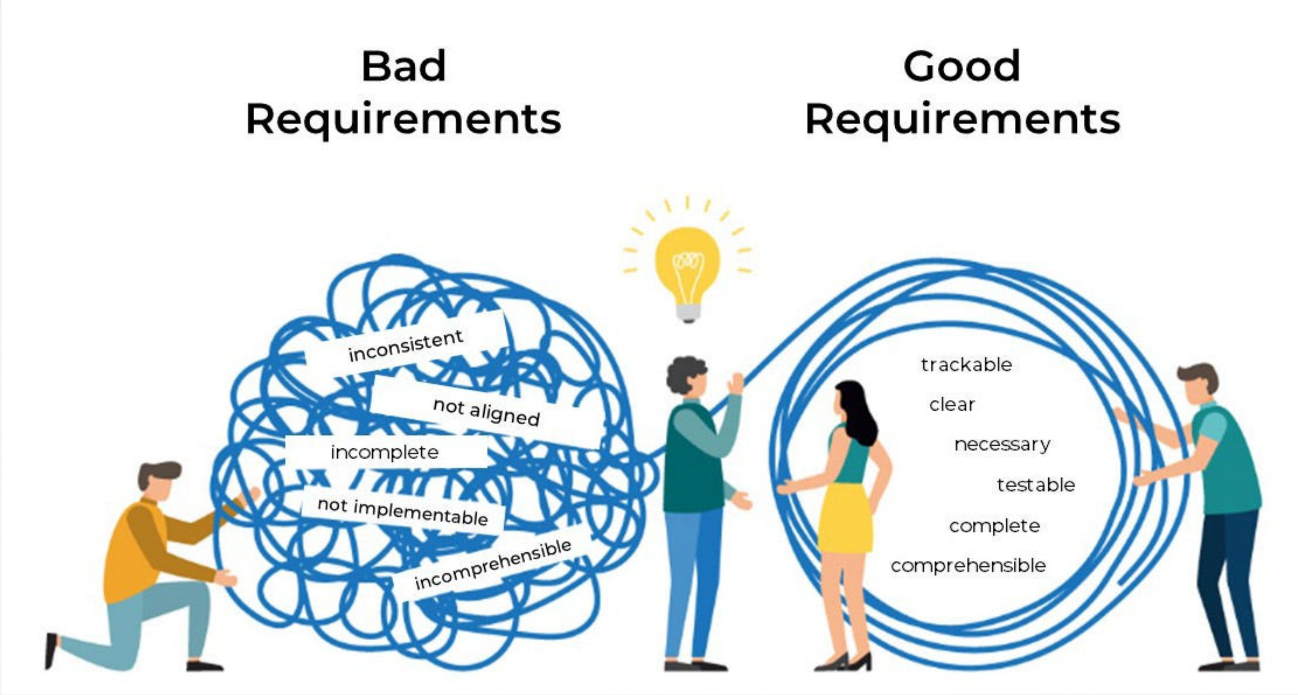

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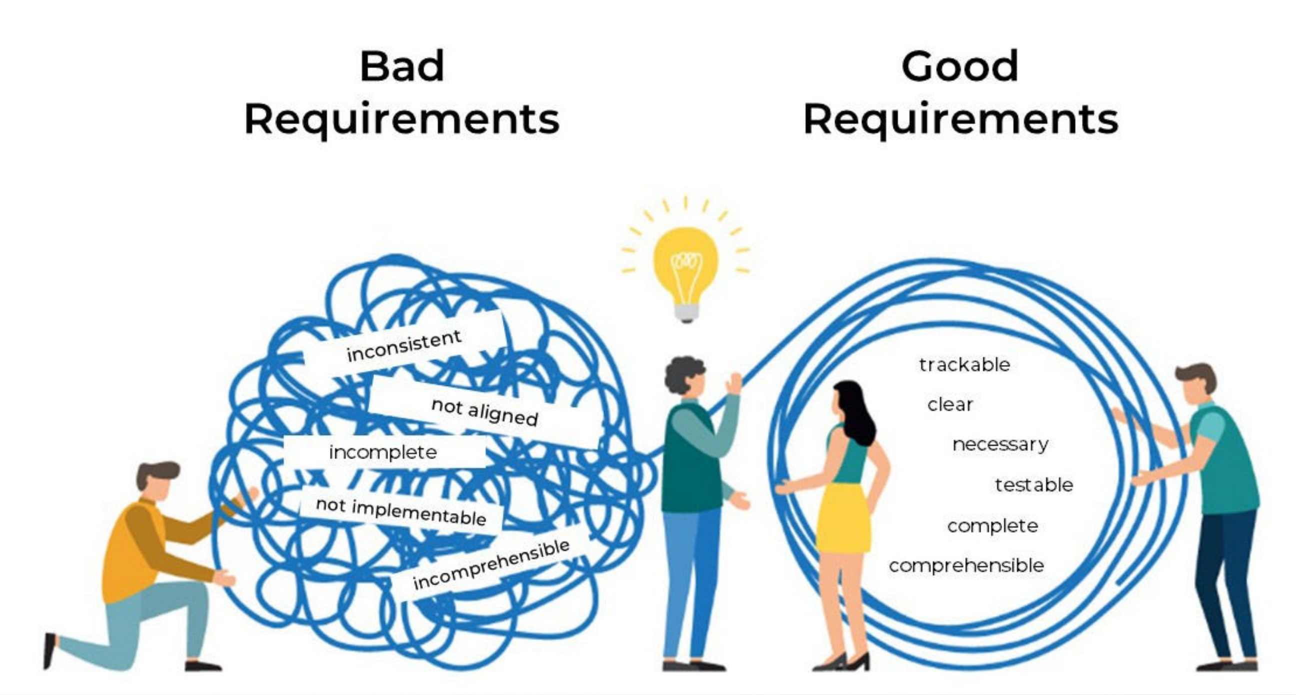
- That sounds logical to many. (except agile folks), and drives (most of) academic research.



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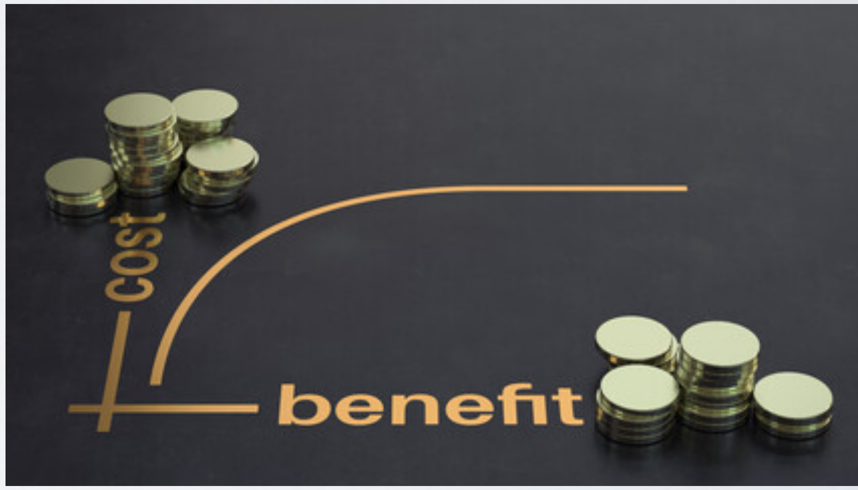

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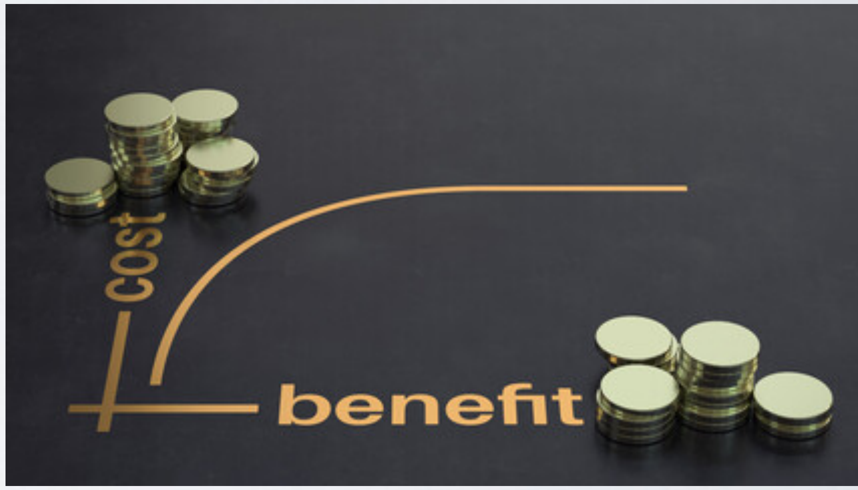

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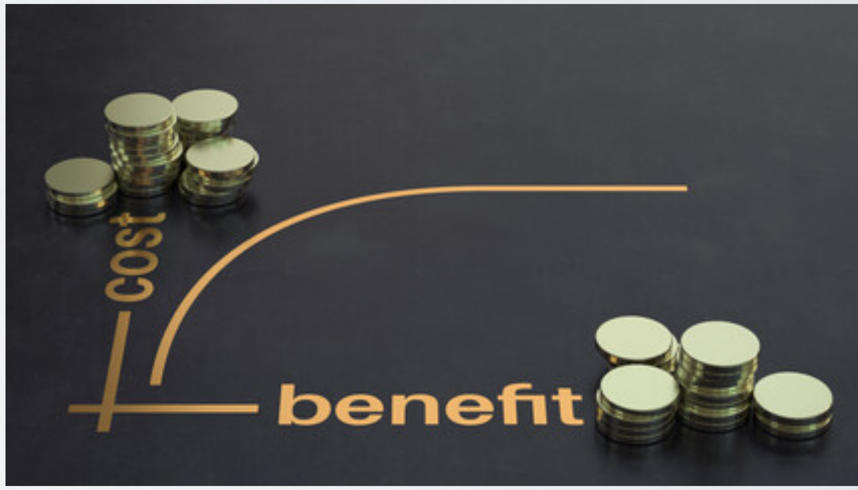

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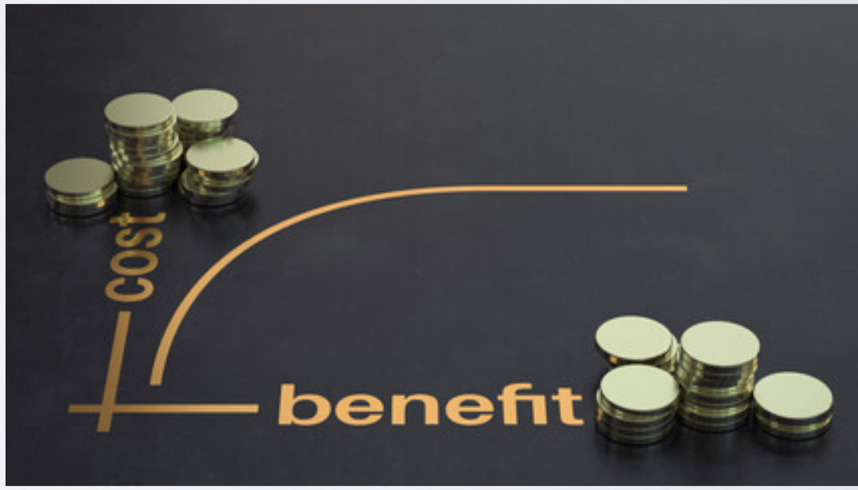

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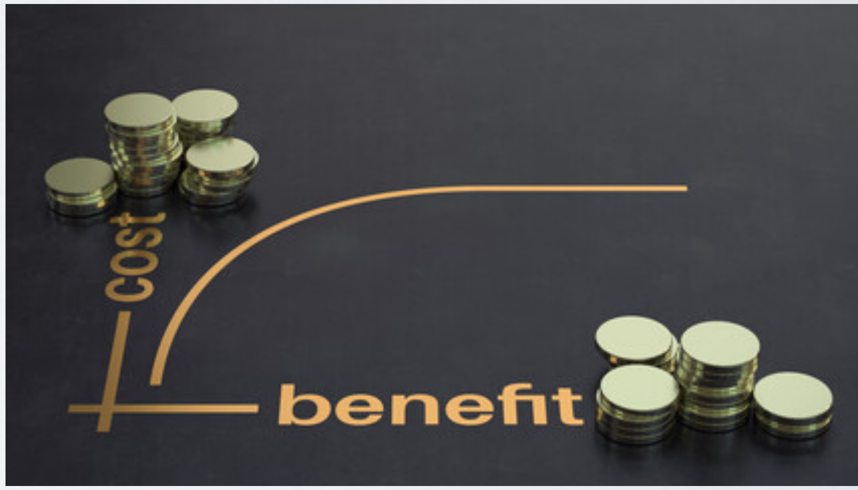
- Diversity: “RE practice differs according to the types of organization developing software, the types of products being developed, and the particular application domain of the product. “ (Lui et al. 2010)



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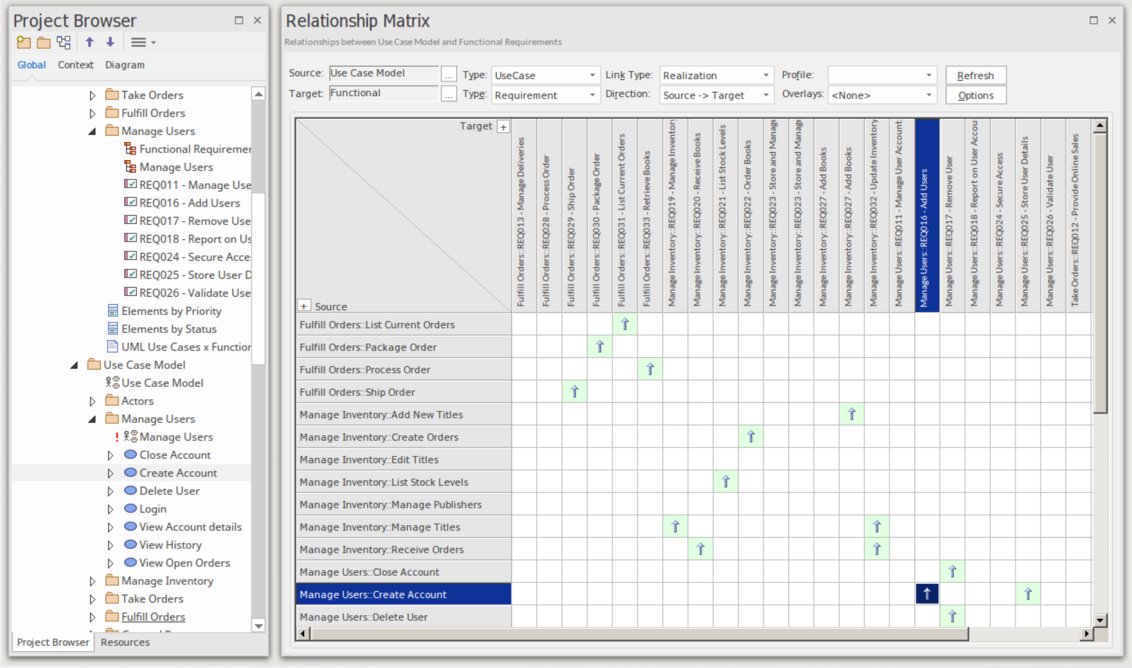

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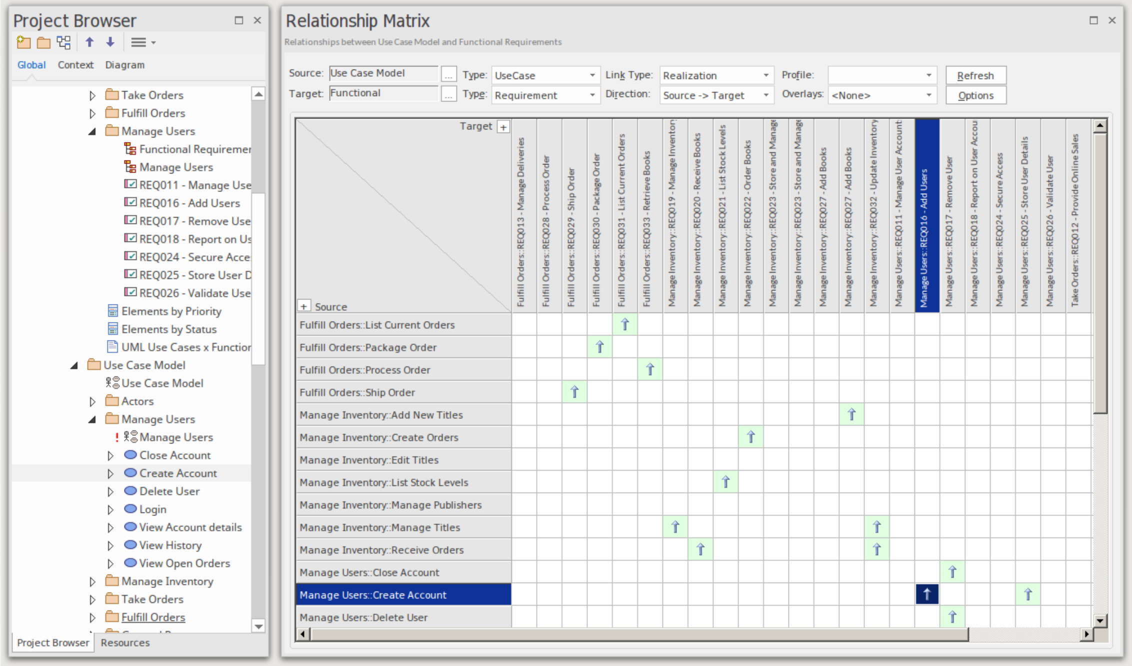

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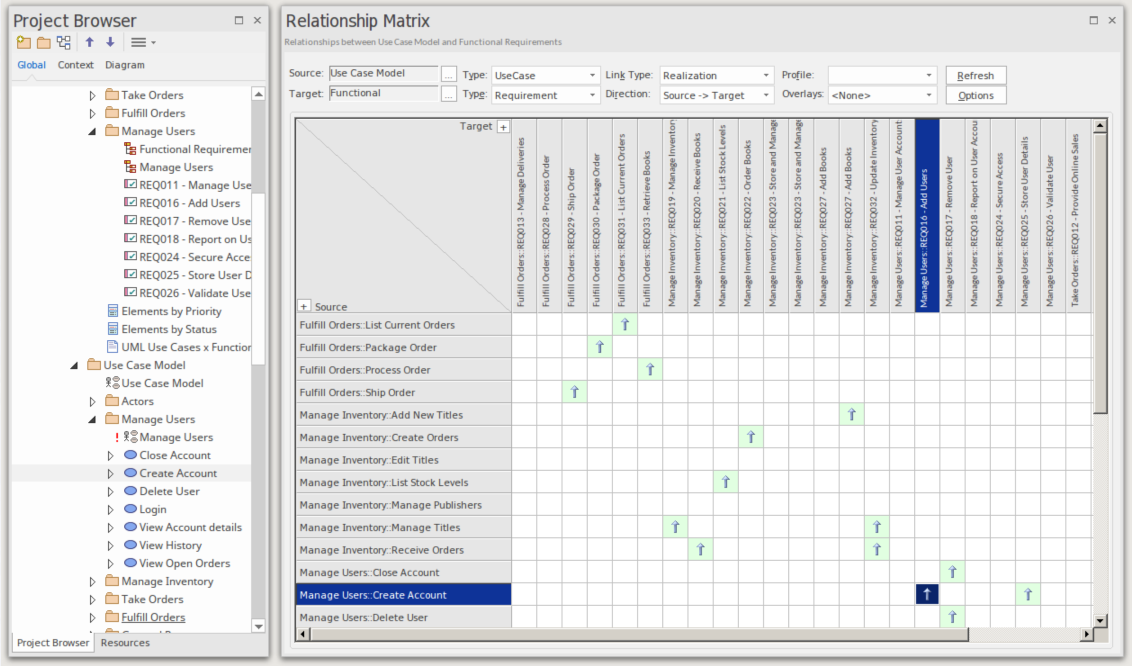
- **The goal is only to achieve certification/regulatory compliance**



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Liu et al., "Why Requirements Engineering Fails: A Survey Report from China", IEEE RE 2010

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- Develop RE tools that **better fit the real-world** needs of the customers and engineers.

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- “The **designers and programmers know what to do**, of course the requirements specification is there to drive it, but in details it is very common that the **requirements don’t really drive** the designers/programmers.”

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- Time pressure, lack of resources
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- Result: Low return on investment (RoI) for precise, complete requirements (real or perceived?)

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- Quality (precision, completeness, …) is relatively low

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Three Essential Technologies

- NL requirements QA
- NL requirements change impact (CI) analysis
- NL Requirements-driven acceptance testing

Requirements Quality Assurance

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Veziaga et al., “On systematically building a controlled natural language for functional requirements.”, Empir. Softw. Eng. 26(4): 79 (2021)

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SYSTEM RESPONSE: VALIDATE | ... 47 action phrases

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Quality Attributes

- Quality attributes enforced by Rimay
  - **Completeness:** Presence of all the information required for the requirement to be complete
  - **Correctness:** Presence of correct information content in the correct order of appearance
  - **Clarity:** Usage of structures, phrases, and words that are free of ambiguity
  - **Atomic requirements:** A requirement with a single system function

Smells

- **10 smells:** "1. Non atomic", "2. Incomplete requirement", "3. Incorrect order requirement", "4. Coordination ambiguity", "5. Not requirement", **"6. Incomplete condition", "7. Incomplete system response"**, "8. Incomplete scope", "9. Passive voice", and "10. Not precise verb"

Condition (Missing Actor)

```
When creating a new participant,
System-A must open in edit mode the detail participant screen.
```

System Response

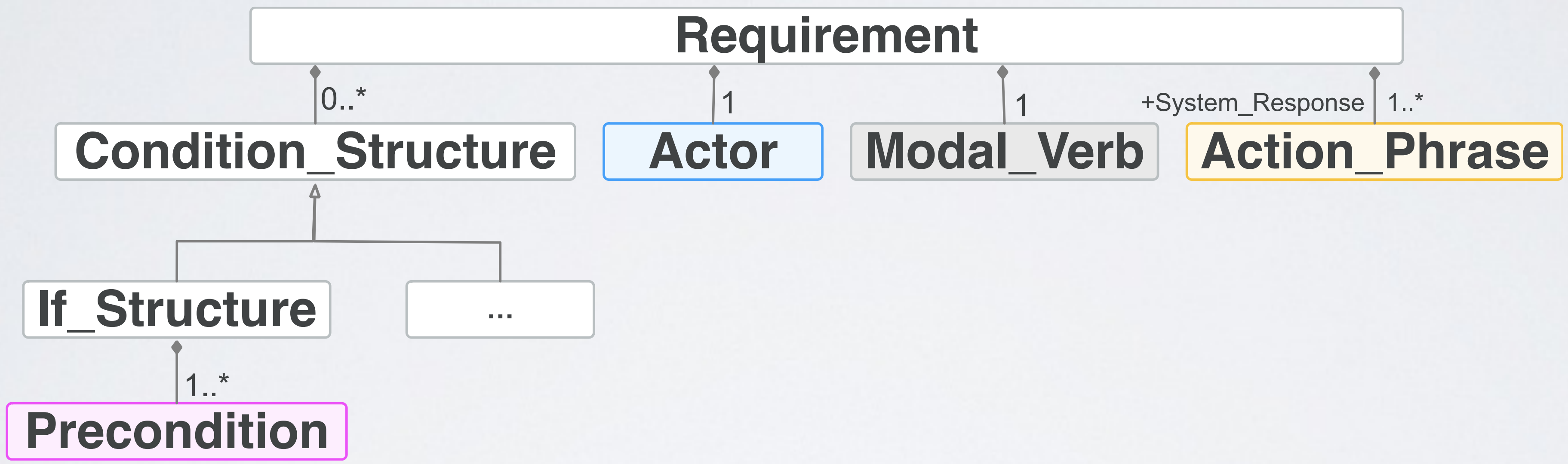
Condition

```
When a settlement request has reached the status "Settled"
then System-A must sed the settlement request to System-B.
```

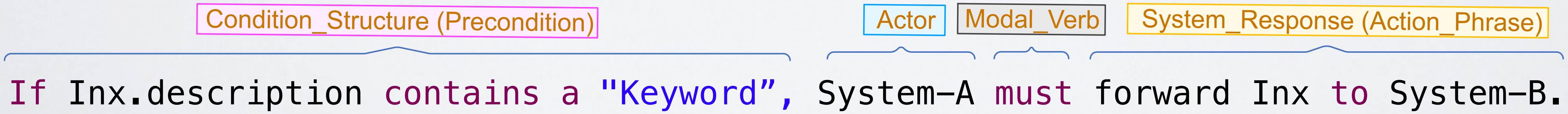
System Response (No verb)

Rimay Patterns

- Excerpt of the Rimay conceptual model:



- Example:



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- Example: `The System-A must link "allegement message-A" to the "outgoing message-123"`

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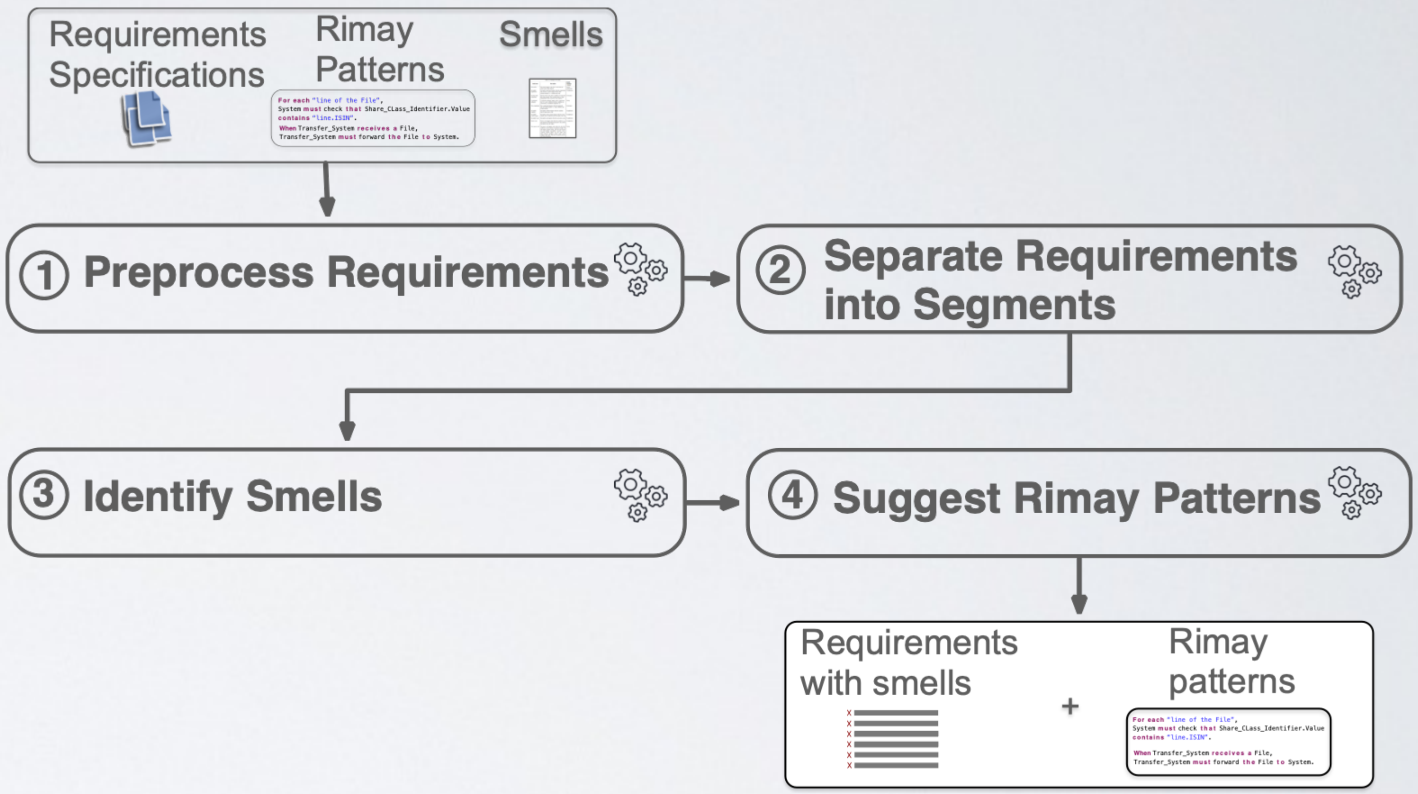

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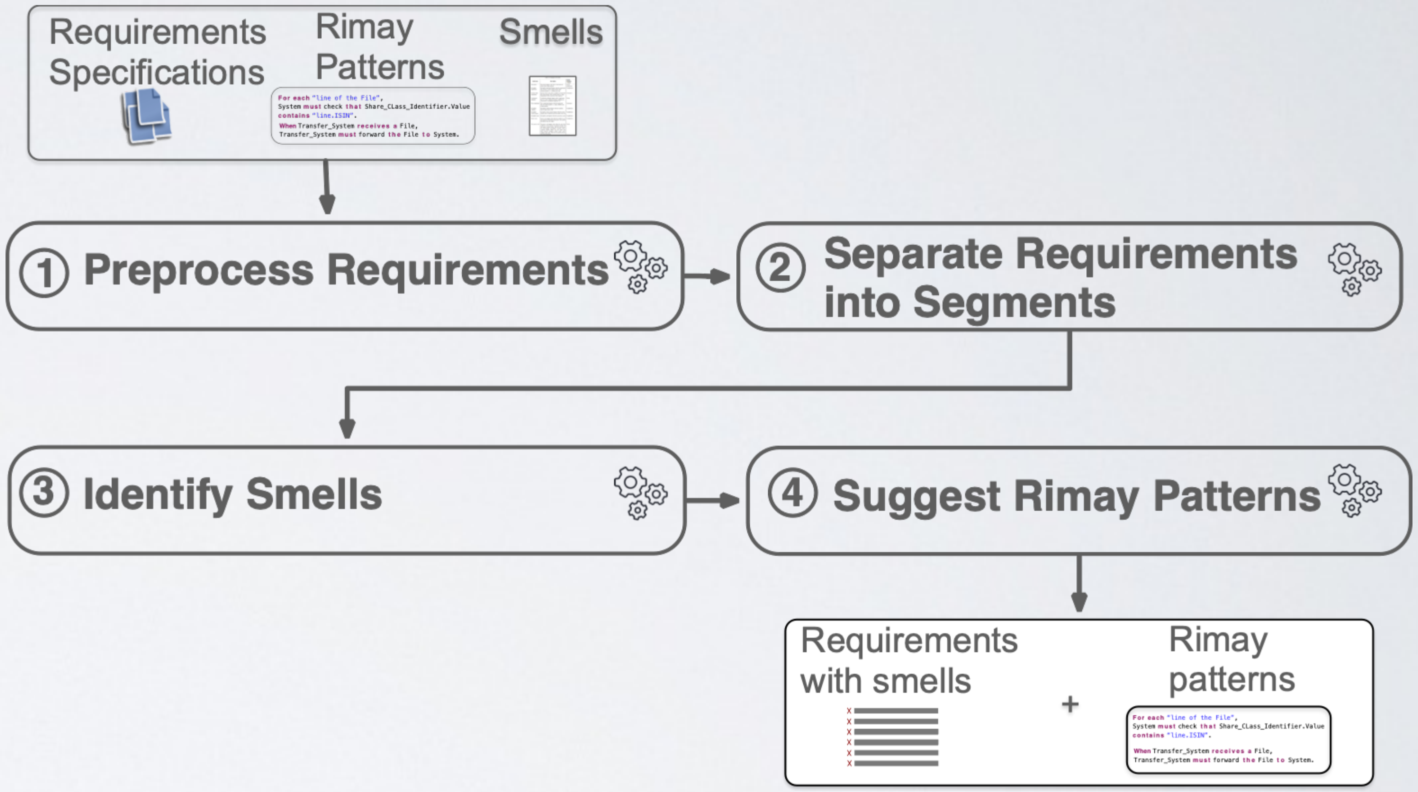

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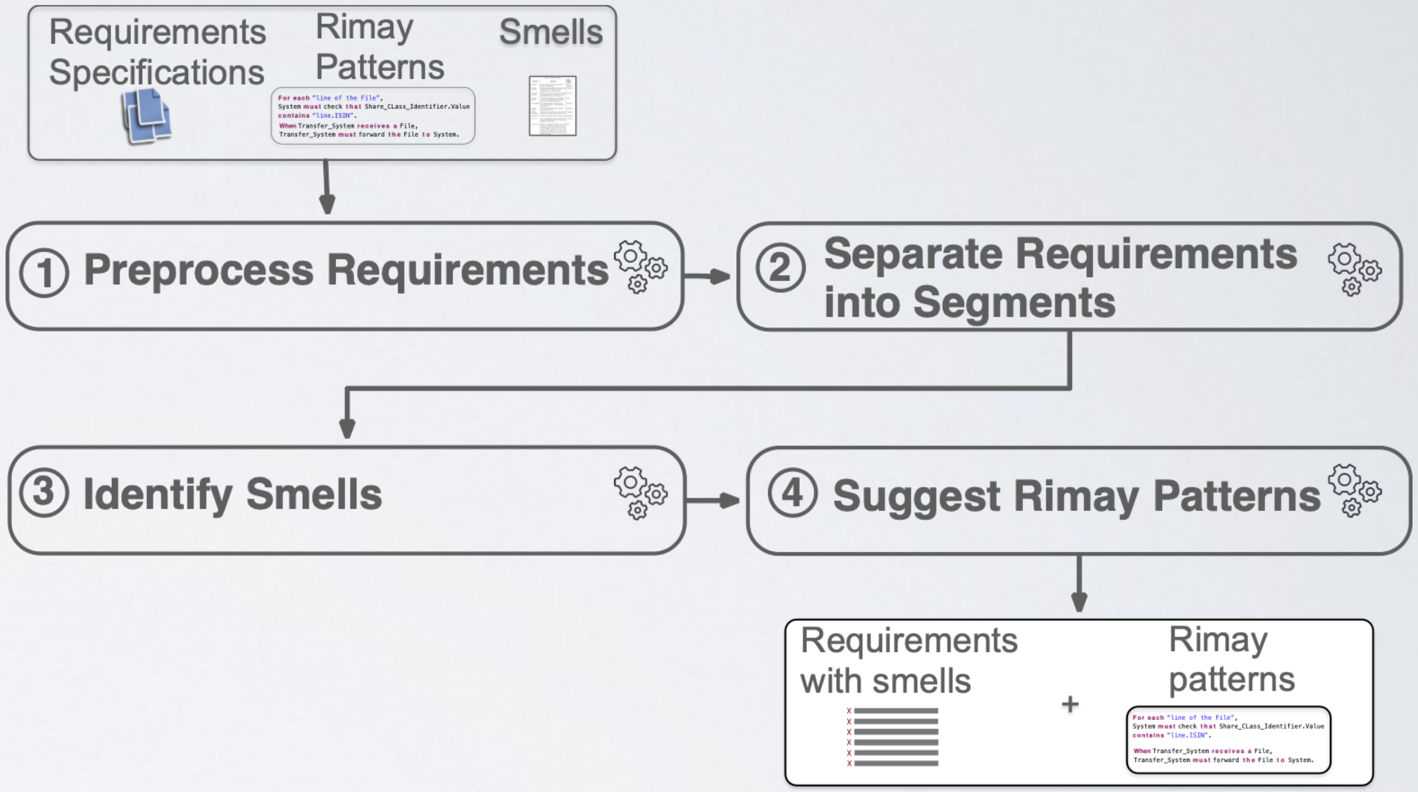

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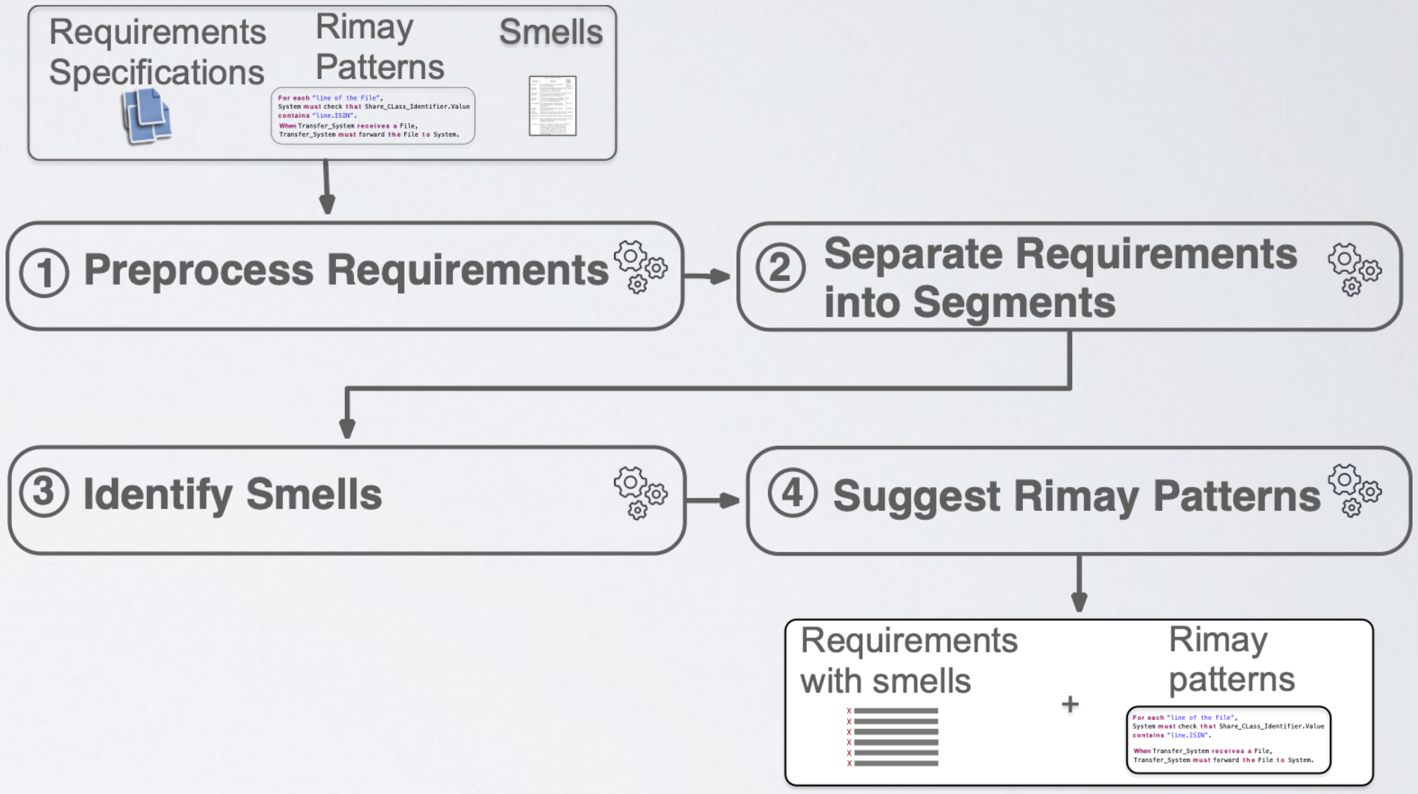

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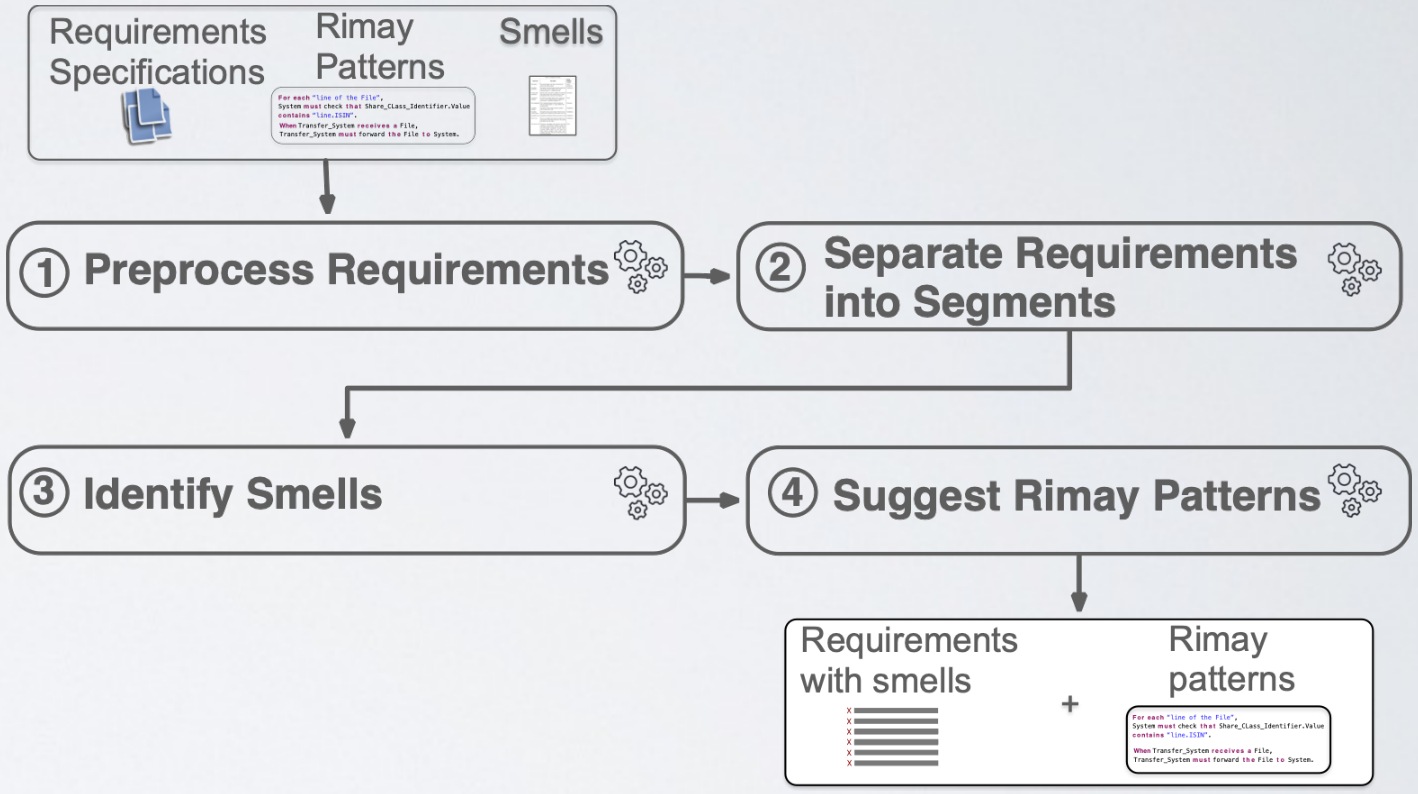

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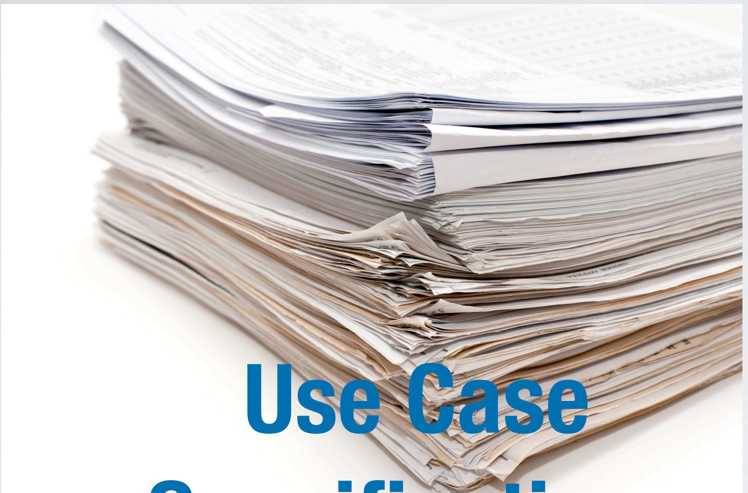
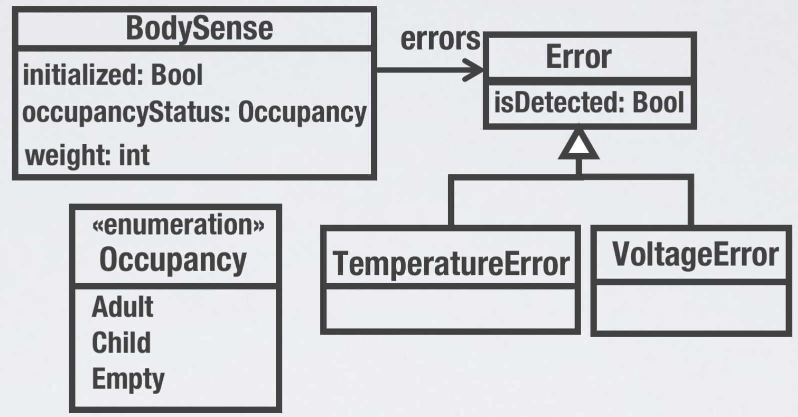
UMTG



Use Case Specifications (RUCM)



Domain Model

```
Error.allInstances()
->forAll( i | i.isDetected = false)
```

Constraints capturing the meaning of conditions

UMTG

https://sntsvv.github.io/UMTG/

Wang et al., "Automatic Generation of Acceptance Test Cases From Use Case Specifications: An NLP-Based Approach", IEEE TSE, 2020

Executable Test Cases

Restricted Use Case Specifications

- Restricted Use Case Modeling (RUCM)
- Experiments shows it yields **better use cases**
- Compliance is **tool-supported** (NLP)
- More **analyzable** with NLP

Yue et al., ACM TOSEM 2013

RUCM Specifications Example

Precondition: The system has been initialized

Basic Flow

1. The SeatSensor **SENDS** the weight **TO** the system.

INPUT STEP

2. **INCLUDE USE CASE** Self Diagnosis.

INCLUDE STEP

3. The system **VALIDATES THAT** no error has been detected.

CONDITIONAL STEP

4. The system **VALIDATES THAT** the weight is above 20 Kg.
5. The system sets the occupancy status to adult.

INTERNAL STEP

6. The system **SENDS** the occupancy status **TO** AirbagControlUnit.

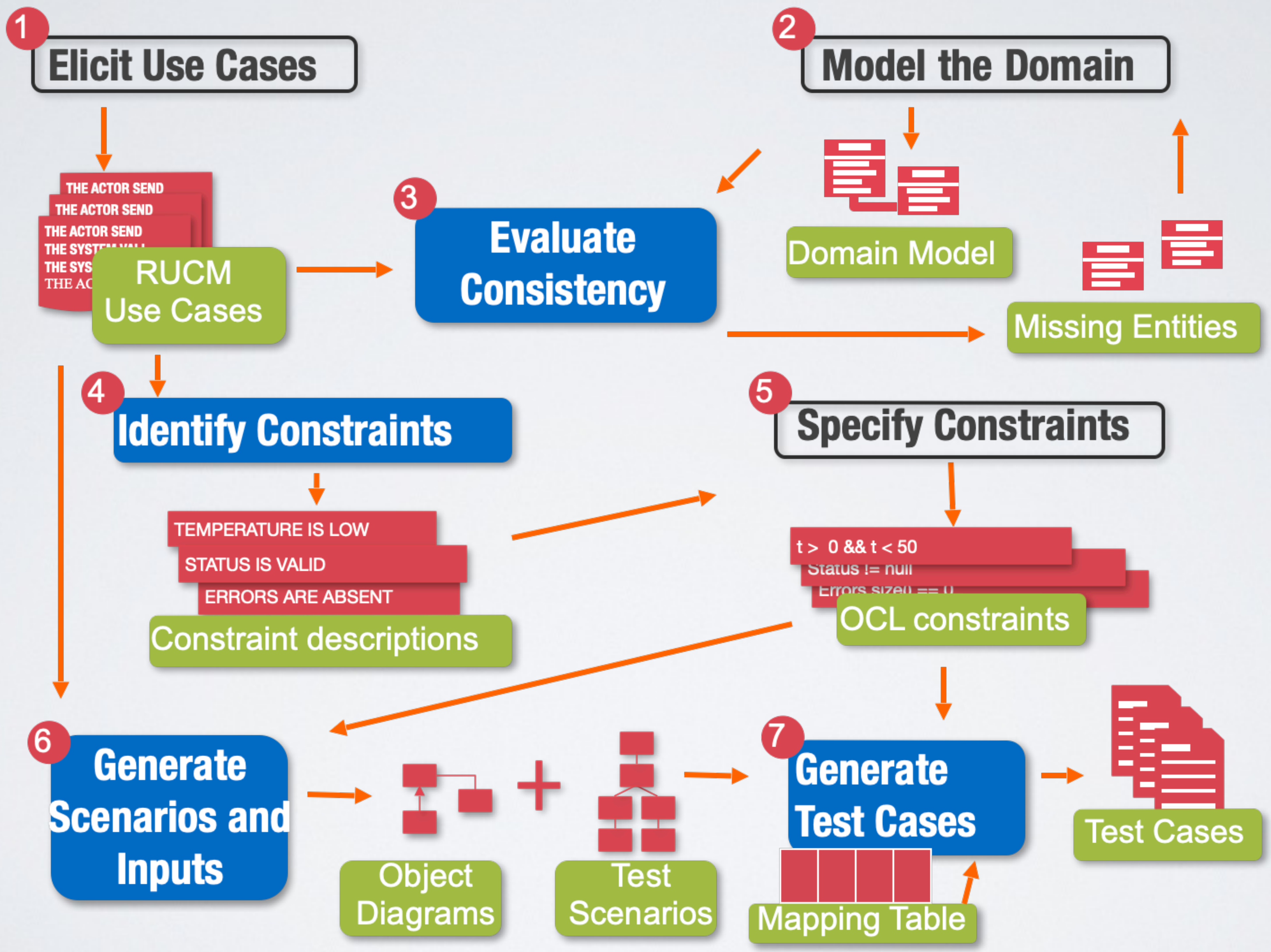
OUTPUT STEP

Alternative Flow

RFS 4.

1. **IF** the weight is above 1 Kg **THEN**
2. The system sets the occupancy status to child.
3. …
4. **RESUME STEP 6.**

UMTG Steps



1
Elicit Use Cases
RUCM
Use Cases
2
Model the Domain
Domain Model
Missing Entities
3
Evaluate
Consistency
4
Identify Constraints
TEMPERATURE IS LOW
STATUS IS VALID
ERRORS ARE ABSENT
Constraint descriptions
5
Specify Constraints
t > 0 && t < 50
OCL constraints
6
Generate
Scenarios and
Inputs
Object
Diagrams
+
Test
Scenarios
7
Generate
Test Cases
Mapping Table
Test Cases

UMTG: Empirical Evaluation

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Inter-Requirements Change Impact Analysis

Traceability

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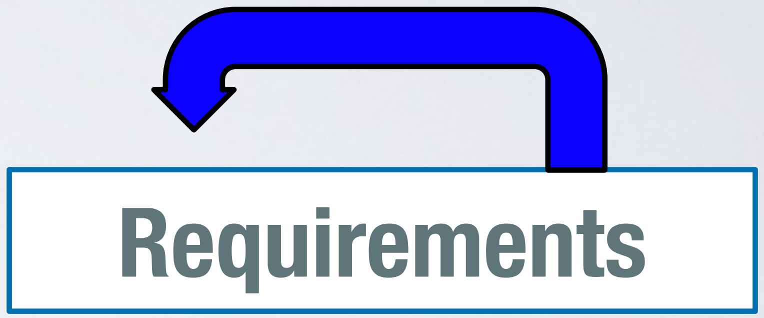
- Requirements traceability: Trace a requirement from its emergence to its fulfillment, e.g., acceptance test cases.
- Motivations:
  - Understand rationale
  - Certification, auditing, compliance with standards
  - Assess impact of change

Traceability between Requirements



- Natural language
- Sometimes structured (template)
- Hundreds of traces
- Domain terminology, concepts, and their relationships are key to discovering traces among requirements
- Rely on syntactic and semantic similarity measures

Requirements-Requirements

[RE 2015, TSE 2015, ESEM 2014, ESEM 2013]

Requirements

SES
your satellite company

Case-A

160 Requirements
9 change scenarios

novay

Case-B

72 Requirements
5 change scenarios

Example

- **R1:** The mission operation controller shall transmit satellite status reports to the user help desk.
- **R2:** The satellite management system shall provide users with the ability to transfer maintenance and service plans to the user help desk.
- **R3:** The mission operation controller shall transmit any detected anomalies with the user help desk.

Change Example

- **R1:** The mission operation controller shall transmit satellite status reports to the user ~~help desk~~ document repository.
- **R2:** The satellite management system shall provide users with the ability to transfer maintenance and service plans to the user help desk.
- **R3:** The mission operation controller shall transmit any detected anomalies with the user help desk.

Challenge#1 - Capture Changes Precisely

- R1: The mission operation controller shall transmit satellite status reports to the user ~~help desk~~ document repository.
- R2: The satellite management system shall provide users with the ability to transfer maintenance and service plans to the user help desk.
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Challenge#2 - Capture Change Rationale

- R1: The mission operation controller shall transmit satellite status reports to the user ~~help desk~~ **document repository**.
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Challenge#2 - Change Rationale

- R1: The mission operation controller shall transmit satellite status reports to the user ~~help desk~~ document repository.
- R2: The satellite management system shall provide users with the ability to transfer maintenance and service plans to the user help desk.
- R3: The mission operation controller shall transmit any detected anomalies with the user help desk.

Rationales:

1: We want to globally rename “user help desk”
2: Avoid communication between “mission operation controller” and “user help desk”
3: We no longer want to “transmit satellite status reports” to “user help desk” but instead to “user document repository”

Solution Characteristics

- **Accounts for the phrasal structure of requirements**

The mission operation controller shall transmit satellite status reports to the user ~~help desk~~ document repository.

user help desk, Deleted
user document repository, Added

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The mission operation controller shall transmit satellite status reports to the user ~~help desk~~ document repository.

user help desk, Deleted
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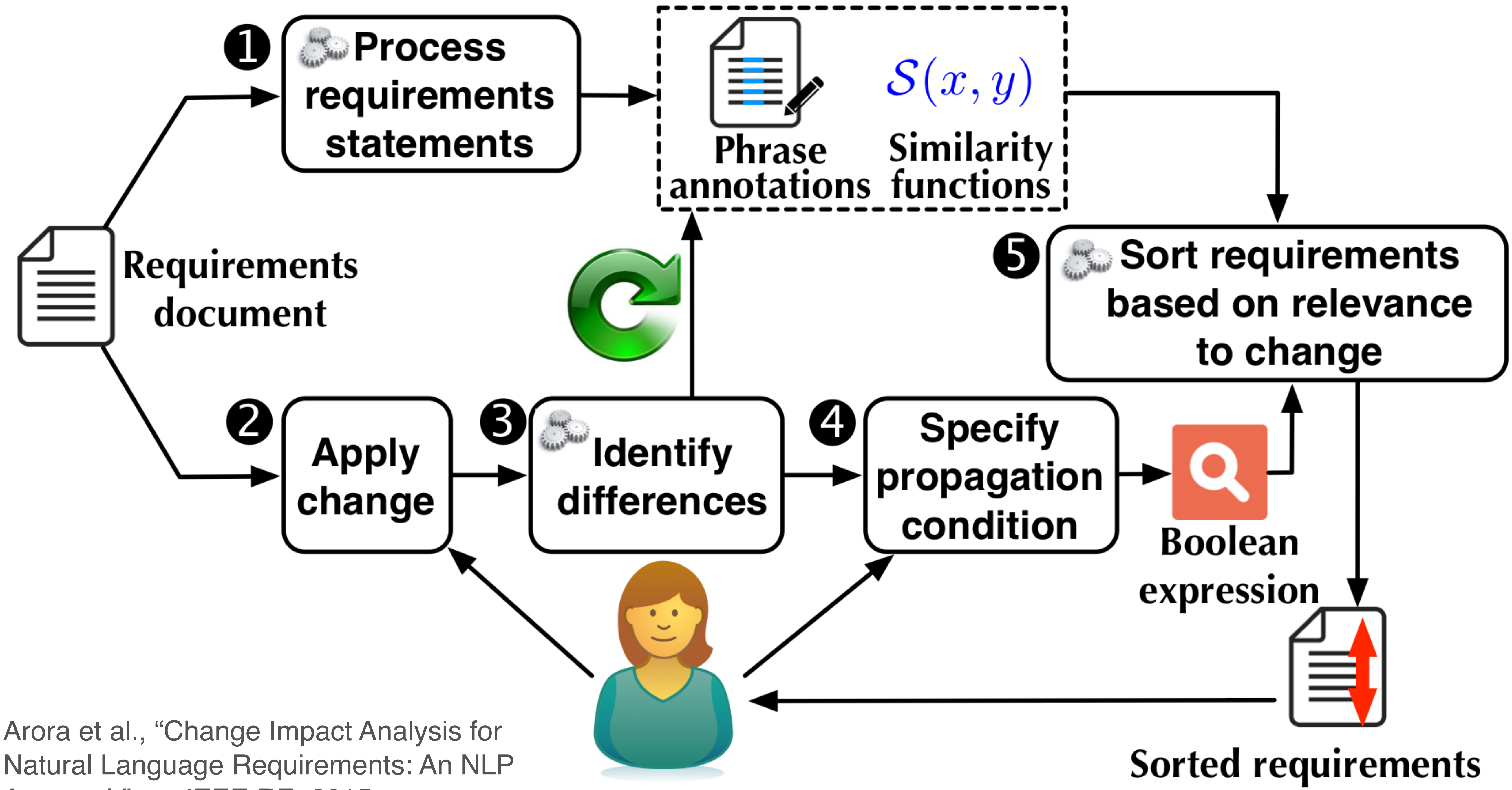
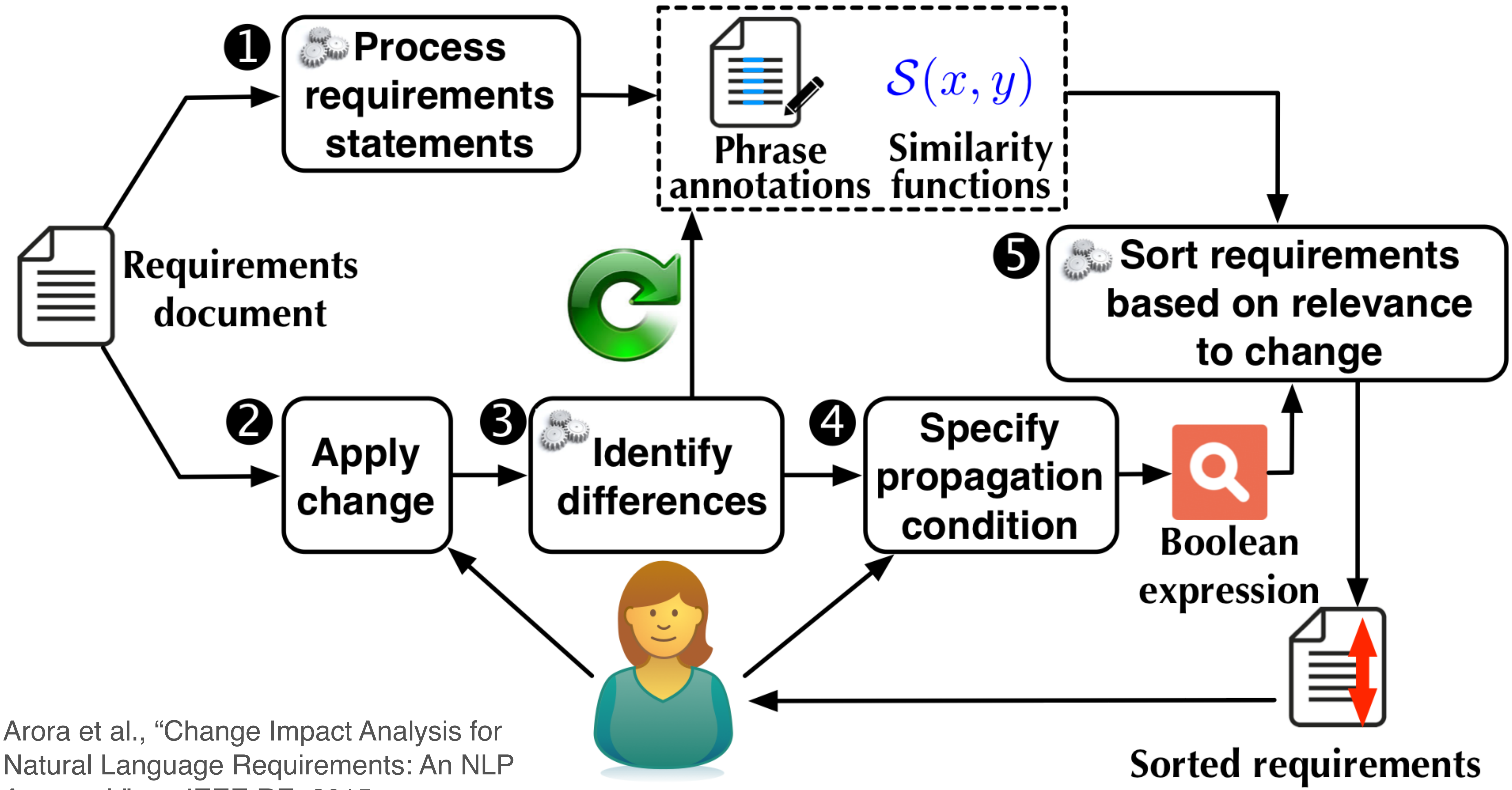
- **Account for semantically-related phrases that are not exact matches and close syntactic variations**

Approach



Arora et al., "Change Impact Analysis for Natural Language Requirements: An NLP Approach", IEEE RE, 2015

Approach



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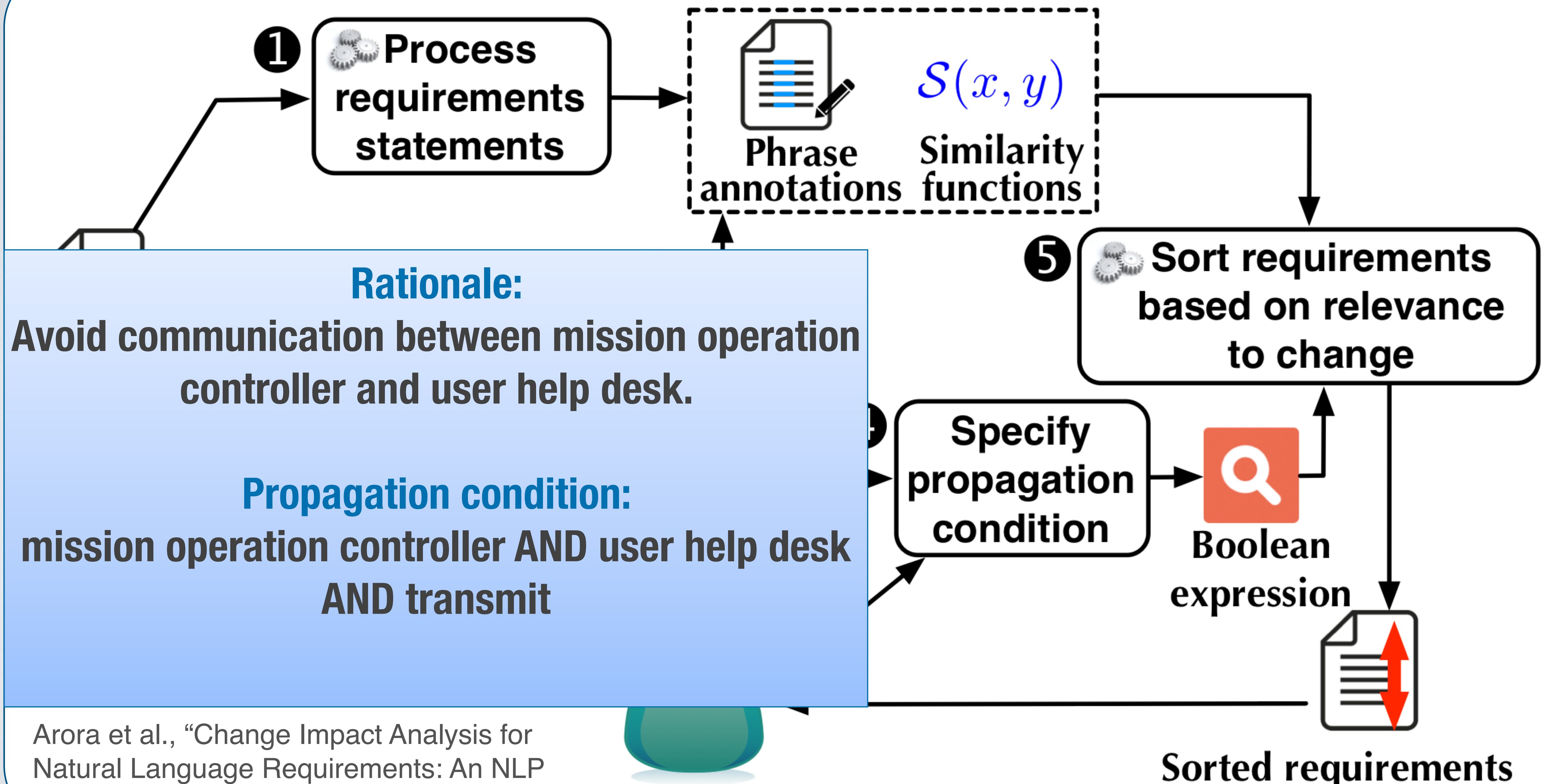


Rationale:

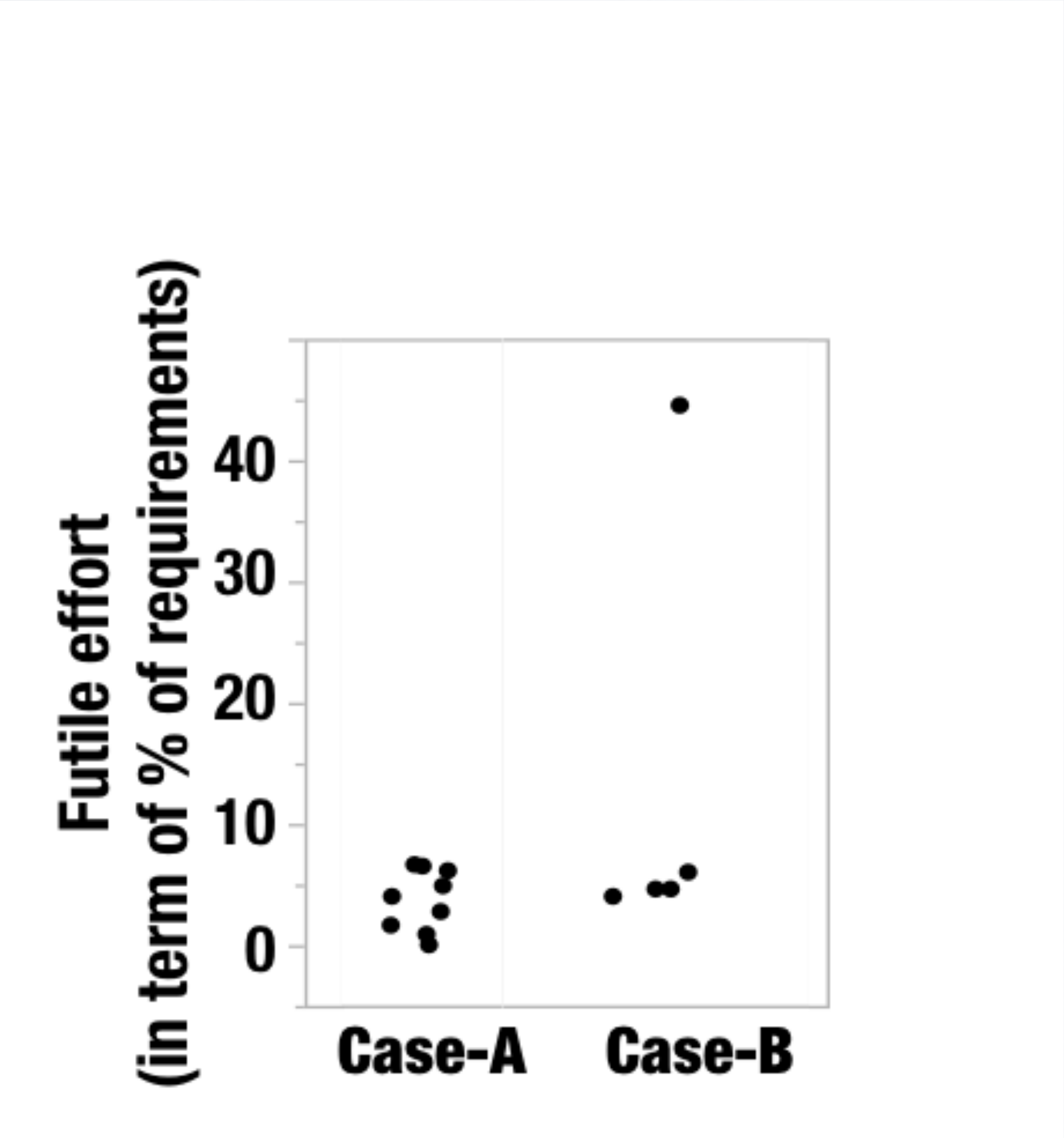
Avoid communication between mission operation controller and user help desk.

Propagation condition:

mission operation controller AND user help desk AND transmit

Arora et al., “Change Impact Analysis for Natural Language Requirements: An NLP Approach”, IEEE RE, 2015

How effective is our approach?



- Extra requirements traversed
    - Case-A between 1%-7%
    - Case-B between 6%-8% except one case
- Number of impacted requirements missed: 1 out of 106

Requirements Change Impact Analysis on Design

Requirements-Design Traceability

- Capture the **rationale of design decisions**
- Support evolution, **avoid violating essential design decisions**
- Useful for impact analysis based on traces
- What is a rationale? Level of granularity?
- Design representation?

DELPHI
Innovation for the Real World

Requirements → Archi. & Design

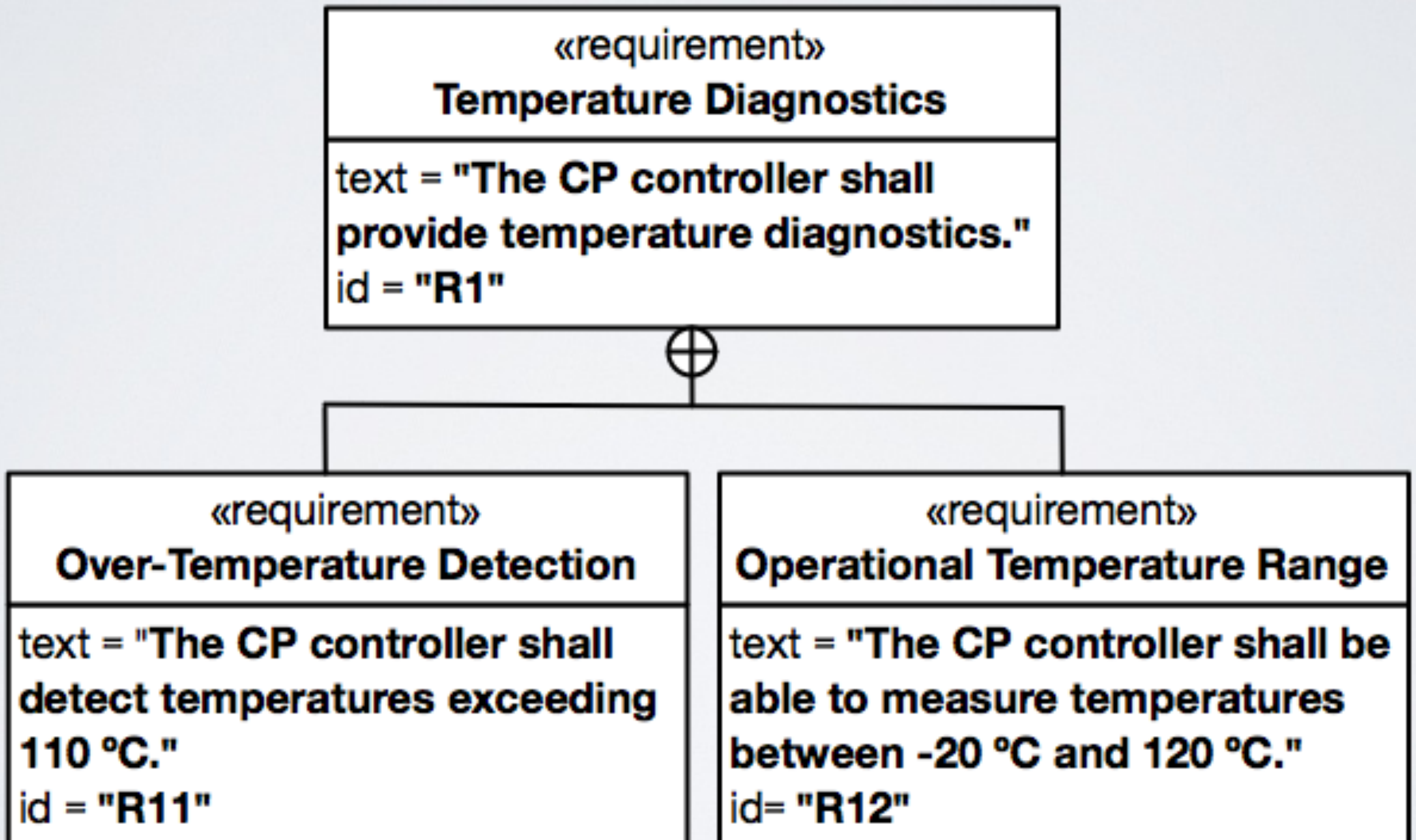
System Design Modeling

- **Systems Modeling Language (SysML)**
  - A subset of UML extended with systems engineering diagrams
  - A standard for systems engineering
  - Preliminary support for requirement analysis and built-in traceability mechanism

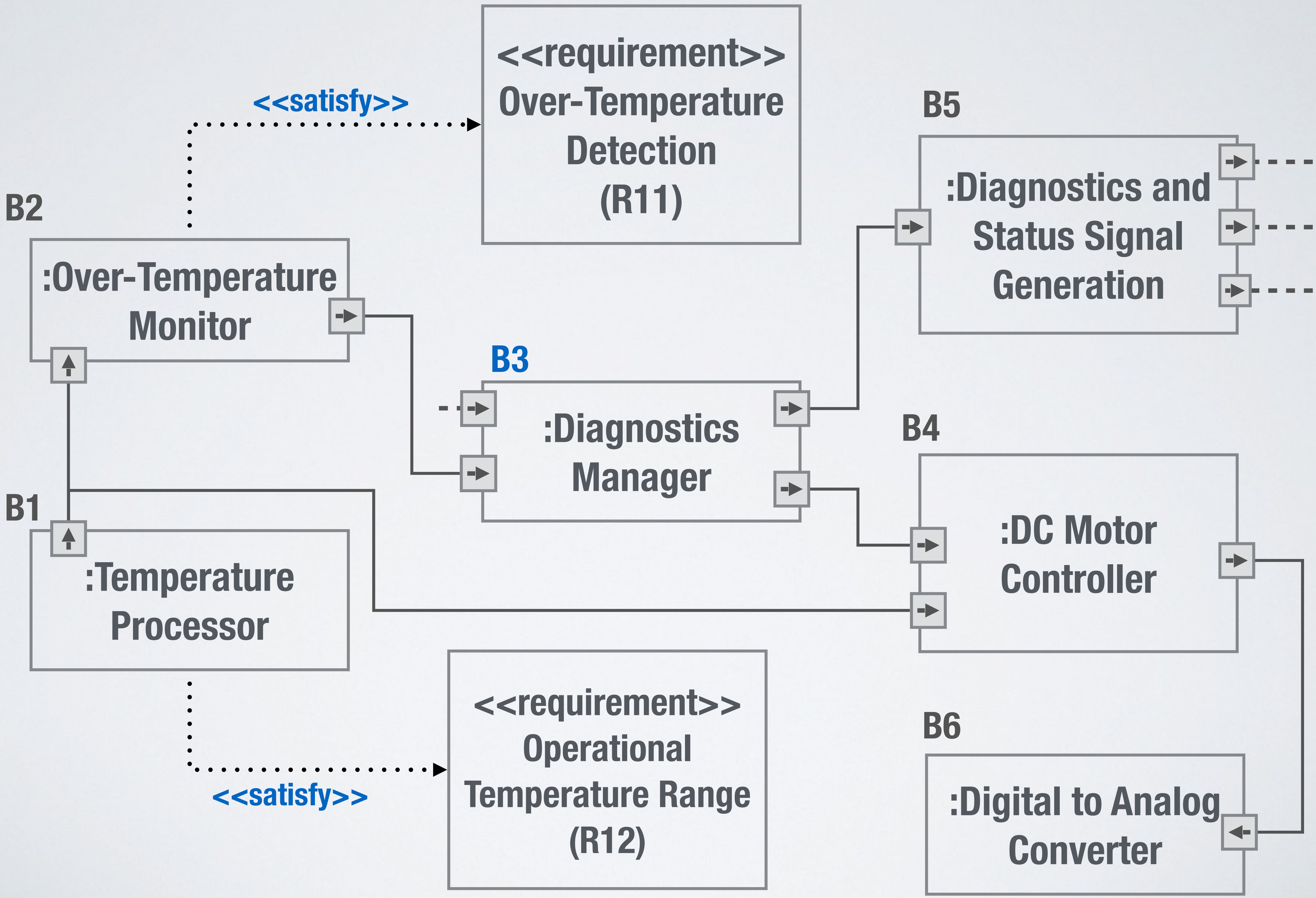
CIA Automation Goal

- Given a change in a requirement, our goal is to compute a set of (potentially) impacted design elements that includes
  - all the actually impacted elements (**high recall**)
  - very few non-impacted elements (**high precision**)

Requirements Diagram



Internal Block Diagrams (IBD)



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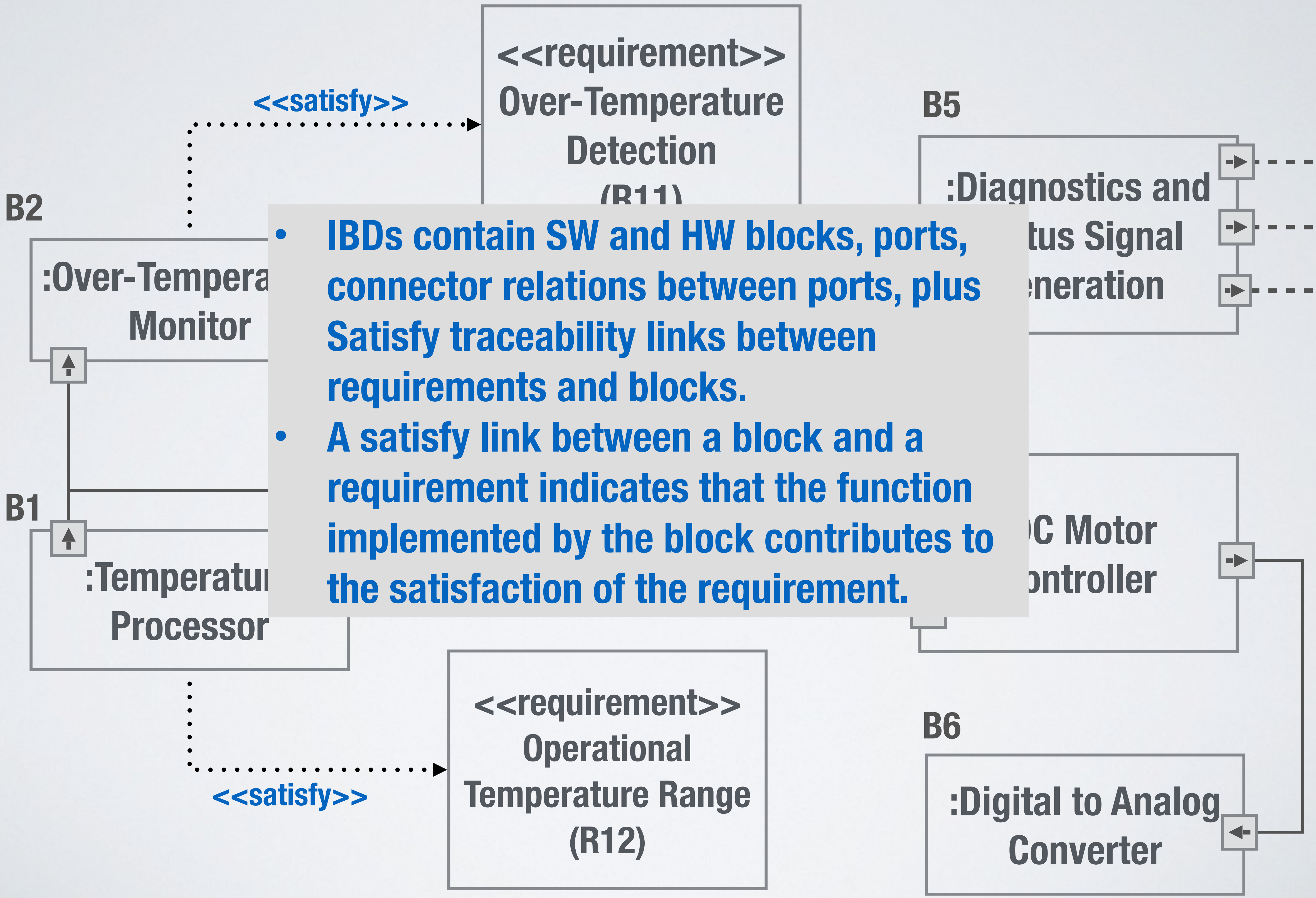
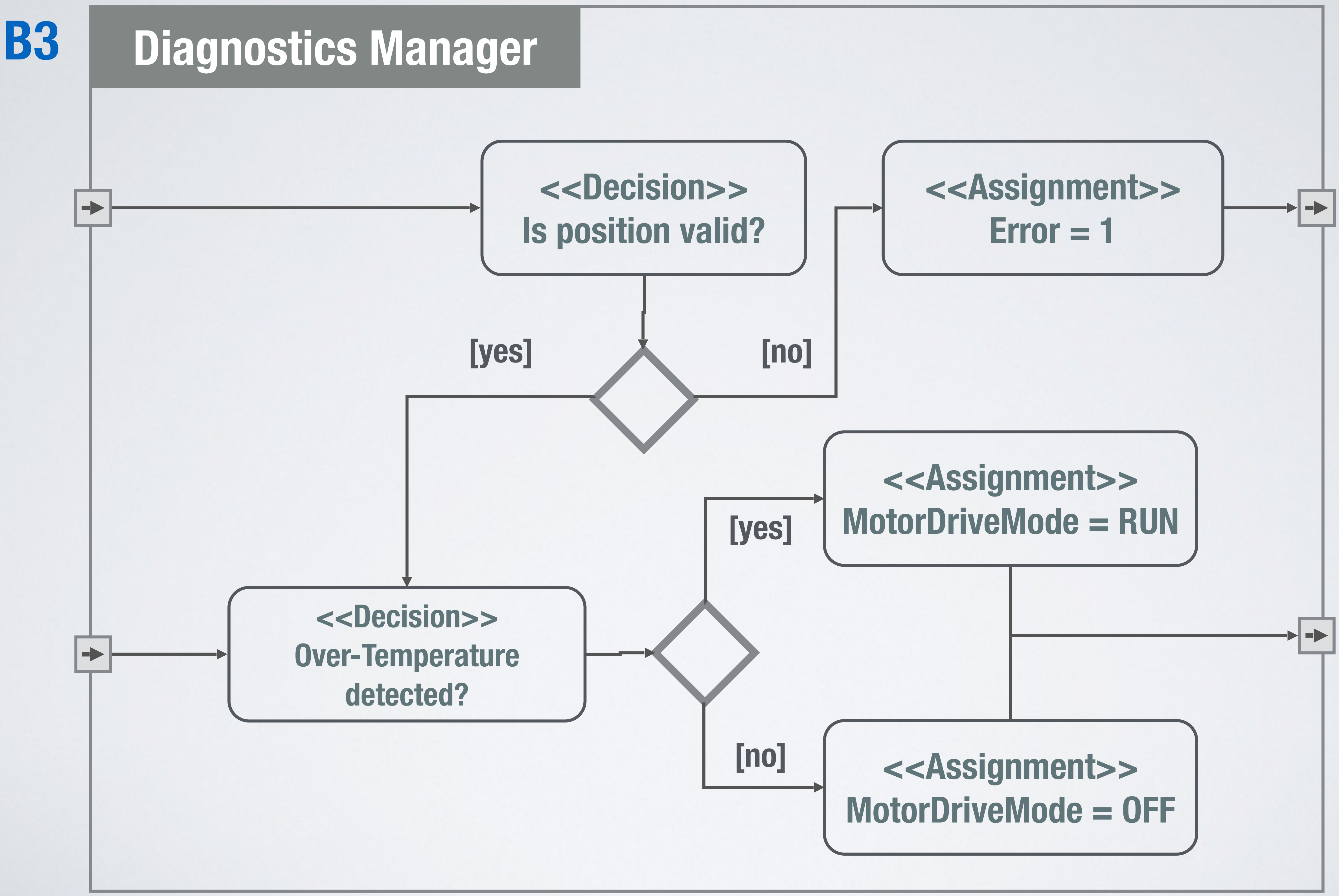
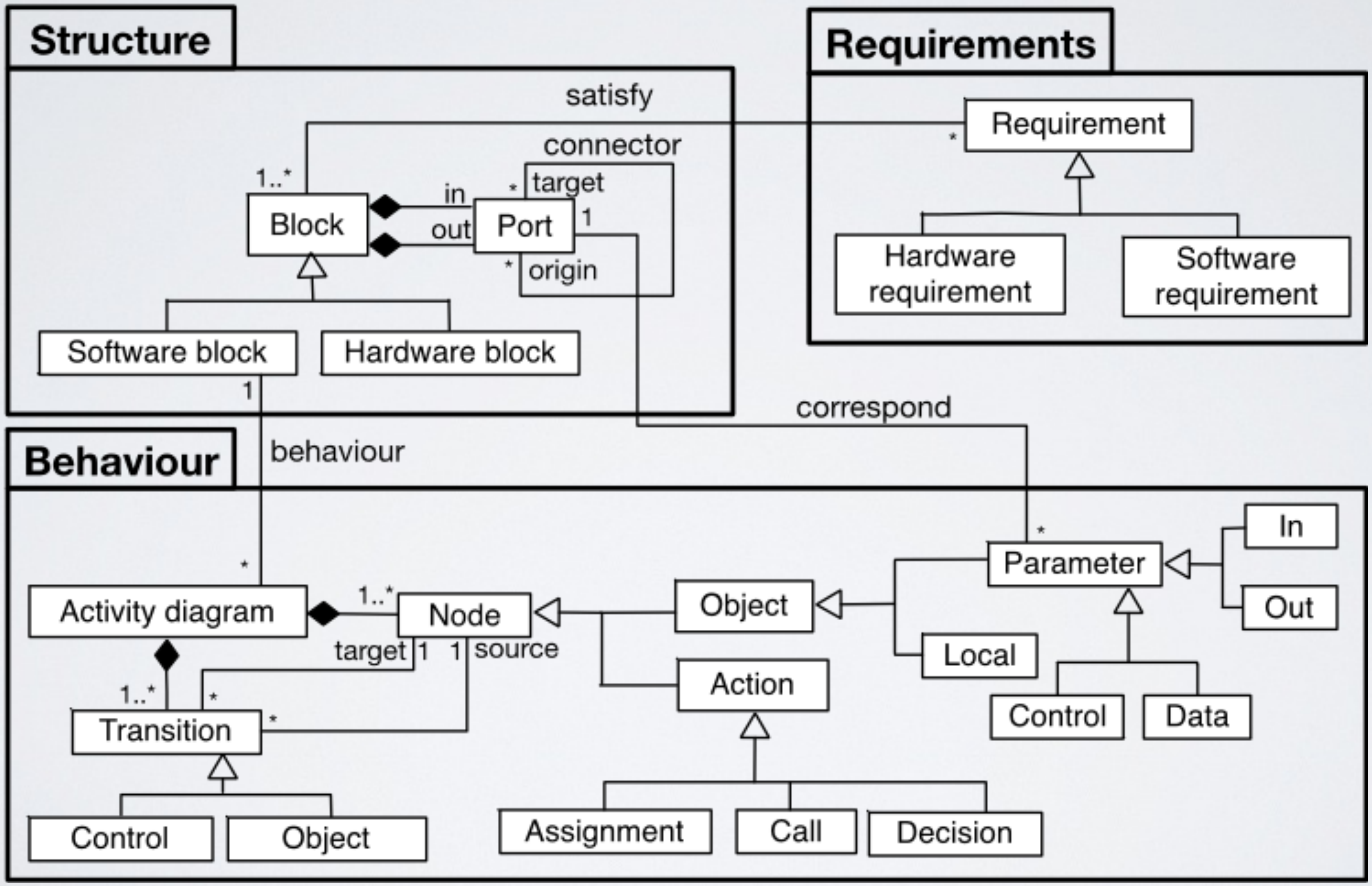


- **IBDs contain SW and HW blocks, ports, connector relations between ports, plus Satisfy traceability links between requirements and blocks.**
- **A satisfy link between a block and a requirement indicates that the function implemented by the block contributes to the satisfaction of the requirement.**

Activity Diagrams (AD)



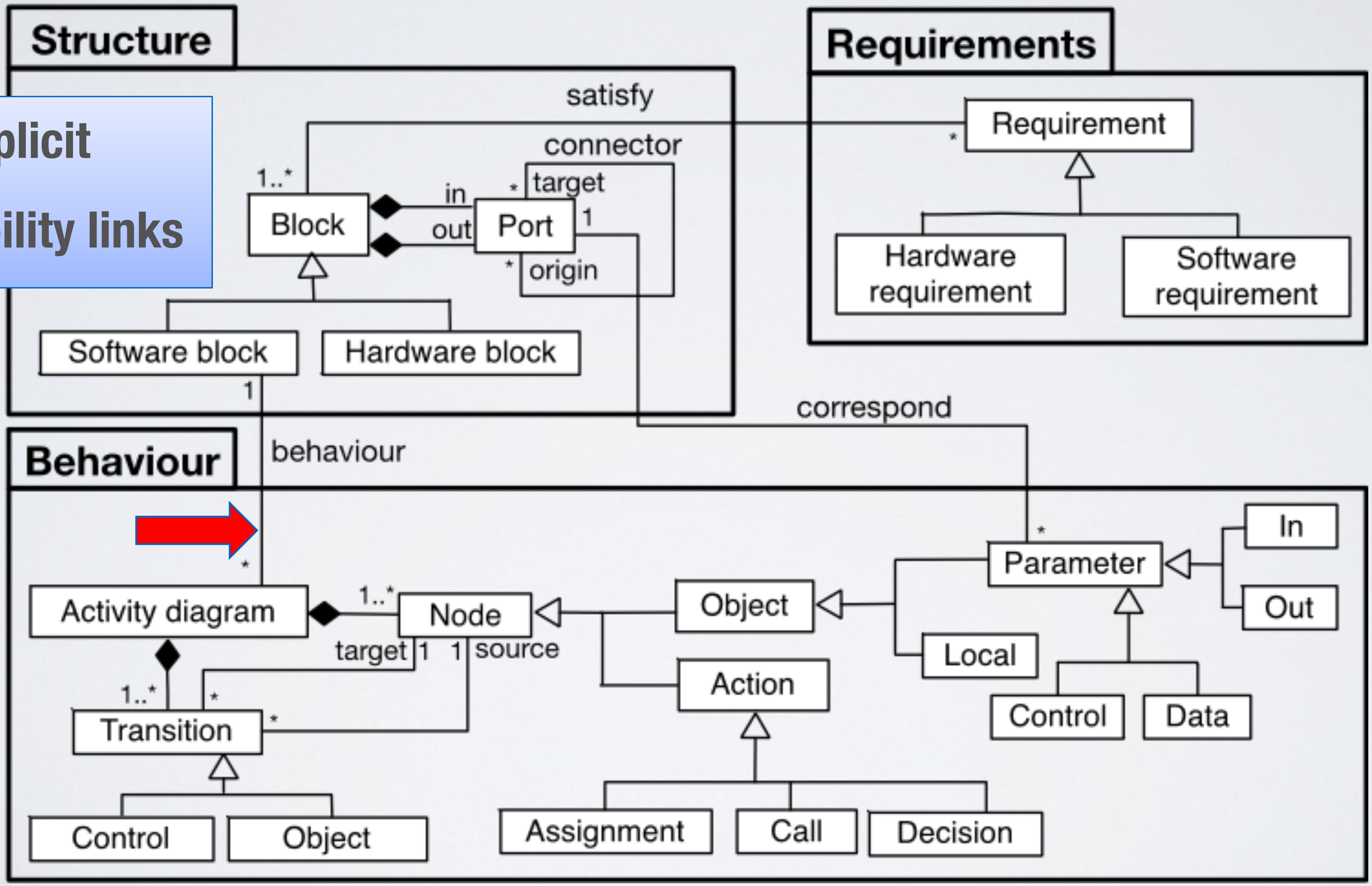
Traceability Information Model



Traceability Information Model

Explicit

traceability links



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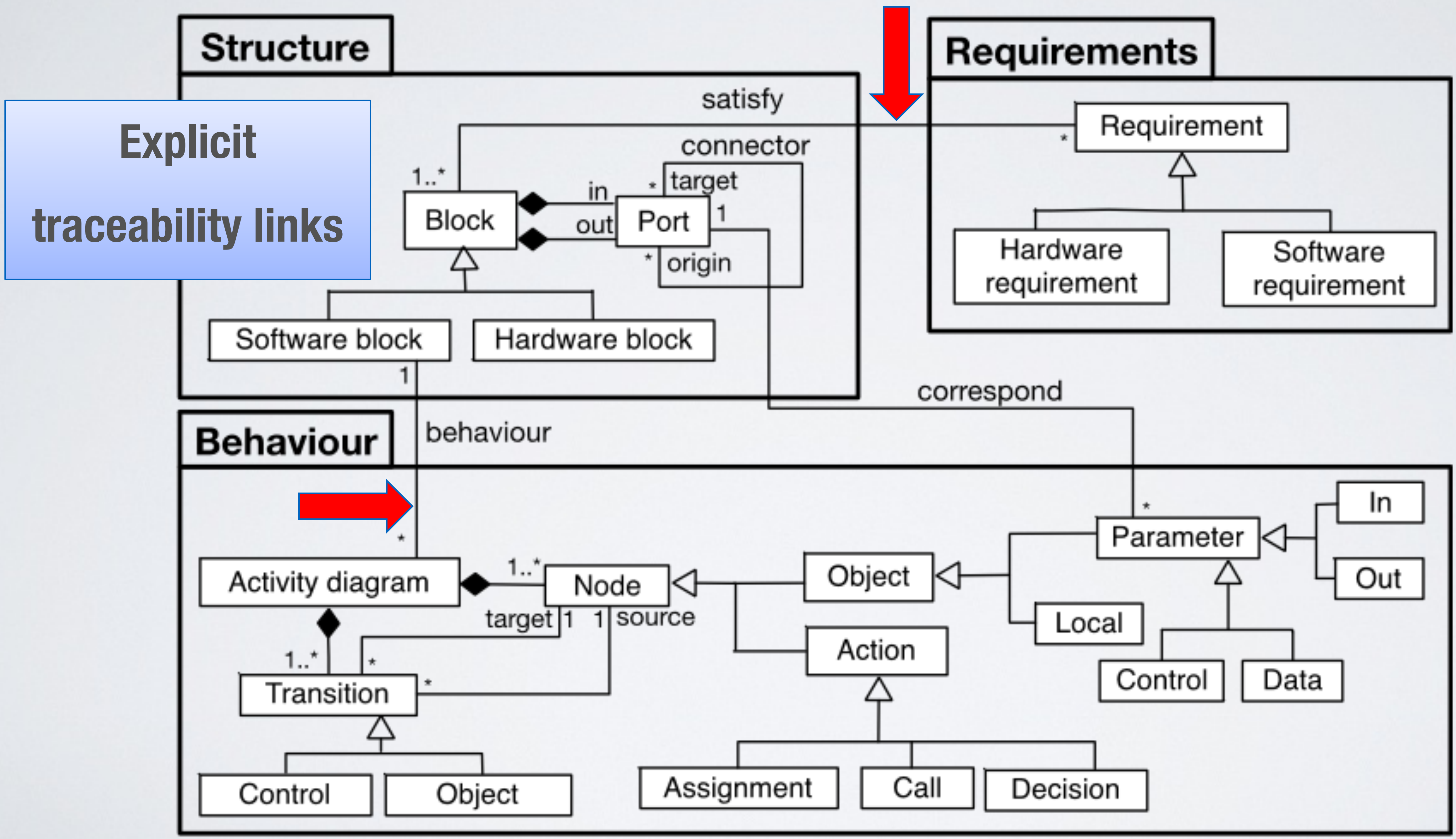


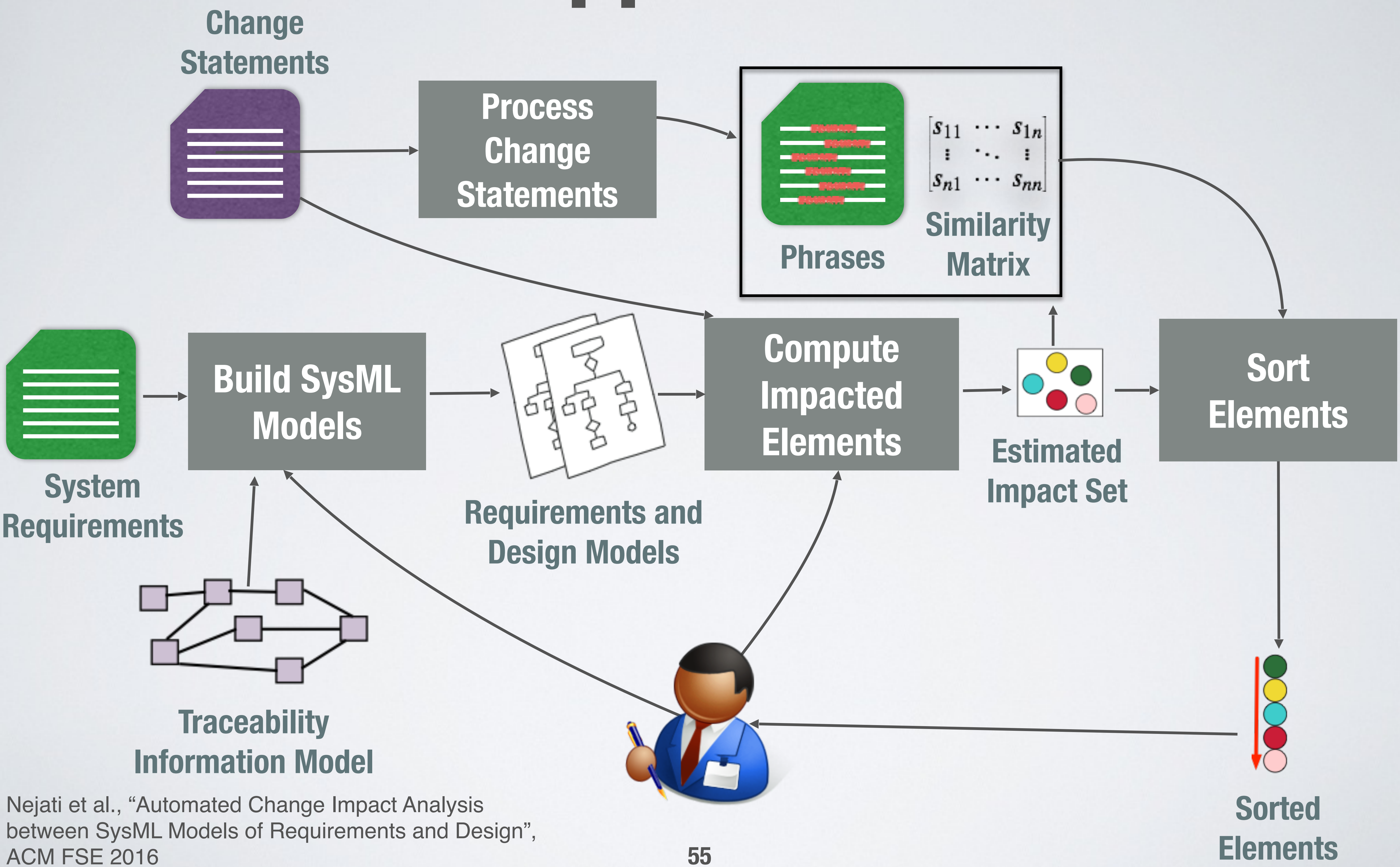
Our CIA Approach

Structural Analysis

Behavioral Analysis

Natural Language Processing Analysis

Approach



Nejati et al., “Automated Change Impact Analysis between SysML Models of Requirements and Design”, ACM FSE 2016

Case Study

DELPHI
Innovation for the Real World

Electronic Variable Cam Phaser (CP)

- Includes mechanical, electronic and software components
- Adjusts the timing of cam lobes with respect to that of the crank shaft in an engine, while the engine is running.
- CP is safety-critical and subject to the ISO 26262 standard.

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  - An algorithm for impact computation that combines models' structure, behavior and textual information
- Industrial case study: Our hybrid approach reduces the number of elements inspected from 370 to 18
- Scalable approach: A few seconds to compute and rank estimated impacted elements

Conclusions

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- **We need to develop practical technologies that increase RoI**

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- With a **high degree of robustness** to unrestricted, flawed NL requirements

- Keeping in mind **scalability**

Requirements for AI Systems

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- Safety, robustness, and security requirements are critical though --- their specification will increasingly be required by regulations
- Operational Design domain must be specified (a form of requirement)
- There is an opportunity for impact here for the RE community!

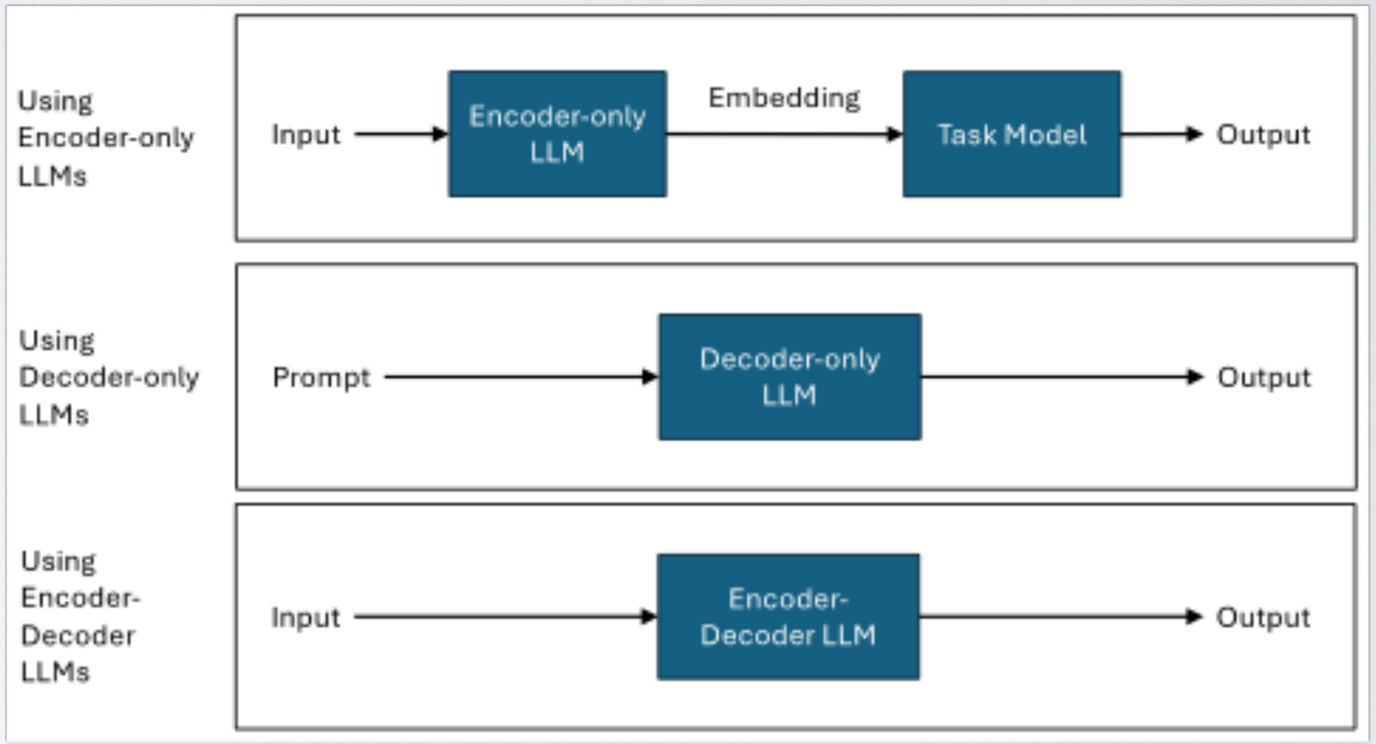
Operational Design Domain

- An operational Design Domain (ODD) refers to the specific conditions under which a system or technology, like an Autonomous Vehicle (AV), is designed to function safely and efficiently.

An ODD includes characteristics such as:

- **Geographic location:** roads, highways, or regions where the system is intended to operate.
- **Environmental conditions:** weather and light conditions such as daytime, nighttime, fog, rain, or snow.
- **Traffic conditions:** types of other road users (vehicles, pedestrians, cyclists), traffic density, and road infrastructure.
- **Operational constraints:** legal restrictions, speed limits, or other rules that the system must adhere to

LLMs in Requirements Engineering



Vogelsang and Fishbach, "Using Large Language Models for Natural Language Processing Tasks in Requirements Engineering: A Systematic Guideline", ArXiv, 2024

LLMs in Requirements Engineering

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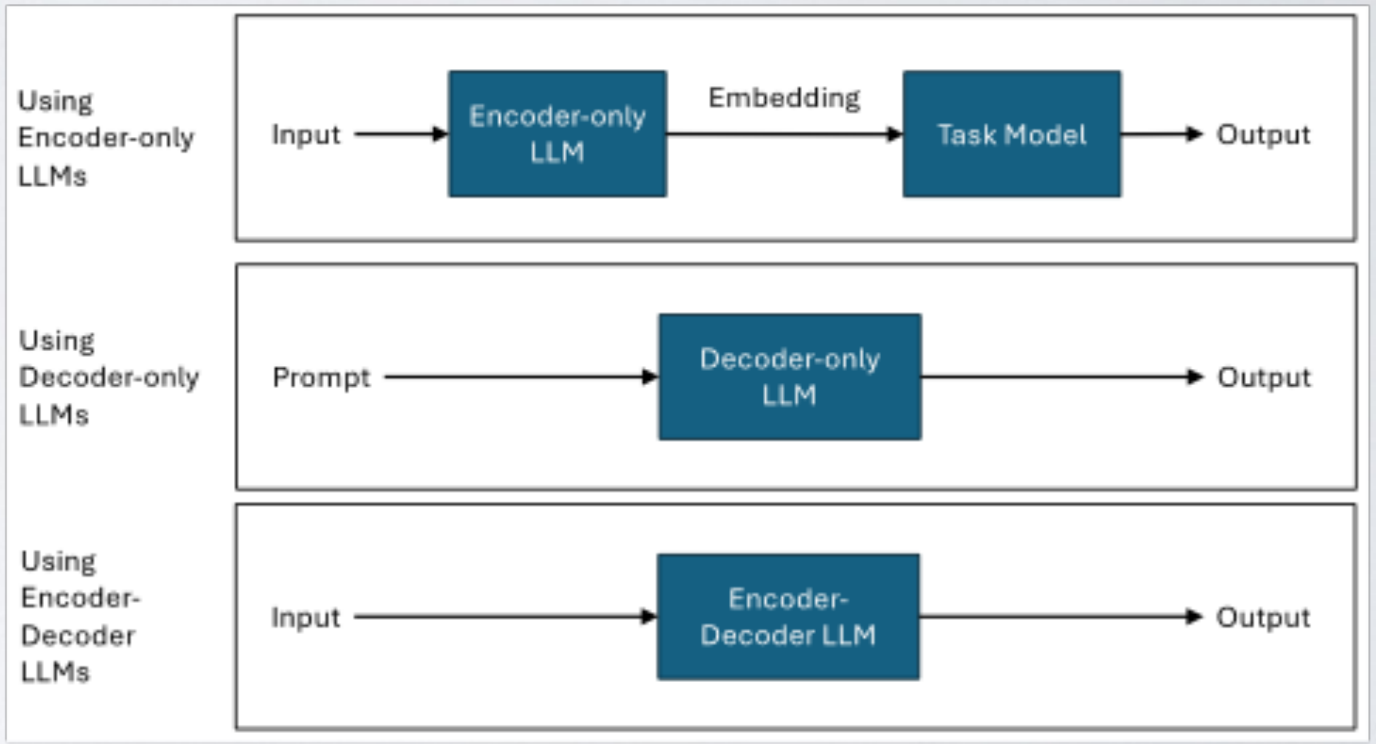

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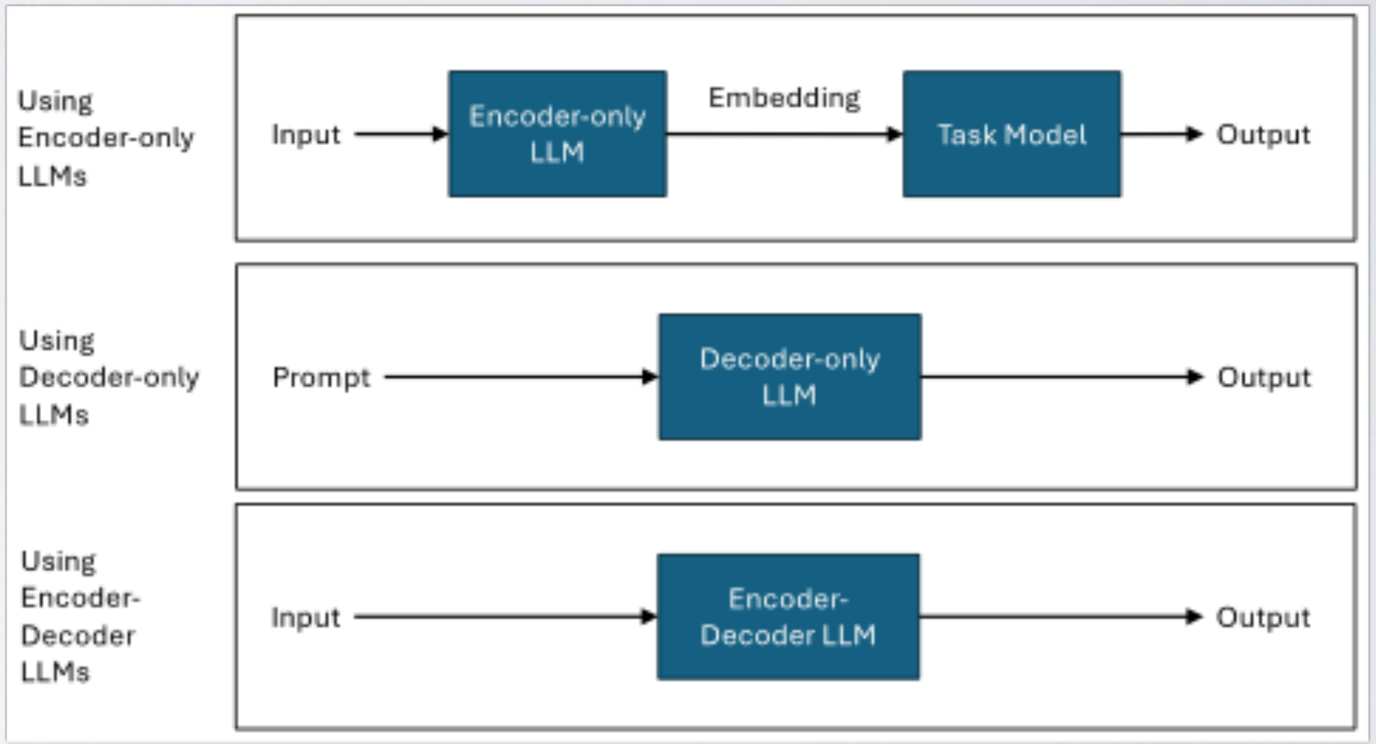

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LLMs in Requirements Engineering

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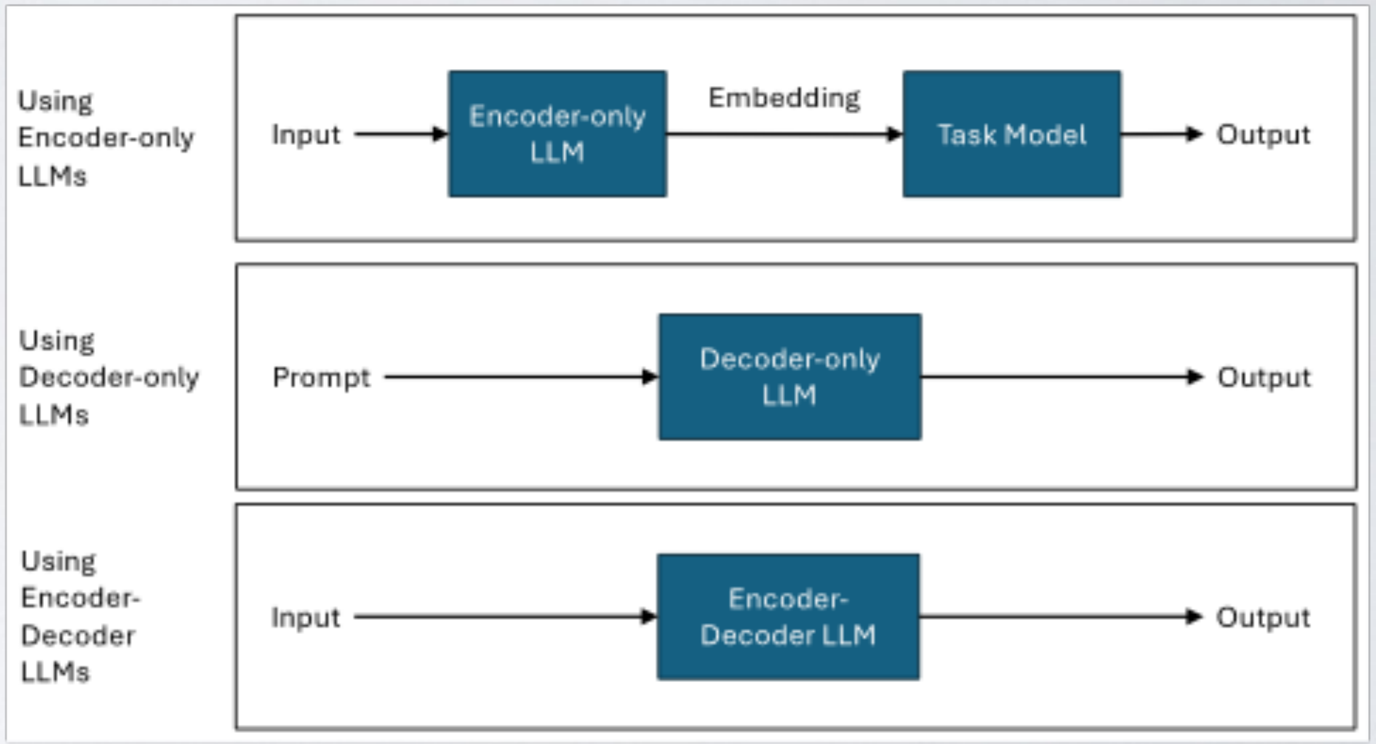

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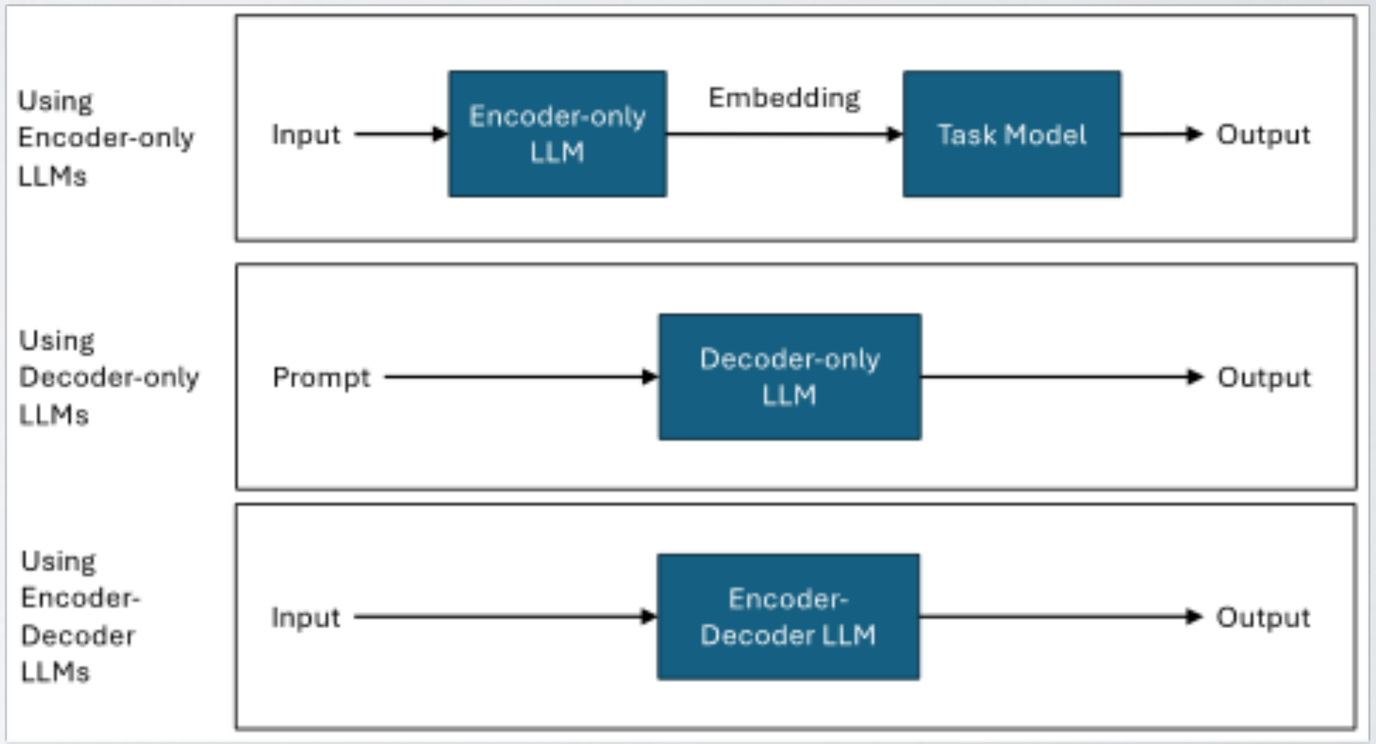
- Requirements classification



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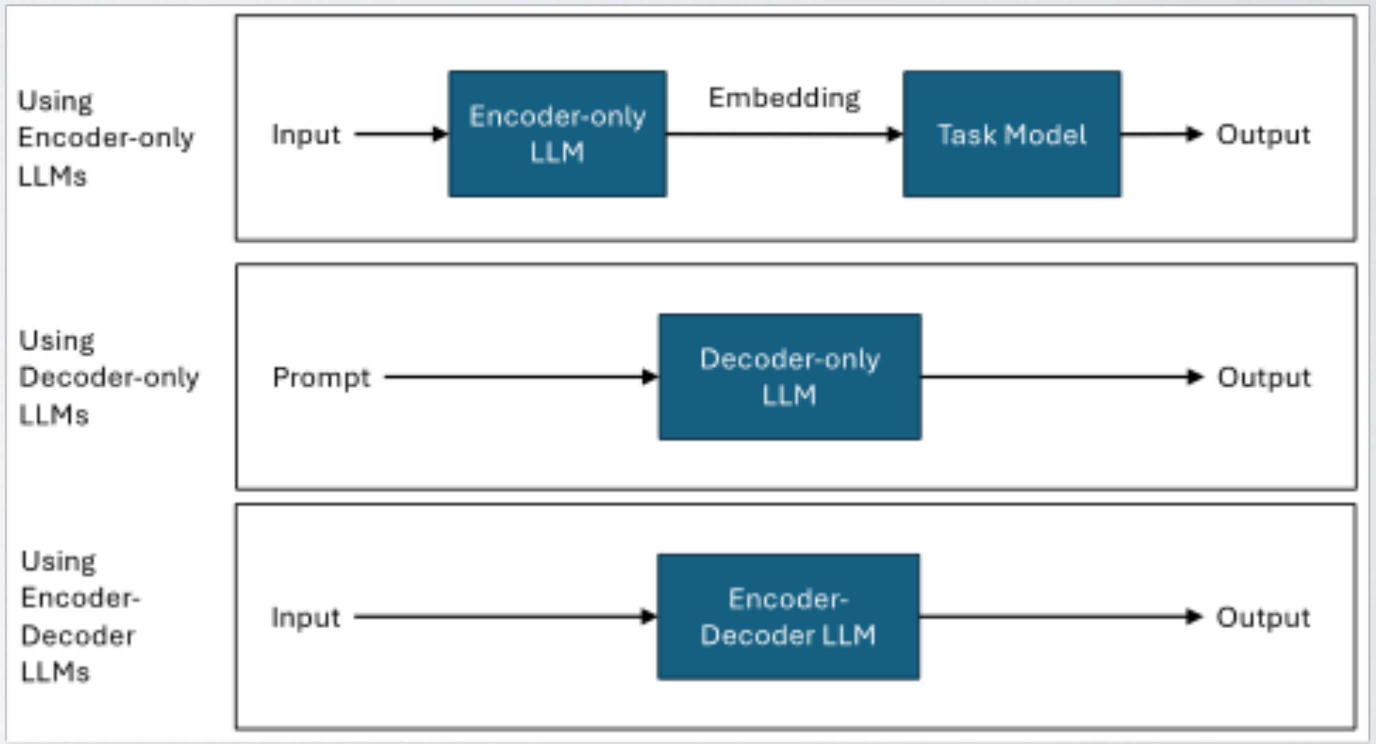

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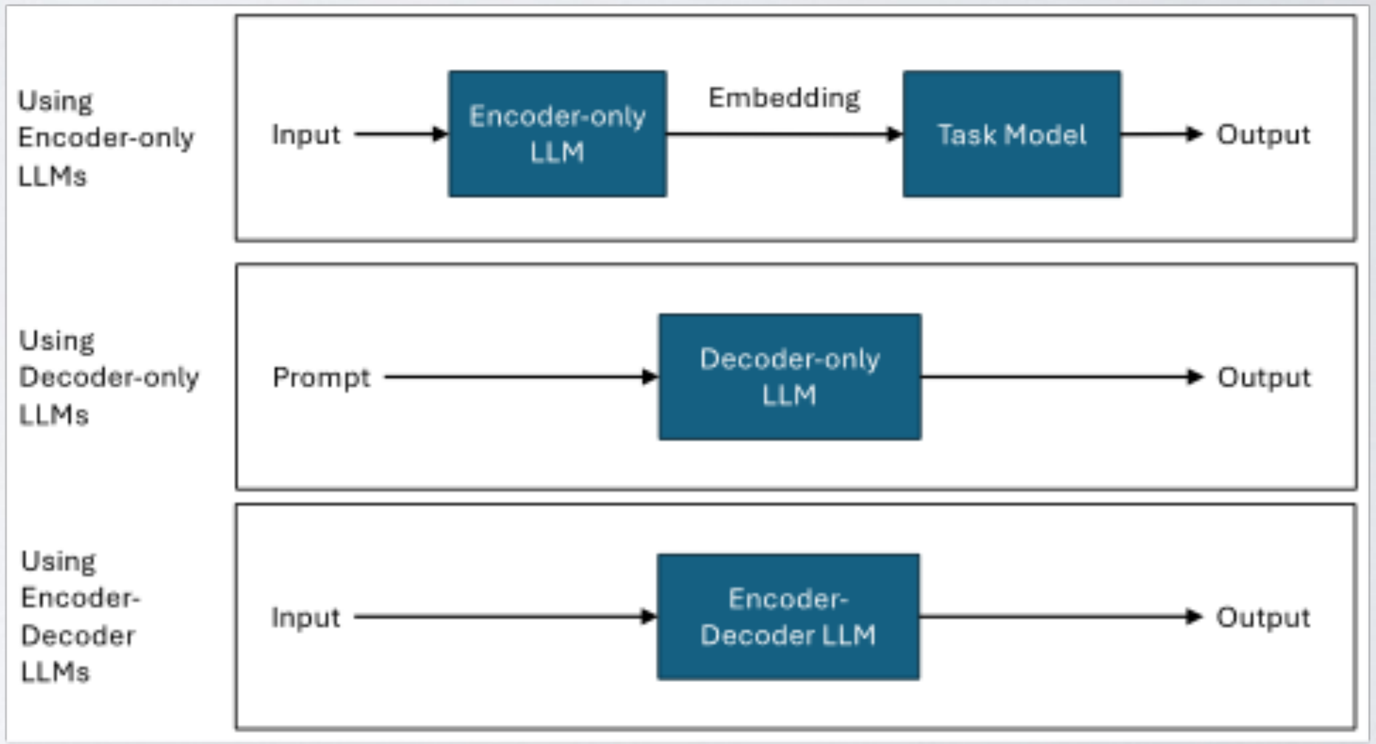
LLMs in Requirements Engineering

- Requirements generation
- Requirements completion
- Requirements to test cases
- Requirements classification
- …
- May render automation more affordable and practical



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Precise and Complete Requirements? An Elusive Goal

Lionel Briand

MO2RE 2024 Keynote

http://www.lbriand.info

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- SyMeCo is a Marie Skłodowska-Curie postdoctoral fellowship programme coordinated by Lero
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