Analyzing and Debugging Normative Requirements via Satisfiability Checking

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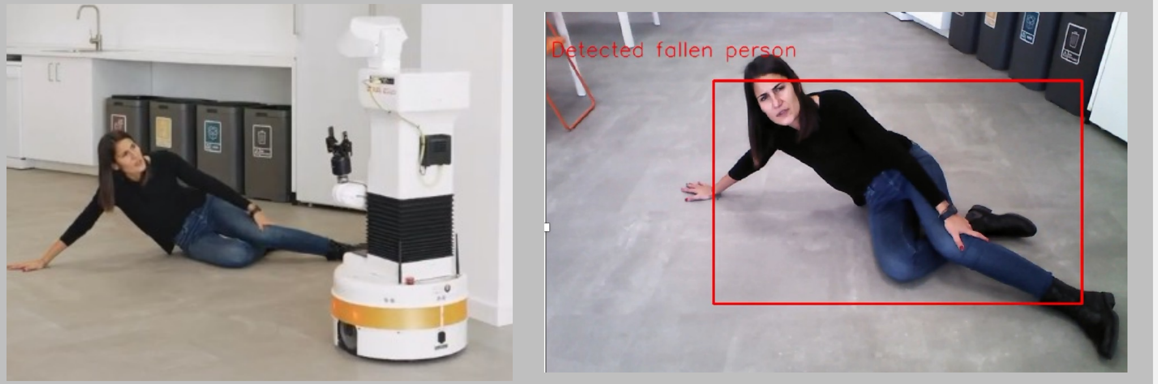
Context

Systems increasingly interacting with humans in various domains

(transport, environment, health and social care)

ALMI: Assistive-care robotics

Helps with food preparation, dressing, fallen-user alert, etc.



Detect the user has fallen

Alert that the user has fallen

ALMI robot from RoboStar (University of York, UK)

Normative Requirements

- Capture **s**ocial, **l**egal, **e**thical, **e**mpathetic, **c**ultural (**SLEEC**) aspects of systems

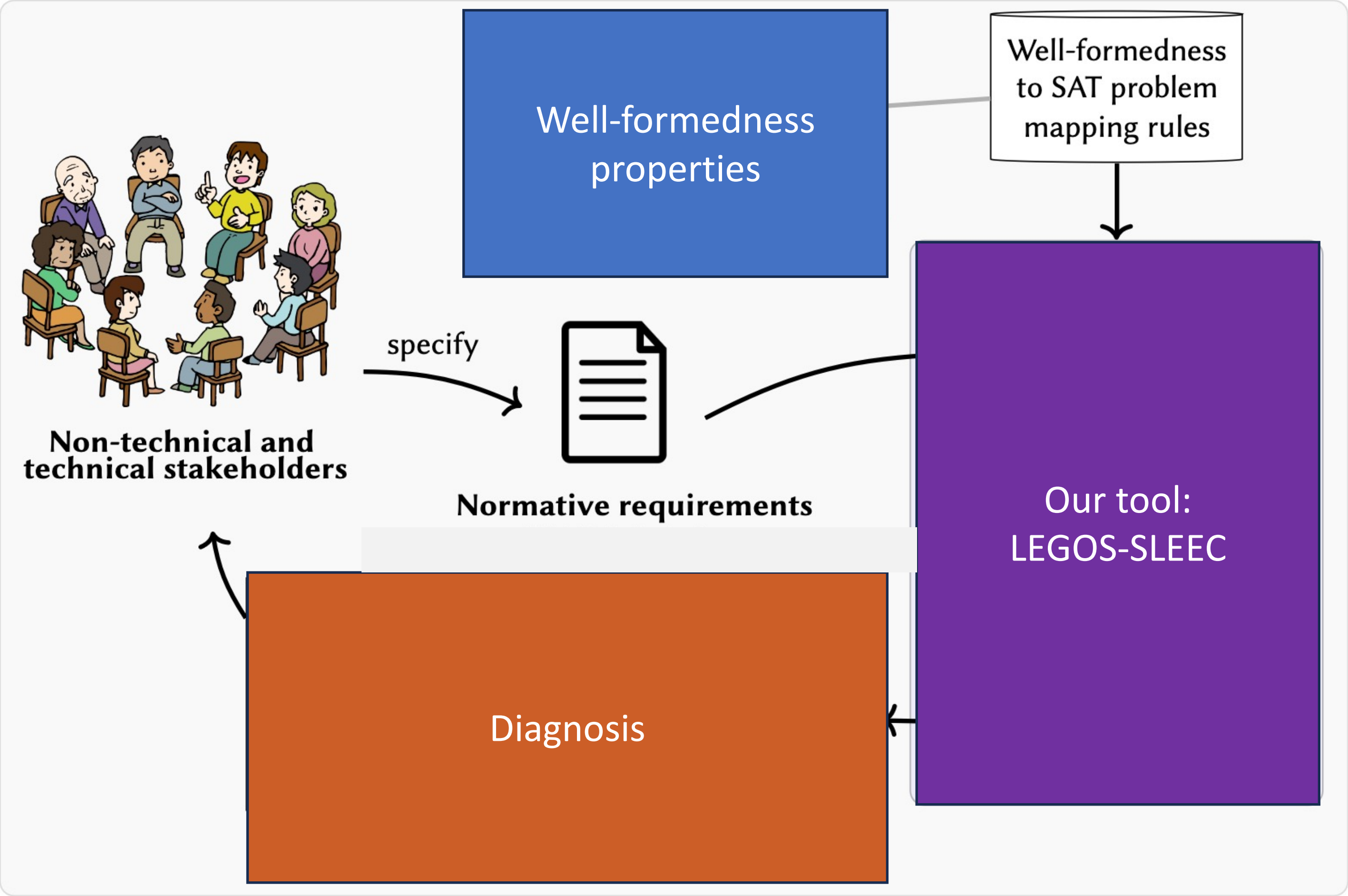
- Specified by stakeholders with non-technical expertise
  - Lawyer, regulators, ethicists, etc.

- Hard to get right
  - Stakeholders from different fields, different vocabularies
  - Their views are often conflicting or redundant
  - Stakeholders might not have sufficient technical background to reason about requirements
  - Requirements are complex: Allow constraints over data and time

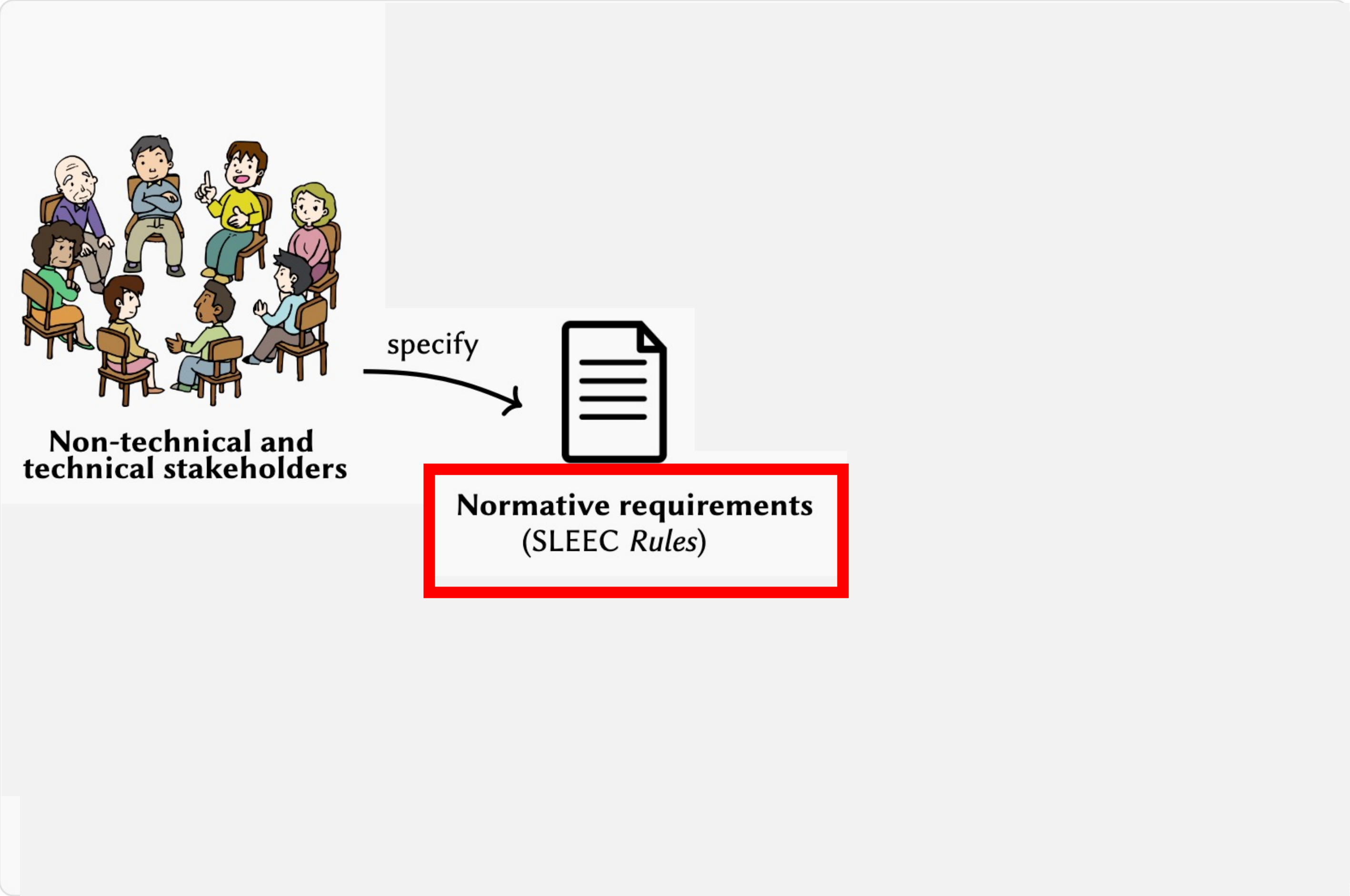
Our goal

Helping non-technical stakeholders elicit a coherent and well-formed set of normative requirements

Overview of the proposed approach



Outline



I. Background: SLEEC DSL

Background: SLEEC DSL [GYBJCC23]

Definitions

definition block

event DressingStarted
event CurtainOpenRqst
event CurtainsOpened

measure userUnderdressed: **Bool**
measure roomTemperature: **numeric**

Events: atomic, instantaneous actions

Measures: readable properties, types: *Boolean, numeric*

Rules

rule block

Rule1 **when** CurtainOpenRequest **then** CurtainsOpened **within** 30 **seconds**

unless userUnderDressed **then** RefuseRequest **within** 30 **seconds**

[GYBJCC23] S. Getir-Yaman, C. Burholt, M. Jones, R. Calinescu, and A. Cavalcanti. "Specification and Validation of Normative Rules for Autonomous Agents", FASE 2023.

Background: SLEEC DSL [GYBJCC23]

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rule block

Rules

Base rule

Rule1 **when** CurtainOpenRequest **then** CurtainsOpened **within** 30 **seconds**

unless userUnderDressed **then** RefuseRequest **within** 30 **seconds**

Defeater

[GYBJCC23] S. Getir-Yaman, C. Burholt, M. Jones, R. Calinescu, and A. Cavalcanti. "Specification and Validation of Normative Rules for Autonomous Agents", FASE 2023.

Background: SLEEC DSL [GYBJCC23]

Definitions

definition block

event DressingStarted
event CurtainOpenRqst
event CurtainsOpened
event CallSuport
measure userUnderdressed: **Bool**
measure roomTemperature: **numeric**

Events: atomic, instantaneous actions

Measures: readable properties, types: *Boolean, numeric*

Rules

rule block

TRIGGER: logical expression combining event & measures

Response

Deadline

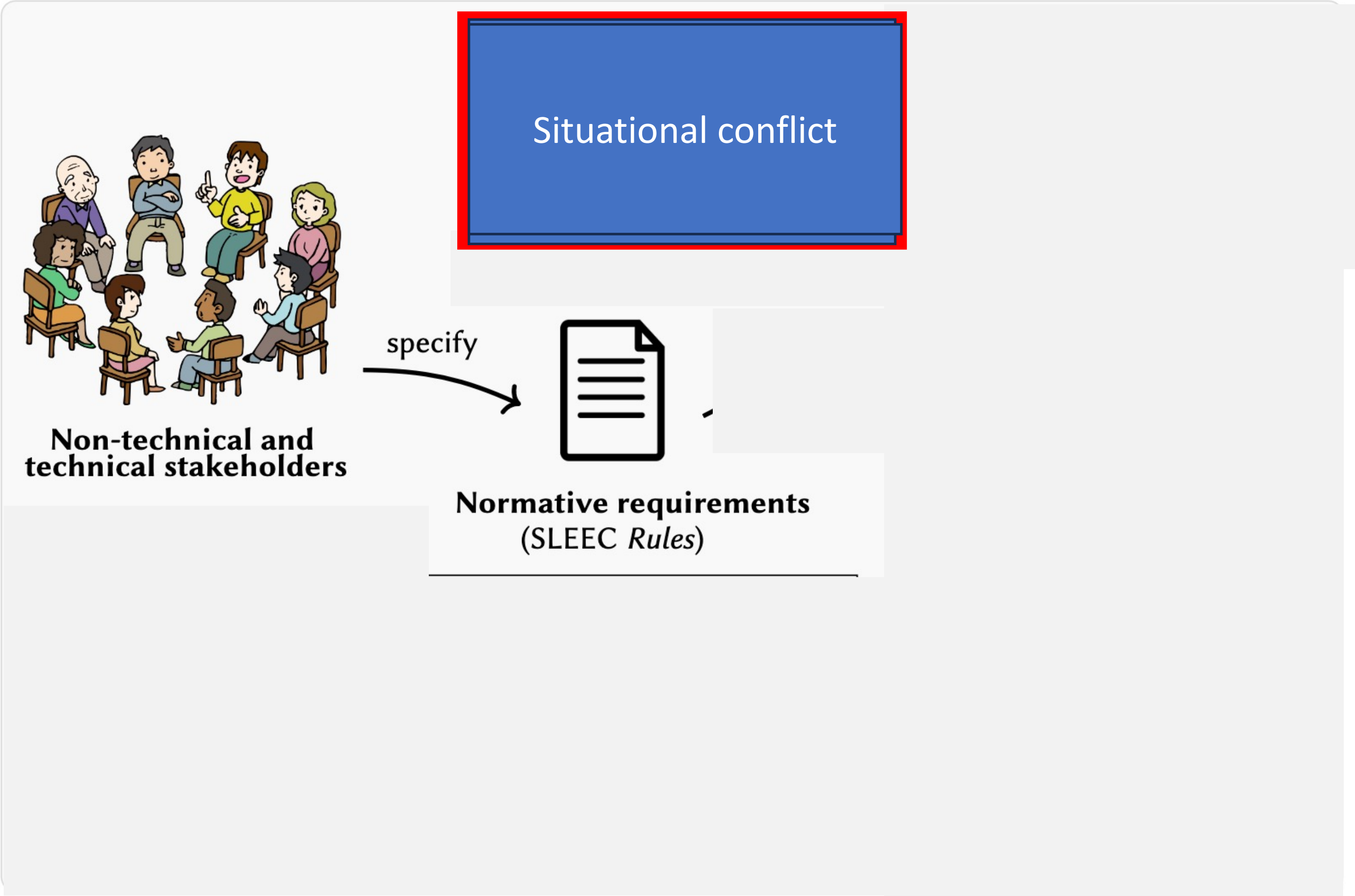
Rule1 **when** CurtainOpenRequest **then** CurtainsOpened **within** 30 **seconds**

otherwise CallSuport

Fallback

[GYBJCC23] S. Getir-Yaman, C. Burholt, M. Jones, R. Calinescu, and A. Cavalcanti. "Specification and Validation of Normative Rules for Autonomous Agents", FASE 2023.

Outline



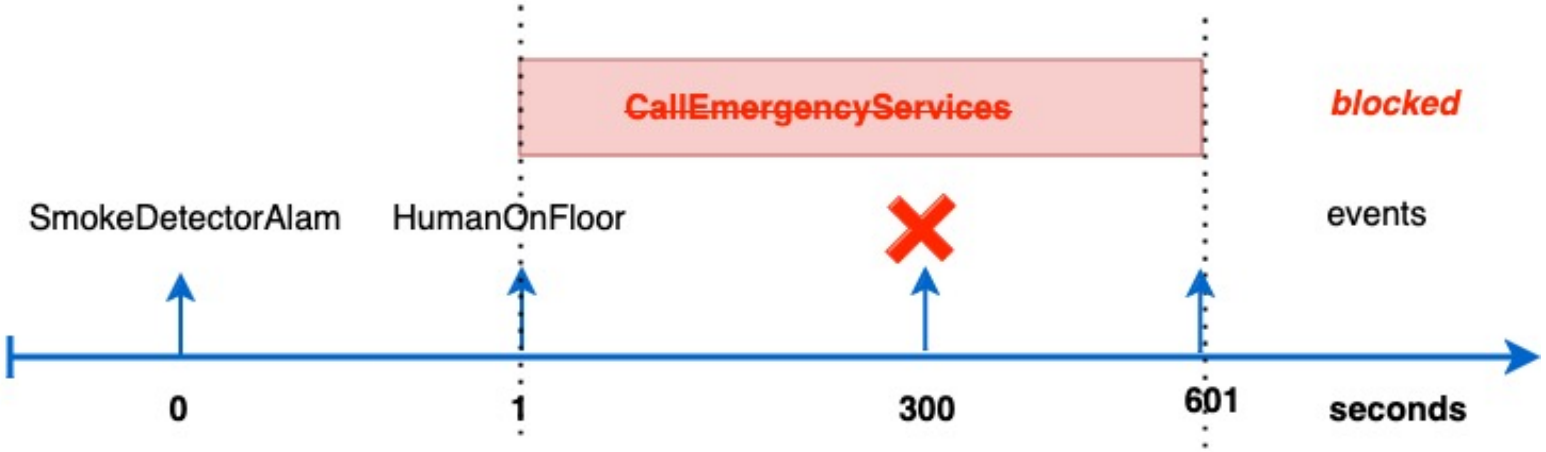
II. Well-formedness properties

Situational conflicts

A given requirement is situationally conflicting if there exists a feasible situation that eventually causes a conflict.

Example:

Situational conflict under situation:



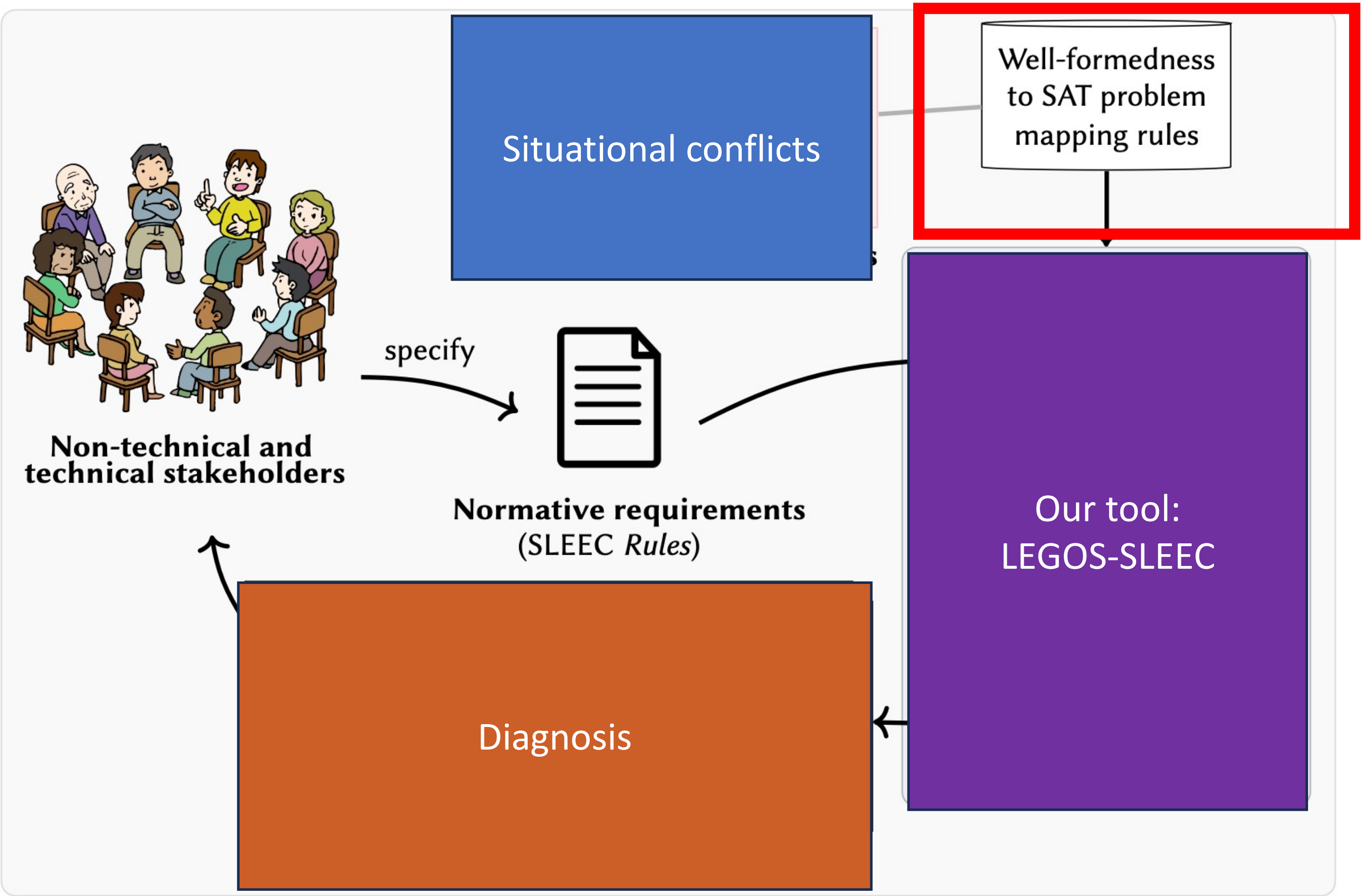
For rule:

R3 **when** HumanOnFloor **and (not** humanAssents) **then not** CallEmergencyServices **within** 600 **seconds**

Because of the following rule:

R21 **when** SmokeDetectorAlarm **then** CallEmergencyServices **within** 300 **seconds**

Outline



III. Well-formedness and satisfiability

Situational conflict verification via satisfiability

1. To find a situation, use backward reasoning symbolically : does there exists a sufficient condition, situation s, such that a rule *ri* is triggered but with the **responses blocked**

Rule1 **when** A **then** B **within** 30 **seconds otherwise** C **within** 5 **seconds**

Situational conflict verification via satisfiability

1. To find a situation, use backward reasoning symbolically : does there exists a sufficient condition, situation s, such that a rule *ri* is triggered but with the **responses blocked**

Rule1 **when** A **then** B **within** 30 **seconds** **otherwise** C **within** 5 **seconds**

We want to block the two responses

Situational conflict verification via satisfiability

1. To find a situation, use backward reasoning symbolically : does there exists a sufficient condition, situation s, such that a rule *ri* is triggered but with the **responses blocked**

Rule1 **when** A **then** B **within** 30 **seconds** **otherwise** C **within** 5 **seconds**

Looking for some rules with a response not B ← Block B within 30 seconds

We want to find some rules that block the response

Situational conflict verification via satisfiability

1. To find a situation, use backward reasoning symbolically : does there exists a sufficient condition, situation s, such that a rule *ri* is triggered but with the **responses blocked**

Rule1 **when** A **then** B **within** 30 **seconds** **otherwise** C **within** 5 **seconds**

Looking for some rules with a response not B ← Block B within 30 seconds

Rule2 **when** D **then** C **within** 30 **seconds** **otherwise not B within** 40 **seconds**

We want to force the necessary condition to block the response

Situational conflict verification via satisfiability

1. To find a situation, use backward reasoning symbolically : does there exists a sufficient condition, situation s, such that a rule *ri* is triggered but with the **responses blocked**

Rule1 **when** A **then** B **within** 30 **seconds** **otherwise** C **within** 5 **seconds**

Looking for some rules with a response not B ← Block B within 30 seconds

Rule2 **when** D **then** C **within** 30 **seconds** **otherwise not B within** 40 **seconds**

C **within** 30 **seconds** → Block C within 30 seconds

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Situational conflict verification via satisfiability

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Rule2 **when** D **then** C **within** 30 **seconds** **otherwise not B within** 40 **seconds**

C **within** 30 **seconds** → Block C within 30 seconds

Looking for some rules with a response not C ← Block C within 30 seconds

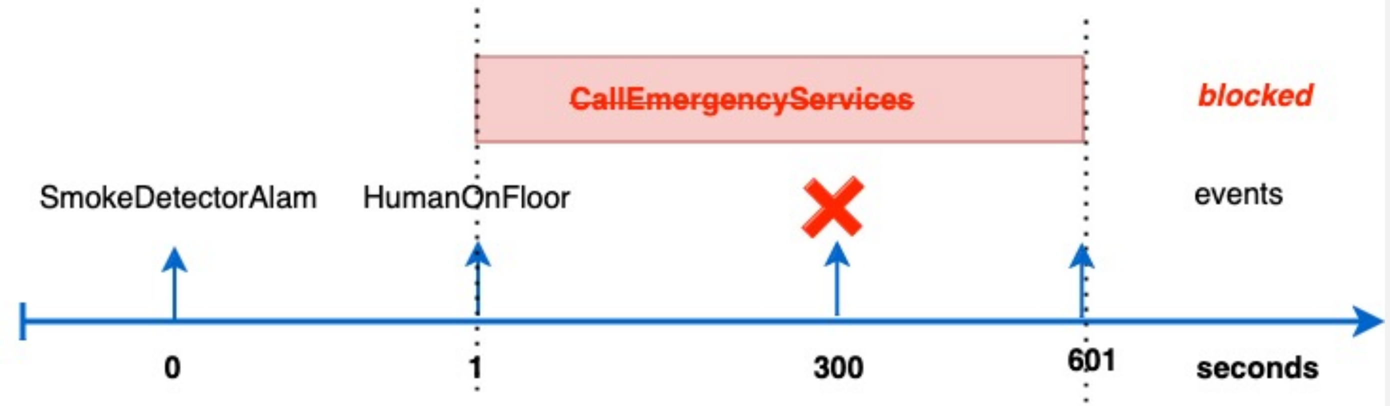
….. (and other constraints)

Backward analysis guarantee to terminate

Situational conflict verification via satisfiability

1. To find a situation, use backward reasoning symbolically: does there exists a sufficient condition, situation s, such that a rule *ri* is triggered but with the response blocked

situation s:



2. To obtain the diagnosis: When such situation exist, we encode s symbolically, and then check whether the entire rule set R and s is UNSAT, we use the UNSAT proof to build a diagnosis

situation s +

For rule:
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then not CallEmergencyServices **within** 600 **seconds**

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Well-formedness issues (WFI)s

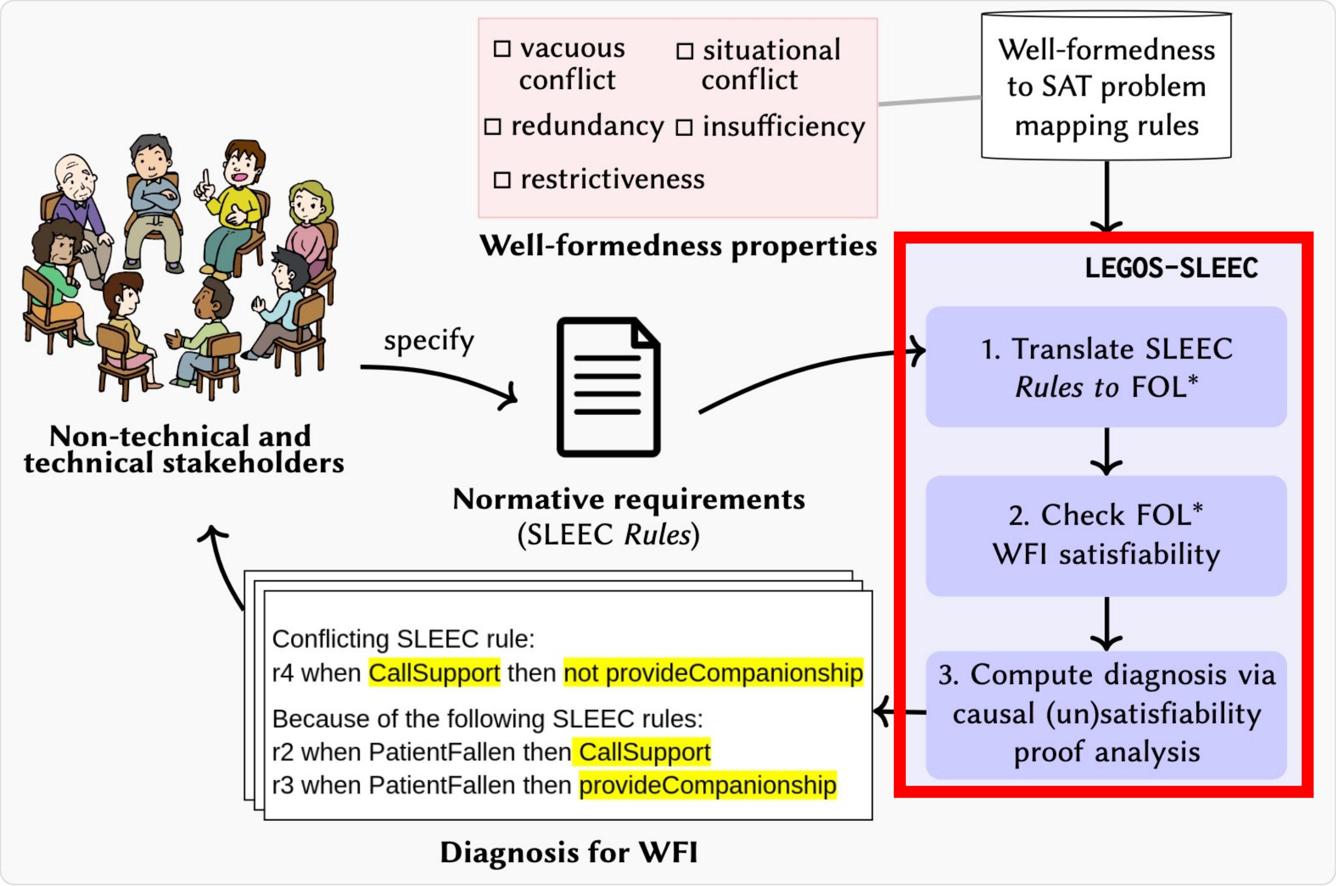
1. Situational conflict and vacuous conflict
2. Restrictive or Insufficient requirements
3. Unecessary redundant requirements

Please find more details in the paper

WFI automatic validation

LEGOS-SLEEC:

- Checks requirements WFIs via FOL* satisfiability checking [CAV23]
- Produces a diagnosis in SLEEC DSL



LEGOS-SLEEC tool: https://github.com/NickF0211/LEGOS-SLEEC

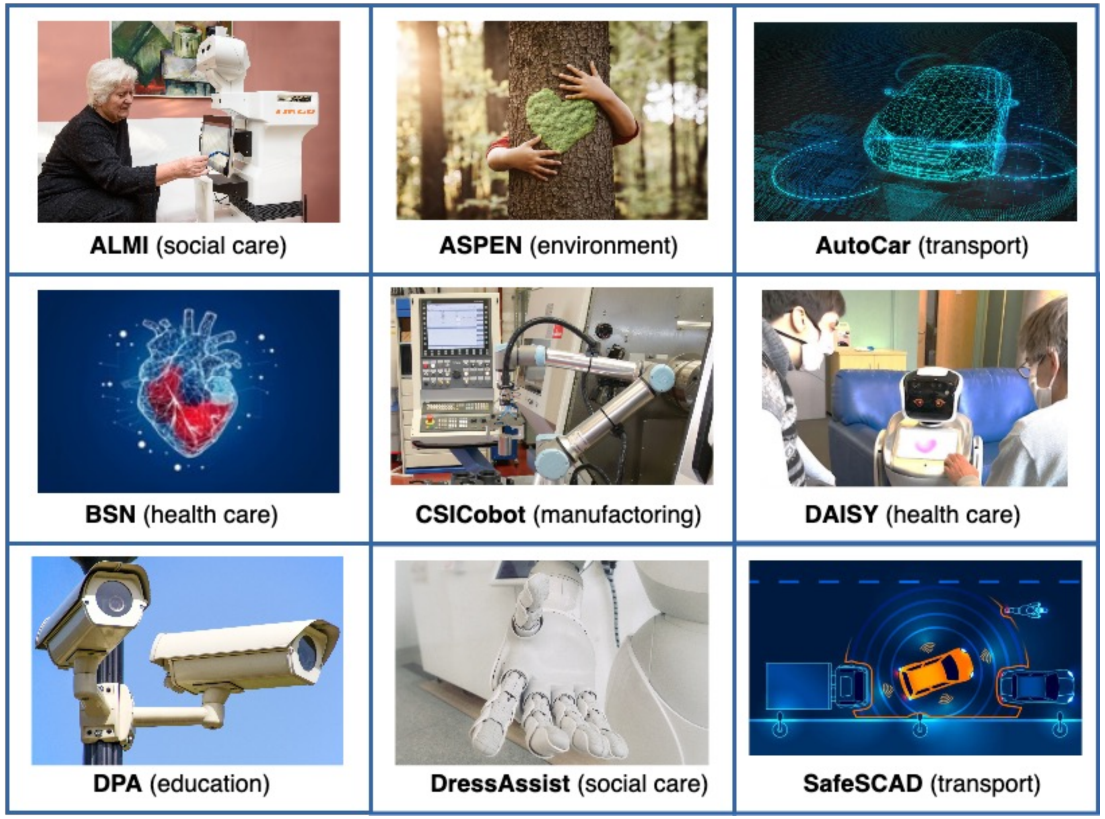
[CAV23] N. Feng, L. Marsso, M. Sabetzadeh, and M. Chechik. "Early verification of legal compliance via bounded satisfiability checking", CAV 2023.

Outline

IV. Evaluation

RESERVE: repository of 9 real-world case studies

- **Domains:** transport, environment, manufacturing health and social care.
- **Different stages:** ranging from the design phase to deployed systems
- **Non-technical stakeholders:** an ethicist, a lawyer, a philosopher, and a psychologist
- **Technical stakeholders:** a safety analyst, and 3 engineers
- **Normative requirements**: 233 N-NFRs in total



RESERVE: http://www.cs.toronto.edu/~sleec/

How effective is LEGOS-SLEEC in detecting WFIs?

For each case study, 1-2 TSs were paired with 1-4 N-TSs:

- Built a set of normative requirements
- Met to manually review, discuss, and agree on these requirements

For each WFI identified by LEGOS-SLEEC, we recorded:

N-TS ability to understand the feedback given by LEGOS-SLEEC
and split the identified WFIs into relevant/spurious

How effective is LEGOS-SLEEC in detecting WFIs?

case studies	v-conf. (TP - FP)	s-conf. (TP - FP)	redund. (TP - FP)	restrict. (TP - FP)	insuffi. (TP - FP)	time (sec.)
ALMI	0 - 0	3 - 0	0 - 0	0 - 0	1 - **1**	30
ASPEN	0 - 0	3 - 0	1 - 0	0 - 0	5 - 0	25.3
AutoCar	0 - 0	4 - 0	2 - 0	0 - 0	9 - 0	27.7
BSN	0 - 0	0 - 0	0 - 0	0 - 0	3 - 0	46
DressAssist	0 - 0	1 - 0	0 - 0	0 - 0	1 - **3**	20.3
CSI-Cobot	0 - 0	0 - 0	2 - 0	0 - 0	6 - **1**	25.3
DAISY	0 - 0	1 - 0	1 - 0	0 - 0	5 - 0	30.4
DPA	0 - 0	0- 0	0 - 0	0 - 0	4 - 0	21.4
SafeSCAD	0 - 0	8 - 0	2 - 0	**2** - 0	4 - **1**	42.4

We also study the resolution effort, please find the details in the paper

Conclusion

Goal: support non-technical stakeholders in eliciting well-formed normative requirements

Our contributions:

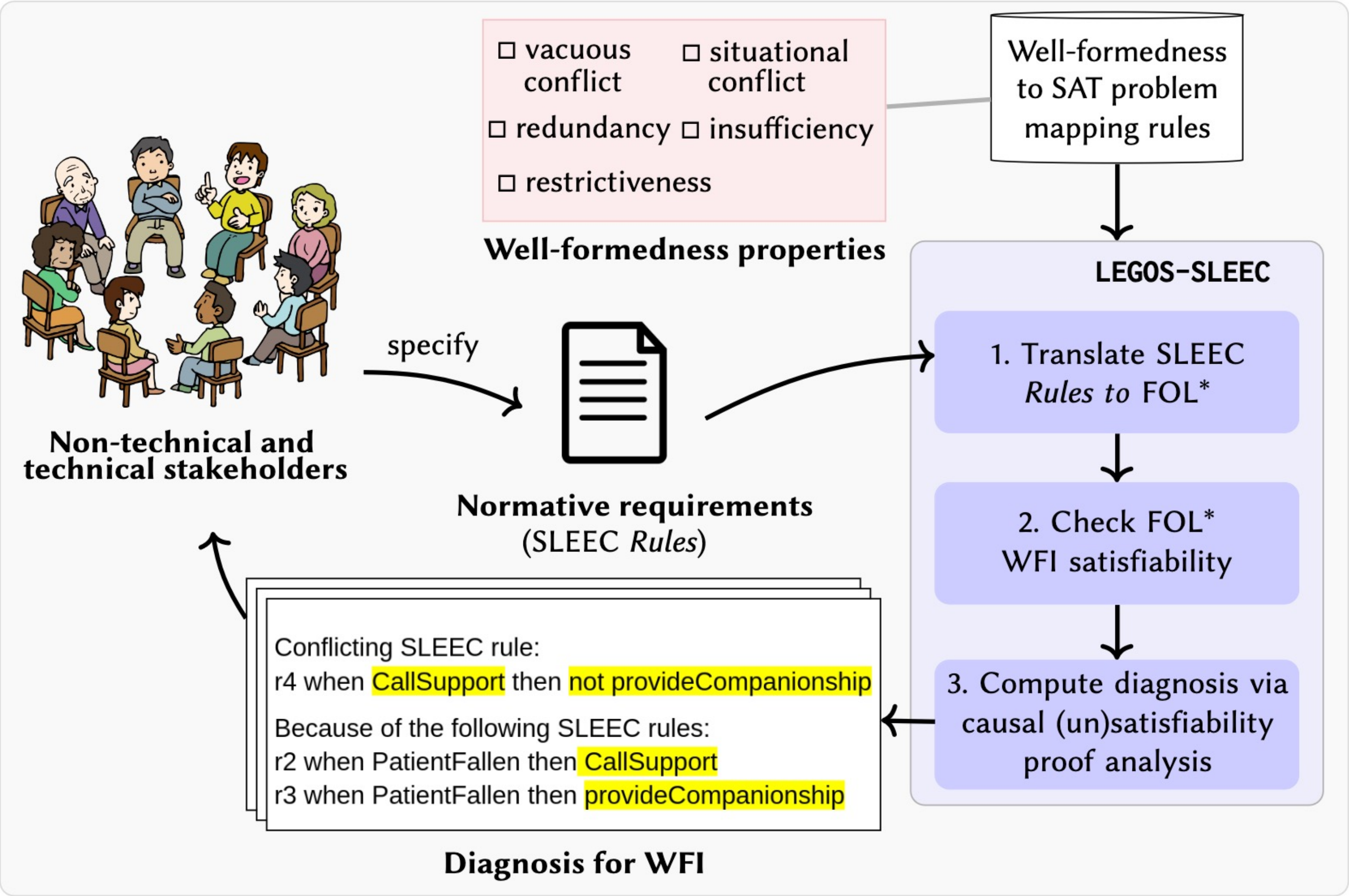
- Provided **automated verification** of five well-formdness properties
  1. situational conflict – 2. vacous conflict –
  3. insufficiency – 4. restrictiveness – 5. redundancy
- Developed **`readable' verification diagnosis**

Outcome: An effective engagement with a formal reasoning tool for non-technical stakeholders!

Future research directions

a) How to capture semantic relations between abstract representation of system capabilities with LLMs?
[Check out our upcoming RE 2024 paper]

b) How to assure that **systems** satisfy their SLEEC constraints:
- Via runtime monitoring
- Via formal verification
- Via synthesis of guardrails



An effective engagement with a formal reasoning tool for non-technical stakeholders!

Thank you!

Questions?

Tool:
LEGOS-SLEEC: https://github.com/NickF0211/LEGOS-SLEEC

Repository:

RESERVE: http://www.cs.toronto.edu/~sleec/