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APSEC 2021

Concepts and Models of Environment of Self-Adaptive Systems: A Systematic Literature Review

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   B. Three Challenges of environment modeling
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Concepts and Models of Environment of Self-Adaptive Systems: A Systematic Literature Review

Introduction

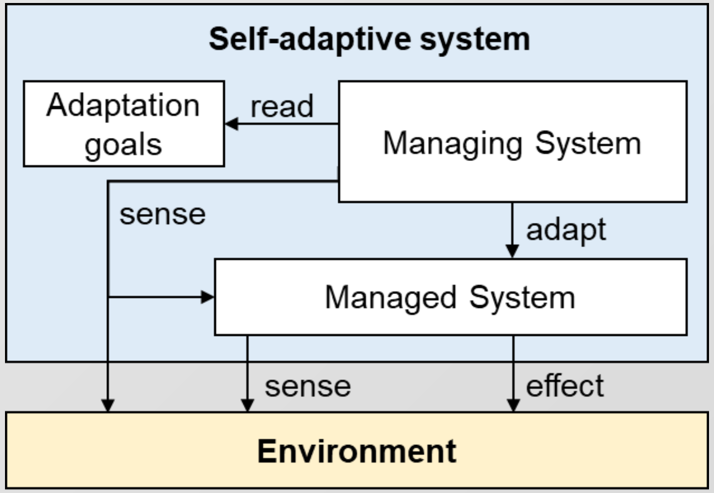
Ambiguous Concept of Environment of SAS

Self-Adaptive System (SAS)

- System that adjust its behavior in response to changes in the environment and the system itself[1]

Environment

- Anything observable by the software system[2]
- Physical world or computing elements that are not under control of the system[3]
- Circumstances that interact with or affect the system[4]



Conceptual model of an SAS

The concept of environment of SAS is implicitly agreed on by researchers, but not precisely analyzed yet.

[1] Weyns, Danny. *An Introduction to Self-adaptive Systems: A Contemporary Software Engineering Perspective.*, 2020.
[2] Monpratarnchai, Supasit, and Tamai Tetsuo. "Applying adaptive role-based model to self-adaptive system constructing problems: a case study.", 2011.
[3] Van Der Donckt, Jeroen, et al. "Effective decision making in self-adaptive systems using cost-benefit analysis at runtime and online learning of adaptation spaces.", 2018.
[4] Solano, Gabriela Félix, et al. "Taming uncertainty in the assurance process of self-adaptive systems: a goal-oriented approach.", 2019.

Motivation & Goal

Motivation

- The ambiguous concept of the SAS environment causes inconsistencies between the SAS studies and makes it difficult for new researchers to understand the concept.

Goal

- To provide an overall landscape of current knowledge of the environment in SAS engineering academia through a systematic literature review (SLR)
  - How various researchers commonly understand the concept of the environment of SAS
  - If there are cases in which their understanding of the environment is expressed as concrete models

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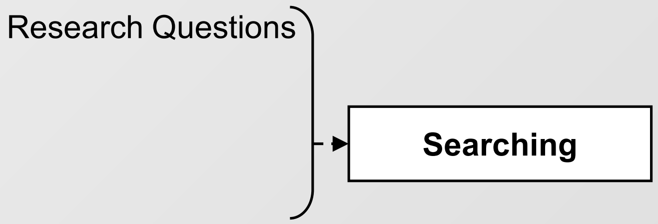
Review Protocol

Research Questions of This SLR*

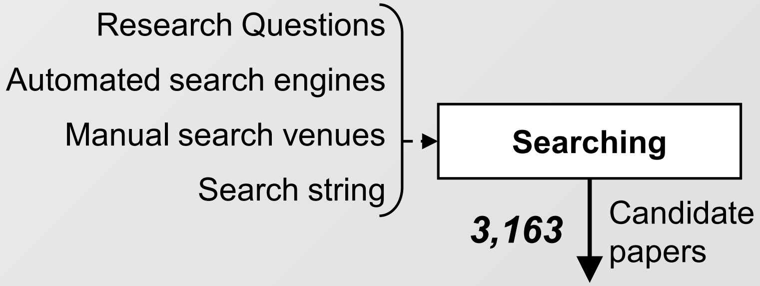
- **RQ1:** What characteristics of the environment of an SAS did primary studies mention in describing it?
- **RQ2:** What did primary studies consider to be the sources of environmental uncertainty?
- **RQ3:** How did primary studies express their understandings of the environment of SAS as explicit models?



* **In the original paper, there are six research questions, but they have been summarized into three questions for the presentation.**

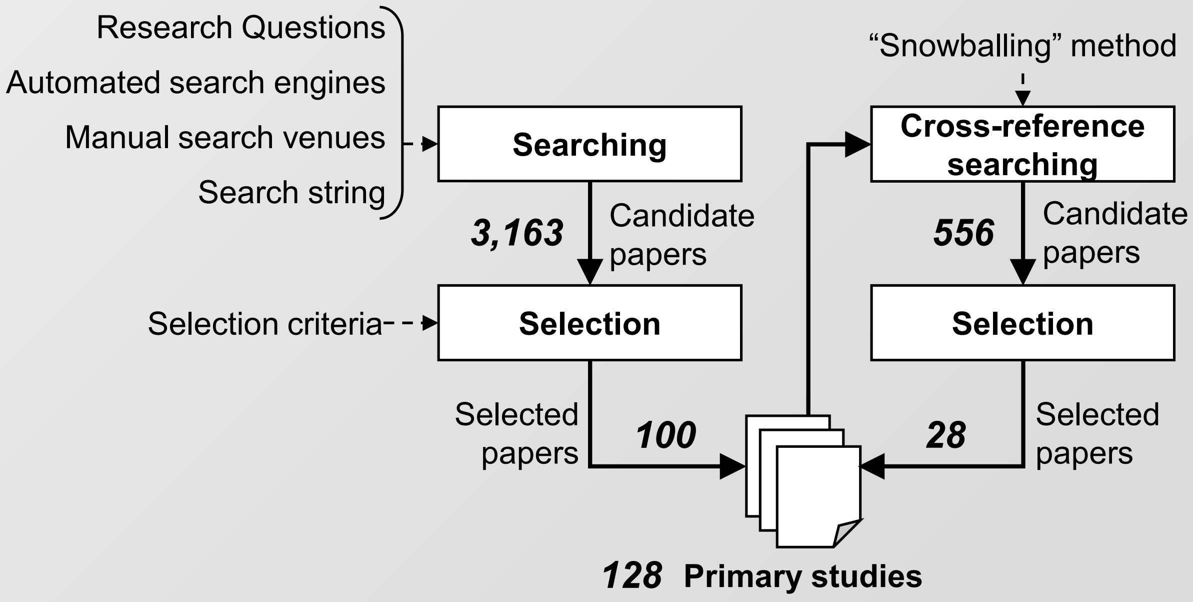
Candidate Study Searching Method

- **9 automated search engines**
  - IEEE Xplore, ACM Digital Library, ACM Digital Library, etc.
- **10 journals and conferences relevant to SAS and software engineering**
  - ACM TAAS, SEAMS, ICSE, etc.
- **Search keywords**
  - (self- OR adapt) AND (software OR system) AND (environment) AND (uncertain)
  - in title, abstract of papers



Primary Study Selection Criteria

Inclusion criteria	
I1	written in English
I2	peer-reviewed
I3	in computer science or other related fields
I4	software engineering approach motivated from environment and its uncertainties
Exclusion criteria	
E1	Duplicated papers
E2	not fully accessible contents
E3	not in the form of a full research paper
E4	Collection of studies
E5	overview, introduction, tutorial, keynote, review, roadmap or survey



128 papers were finally selected as primary studies from 3719 papers.

Data Extraction Items

Items for RQ1

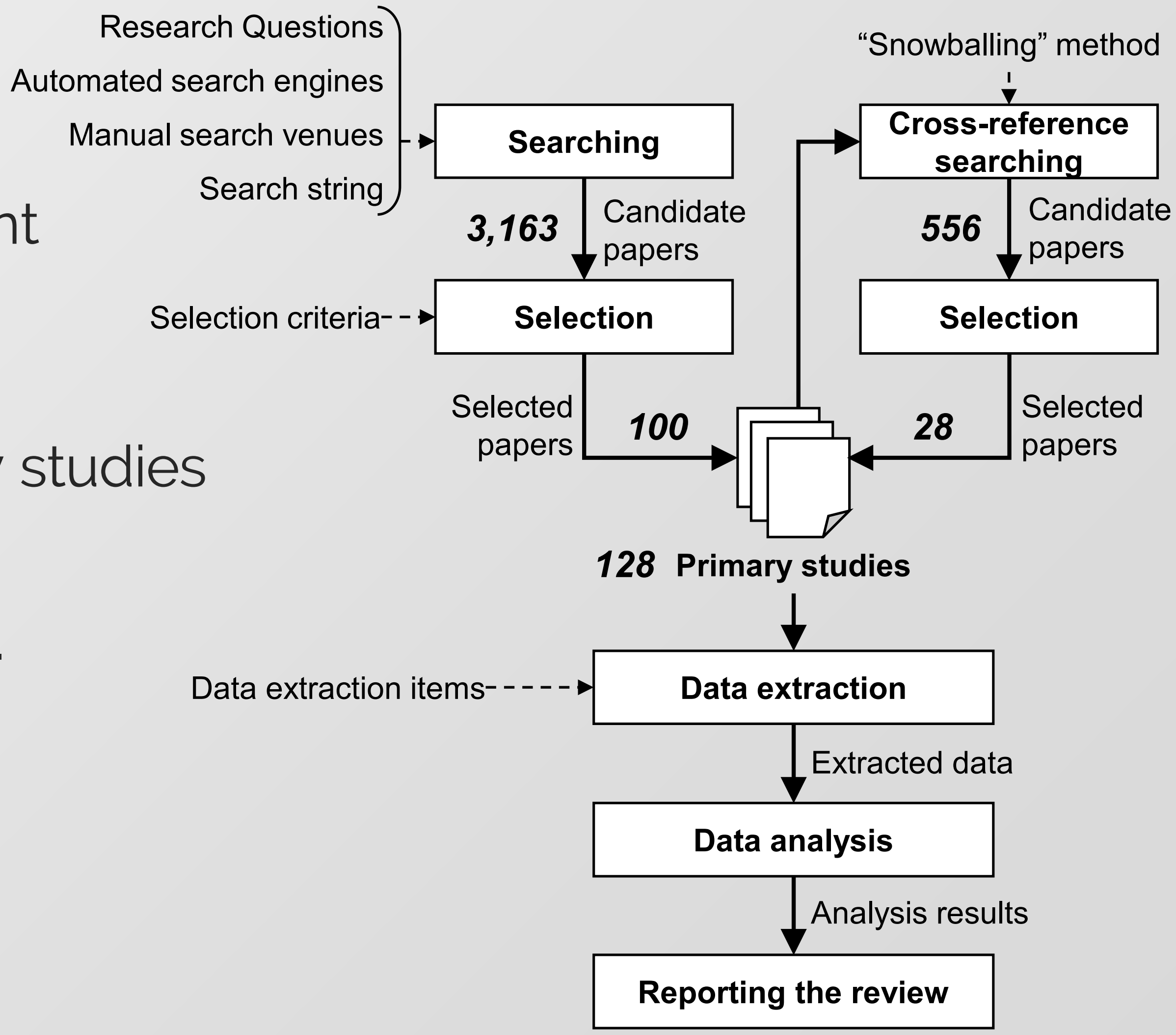
- Expressions (noun, adjective, etc.) mentioned to describe the environment

Items for RQ2

- The cause of the environmental uncertainty that motivated the primary studies

Items for RQ3

- Modeling process, purpose, effort, etc. of the environment models



* **All extracted data is available in [**https://sites.google.com/se.kaist.ac.kr/sas-environment-slr/**]**

Review Result

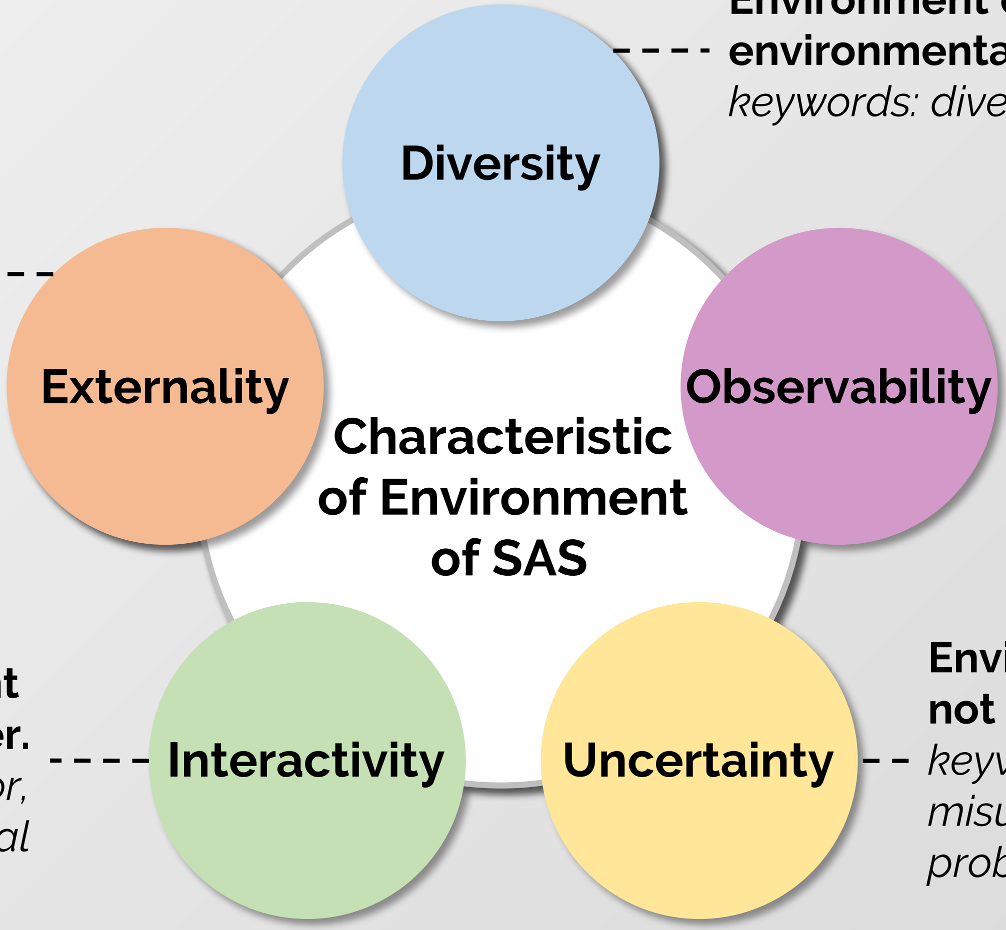
- Five common characteristics of the environment of SAS
- Two common sources of environmental uncertainty
- 14 reference environment models for SAS

Five Common Characteristics of Env. of SAS

Environment consists of diverse environmental factors.
keywords: diverse environmental factors

Environment is outside of system boundary
keywords : system boundary, out of control

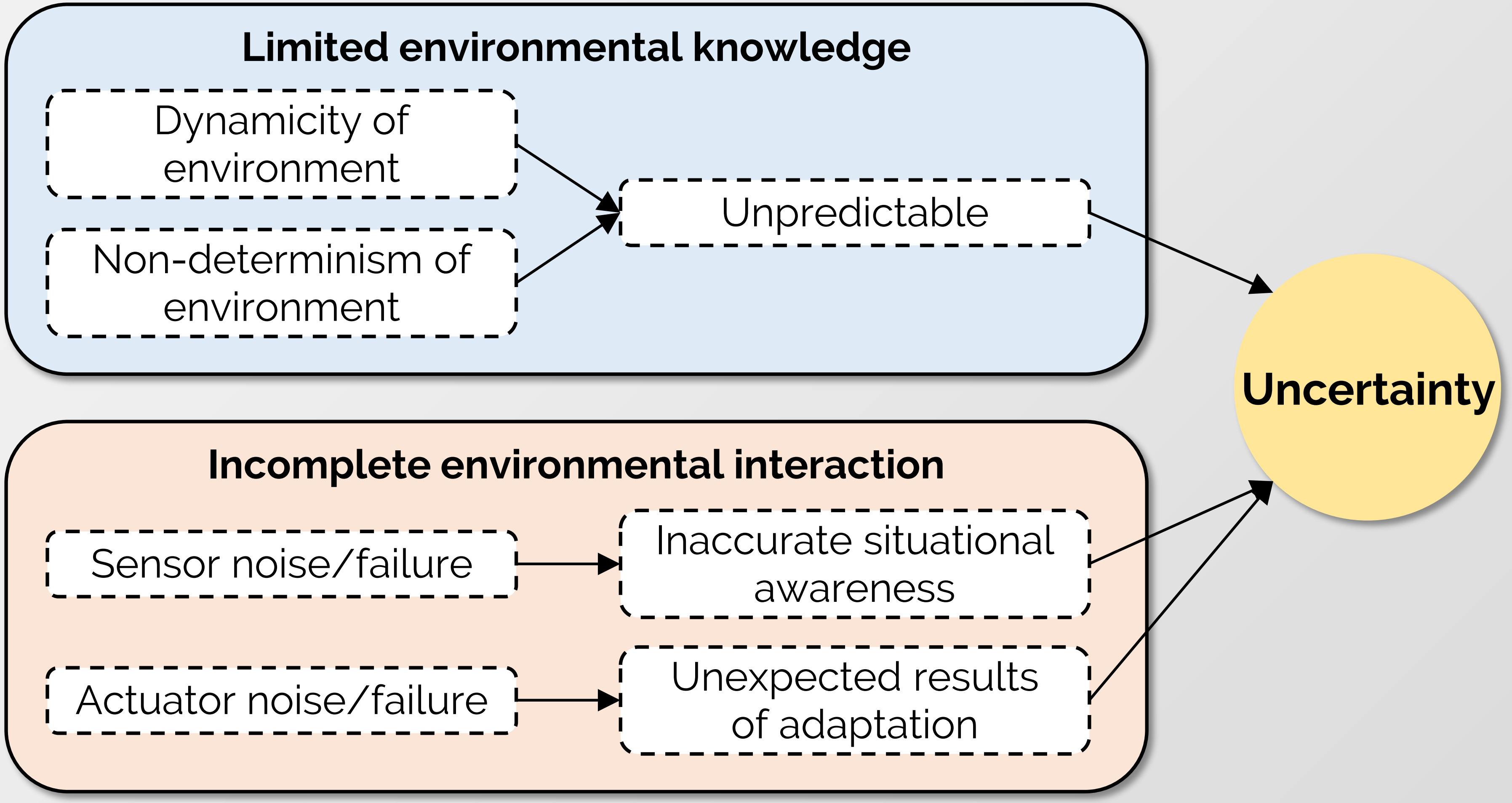
Environment is observable by SAS.
keywords : sensor, value, data



SAS and environment affect each other.
keywords : sensor, actuator, influence, system goal

Environmental state at runtime is not fully anticipated at design time.
keywords : unpredictable, misunderstanding, dynamic, probabilistic

Two common sources of environmental uncertainty



Environmental state at runtime is not fully anticipated at design time.

14 Reference Environment Models

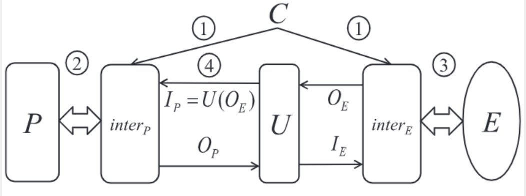
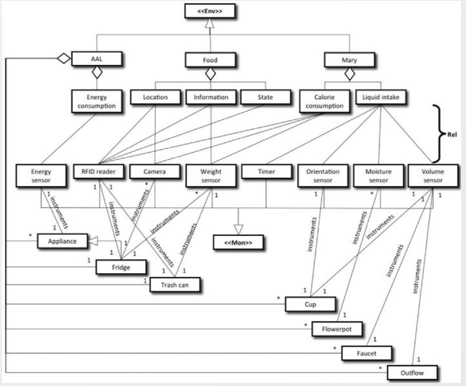


Fig. 1. IAM's iterative reaction loop.




```
const INIT_X, error, MAX_TURNS;
module environment
  t : [−1..MAX_TURNS] init 0;
  [] (t>=0 & t<MAX_TURNS) & (turn=ENV_TURN) −> // 1.Generate value of real x
              (t'=t+1) & (turn'=SYS_TURN) & (real_x'=INIT_X);
endmodule
```

Listing 2. Simple environment model definition.

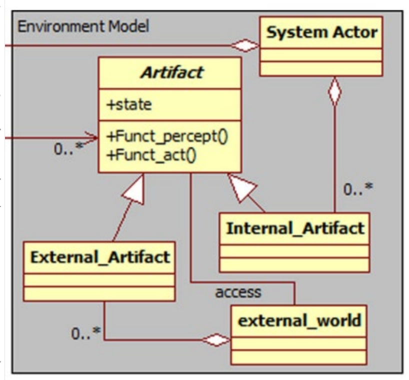
```
module sensor
        [sense] true −> 0.5:(obs_x' = real_x) + 0.5:(obs_x' = real_x+error);
endmodule
```

Listing 3. Sensor definition.

```
const step;
formula s_step = obs_x−step >= 10 | obs_x < 10 ? step : obs_x − 10;

module target_system
expected_x:[0..20] init 0;
new_info:[0..1] init 0;
    [sense] (new_info=0) & (turn=SYS_TURN) −> (new_info'=1); // 2. Sense
    [act] (new_info=1) & (turn=SYS_TURN) −> // 3.a. Act
          (real_x'=real_x−s_step>=0?real_x−s_step:0) & (new_info'=0)
      & (expected_x'=obs_x−s_step>=0?obs_x−s_step:0) & (turn'=ENV_TURN);
    [] (new_info=1)&(turn=SYS_TURN) −> // 3.b. Do nothing
                (expected_x'=obs_x) & (turn'=ENV_TURN) & (new_info'=0);
endmodule
```

Listing 4. Simple system model definition.



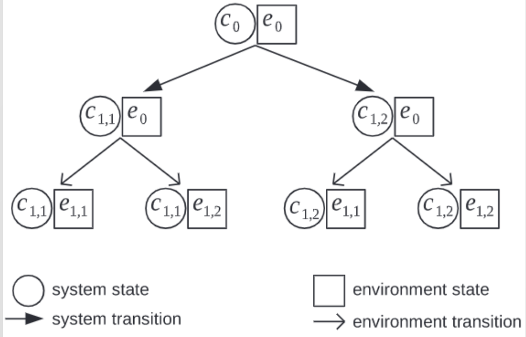


Fig. 4. System and environment transitions.

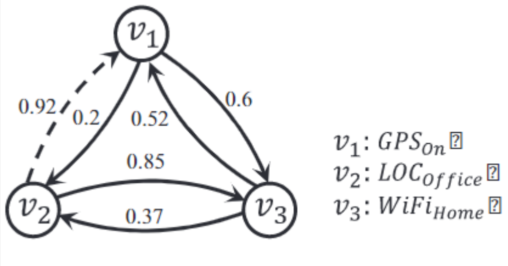


Fig. 5. An example constraint graph.

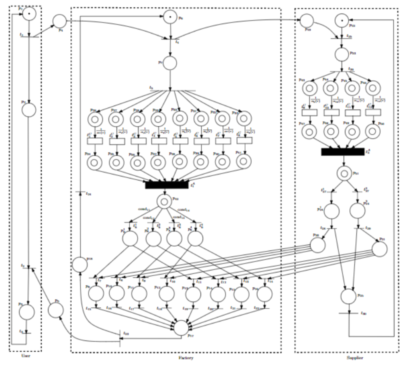


Figure 5: The $PN^{\mathcal{N}}$ model for the manufacturing system.

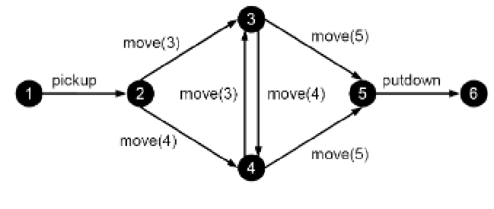


Fig. 2. Robot domain model.

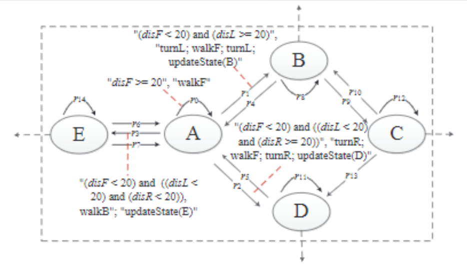


Figure 2: A partial ISM model for our example self-adaptive robot-car application (ellipses represent states and arcs represent rules).

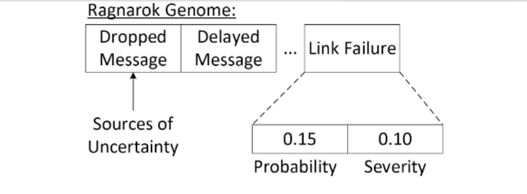


Figure 5: Genome for Ragnarok genetic algorithm.

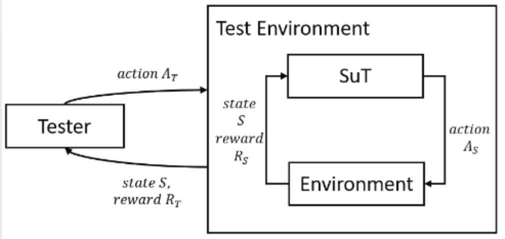


Figure 1: General setting of the Game of Testing combining two decision processes, one for the SuT and one for the tester.

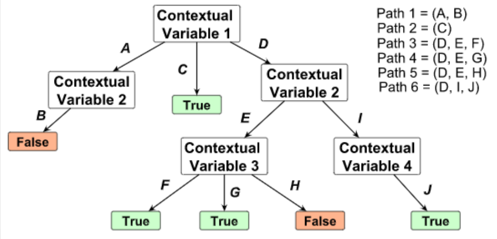


Fig. 4. Decision tree with contextual variables dependencies and their hierarchy.

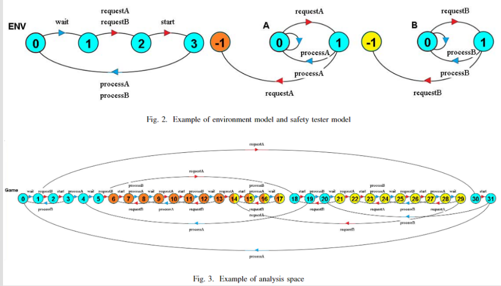


Fig. 2. Example of environment model and safety tester model

Fig. 3. Example of analysis space

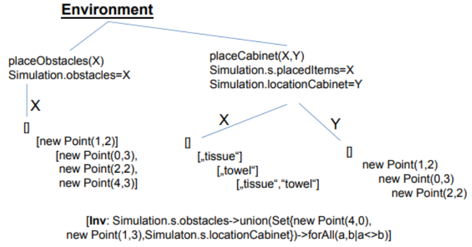


Fig. 6. Environment configuration variability model.

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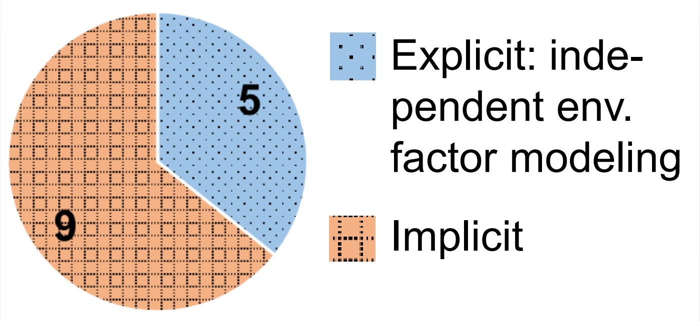
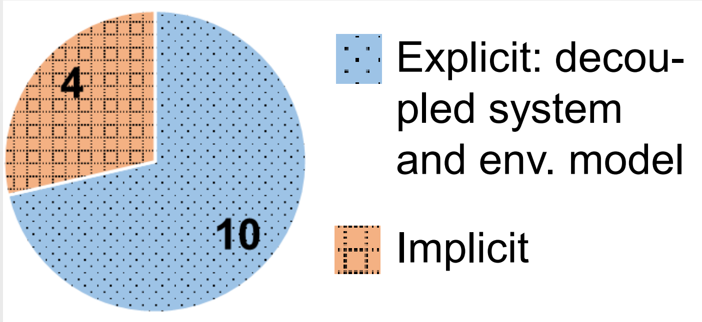
* **References of these reference models are listed in the original paper.**

Expressiveness of the Reference Models

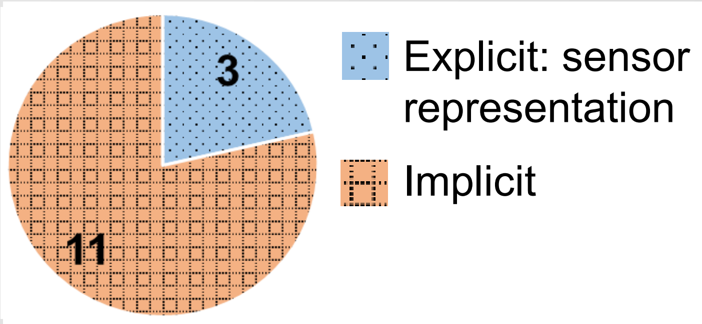
Diversity



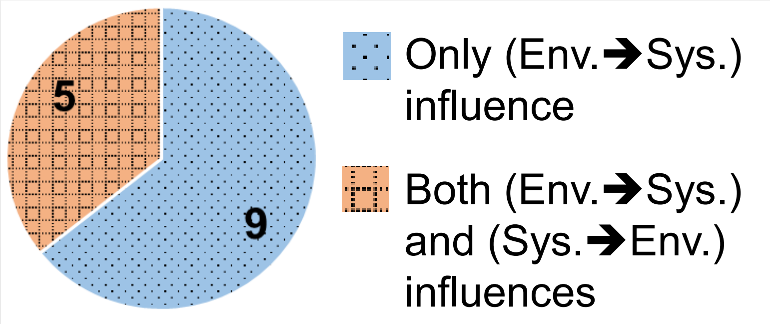
Externality



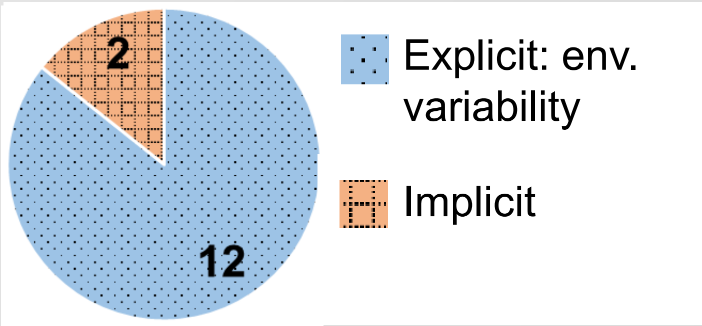
Observability



Interactivity



Uncertainty



The reference models have different modeling purposes and expressiveness.

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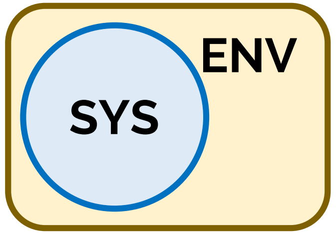
Discussion

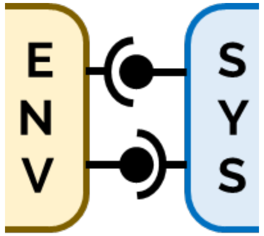
- Four common perspectives of environment of SAS
- Challenges of environment modeling

Four Common Perspectives of Environment of SAS

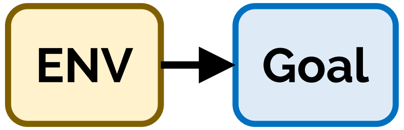
- **Not restricted to a specific RQ, we found four common perspectives of specifying and modeling the environment of an SAS.**



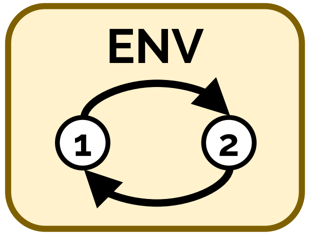
SAS boundary and external factors



Interface of SAS-environment interaction



Environmental impact on the SAS goal



Variability of the environment

Various perspectives can give engineers a comprehensive understanding of the environment of interest.

Challenges and Future Works of Env. Modeling

- **Limited consideration of various environmental characteristics**
  - Future modeling should reflect the diverse characteristics and perspectives of the SAS environment.

- **Limited consideration of various sources of environmental uncertainty**
  - Future research should also address complex environmental uncertainty in which various sources are combined.

- **Considerable manual effort and domain knowledge required for modeling**
  - For the effective use of the environment model, additional research on automated or data-driven model generation is needed.

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Conclusion

Contributions

- **Provided a concrete knowledge of the concept of the environment in SAS engineering academia through SLR**
  - 5 common characteristics of environment of SAS
  - 2 common sources of environmental uncertainty
  - 14 reference environment models
  - 4 common perspectives of specifying environment of SAS
  - 3 research challenges of environment modeling

Refer the original paper for a more detailed review report.

Visit [*https://sites.google.com/se.kaist.ac.kr/sas-environment-slr*] to access the review data and for further discussion.

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Thank You.

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