9th UCAAT User Conference on Advanced Automated Testing

Identifying and Classifying Uncertainties to support Testing of Industrial Elevators

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Industry Context

Orona

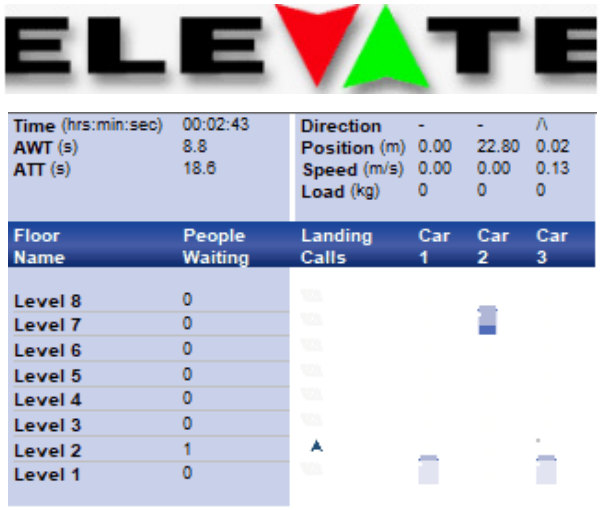
- Develop and maintain elevators
- SiL testing

Elevator attributes

- Safety
- Quality of service (QoS)
- ...

Elevate

- Performance analysis
- Simulation with visual display
- Building, elevator and passenger data



What uncertainties do elevators face?

Uncertainties

Hardware

- **Start delay**
- **Door dwell**
- **…**

Passenger

- **Attributes (e.g., Mass)**
- **Behaviors (e.g., Arrival, Loading and Unloading)**

Rush to an elevator

Uncertain destination

Block the door

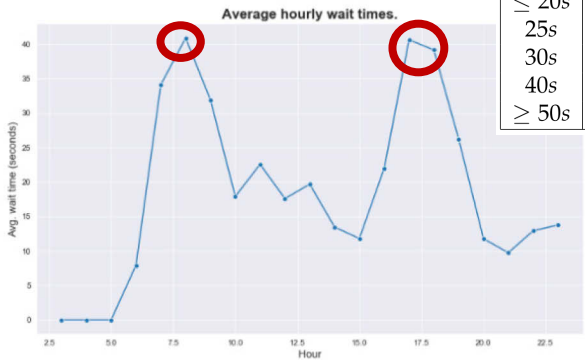
How to **cost-effectively** test elevators in the presence of **uncertainties** to ensure their **dependability**?

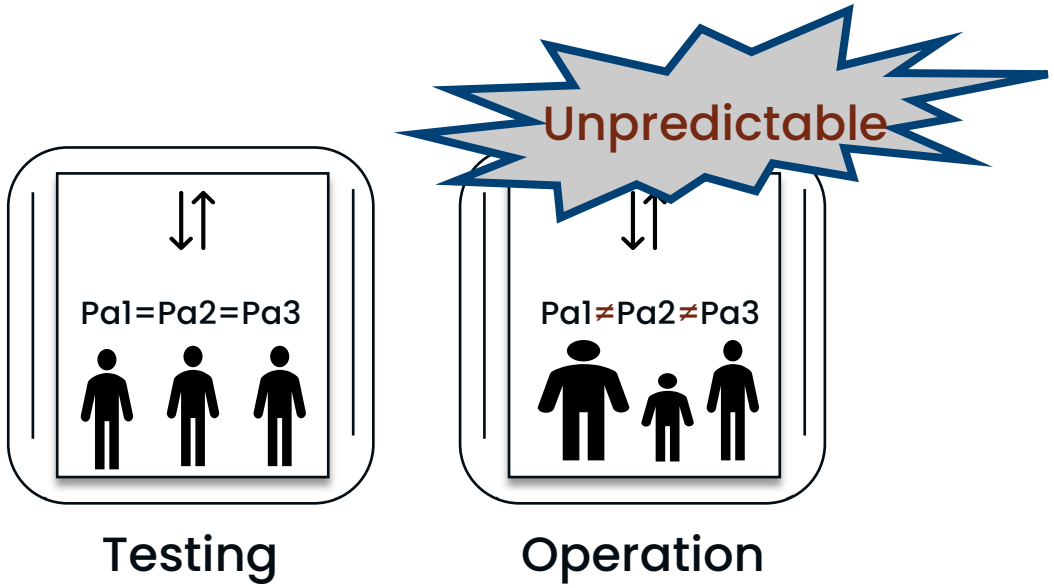
Practices and Challenges

Practices

- SiL testing with Elevate manually
- Fixed passenger attributes (e.g., mass)
- Lack of testing of SUT under uncertainty

AWT	Quality of Service
$\leq 20s$	Excellent
$25s$	Very good
$30s$	Good
$40s$	Poor
$\geq 50s$	Unsatisfactory

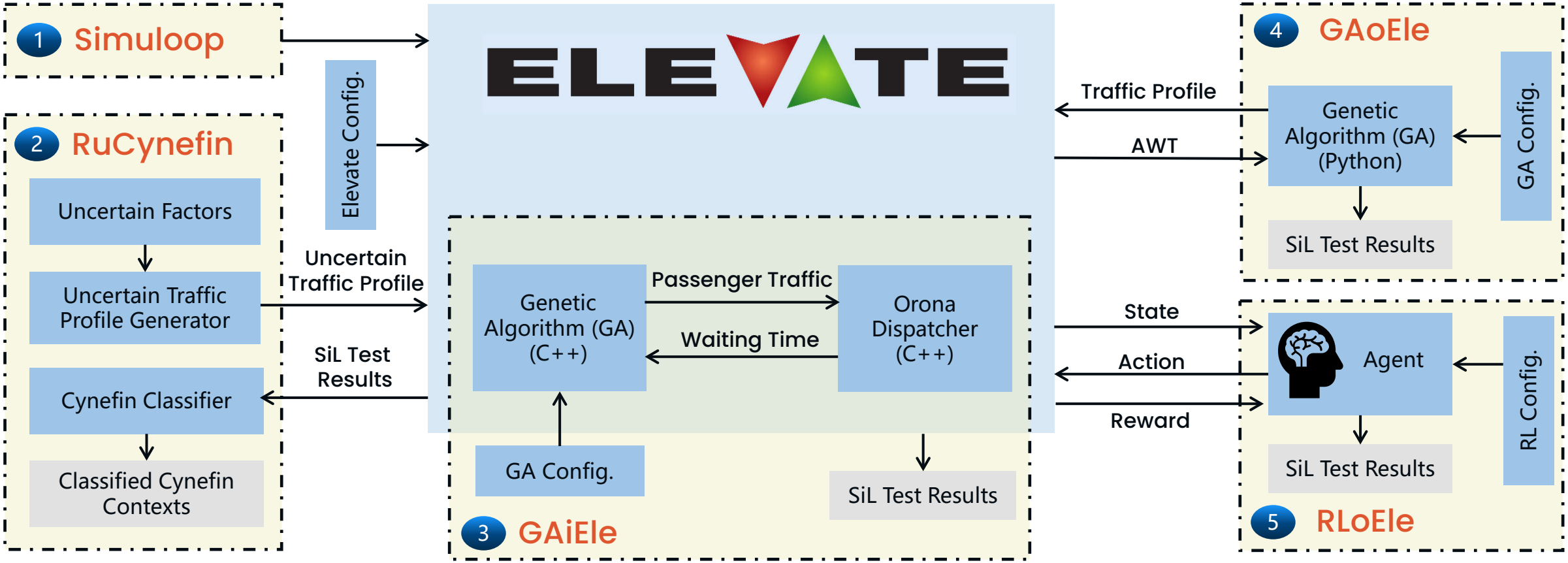




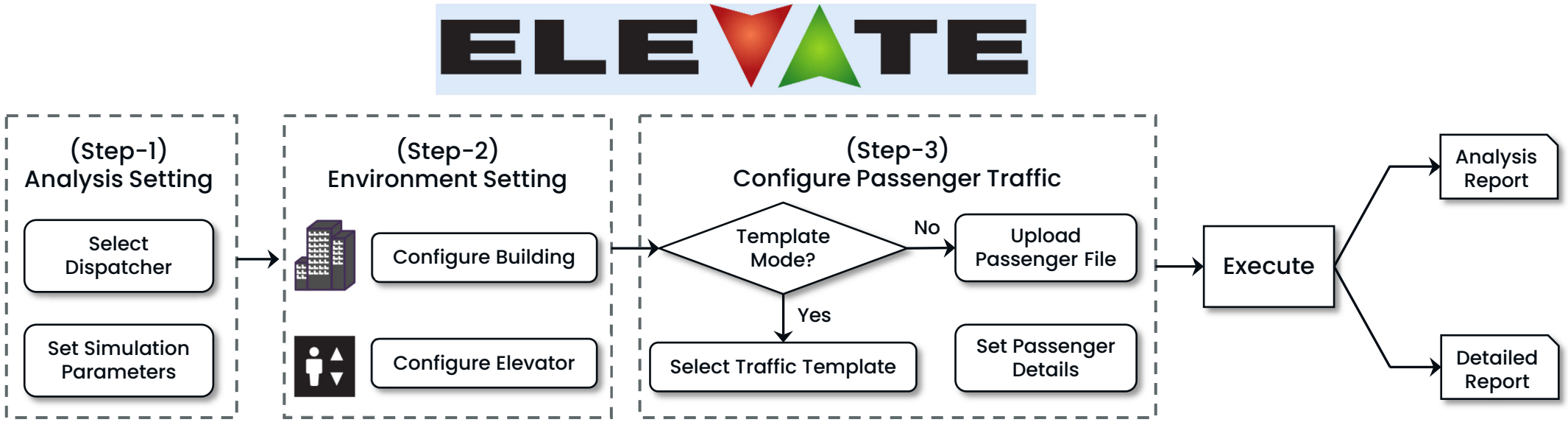
Challenges

- Automate SiL ⇨ Simuloop
- Classify passenger uncertainties ⇨ RuCynefin
- Search and RL based testing of elevators under uncertainty ⇨ GAiEle & GAoEle & RLoEle

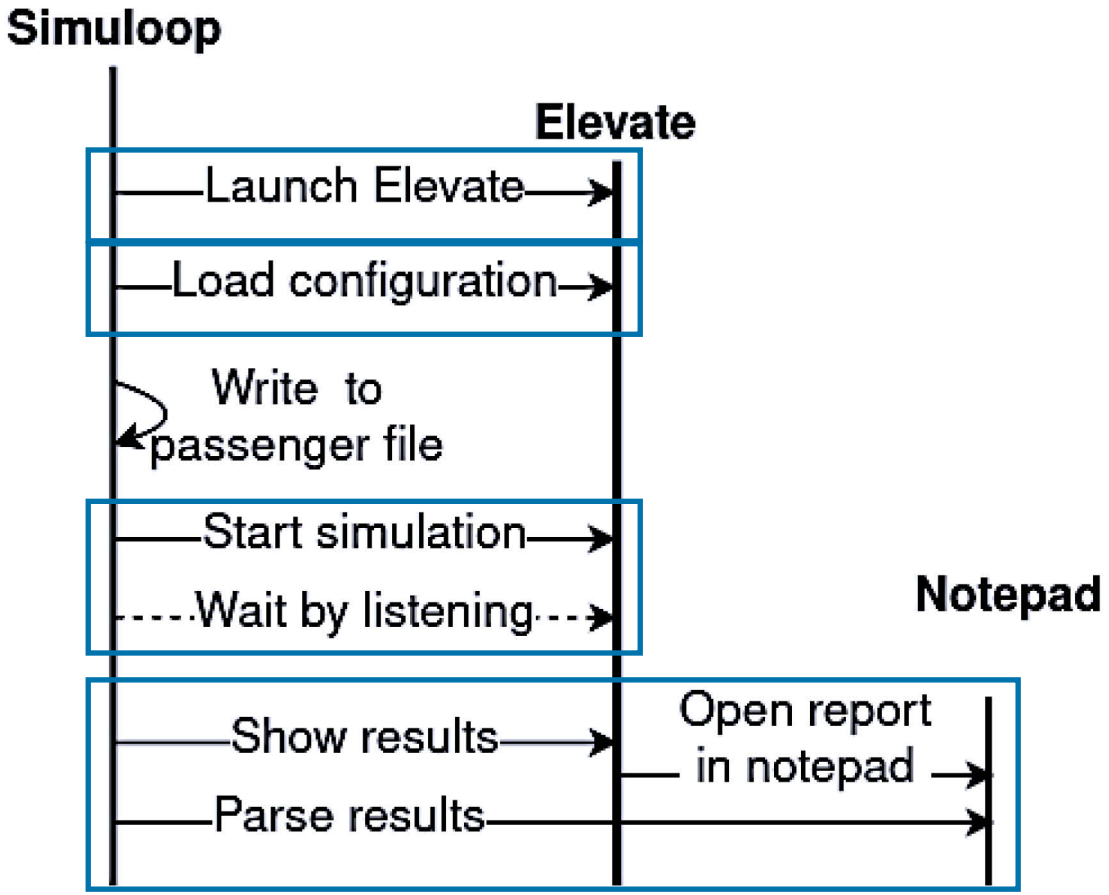
Our SiL-based Methods

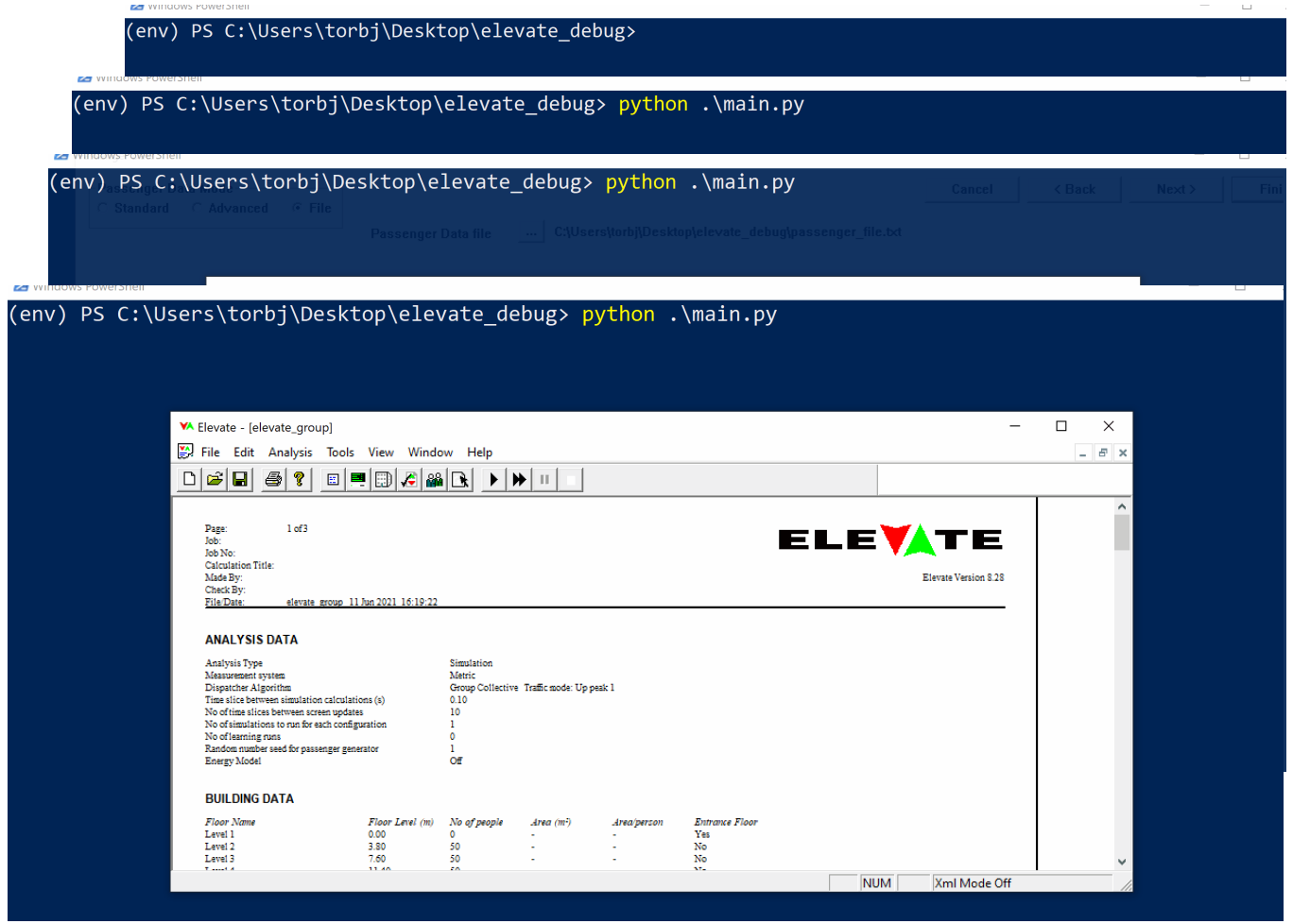


SiL with Elevate



Simuloop: Automate SiL





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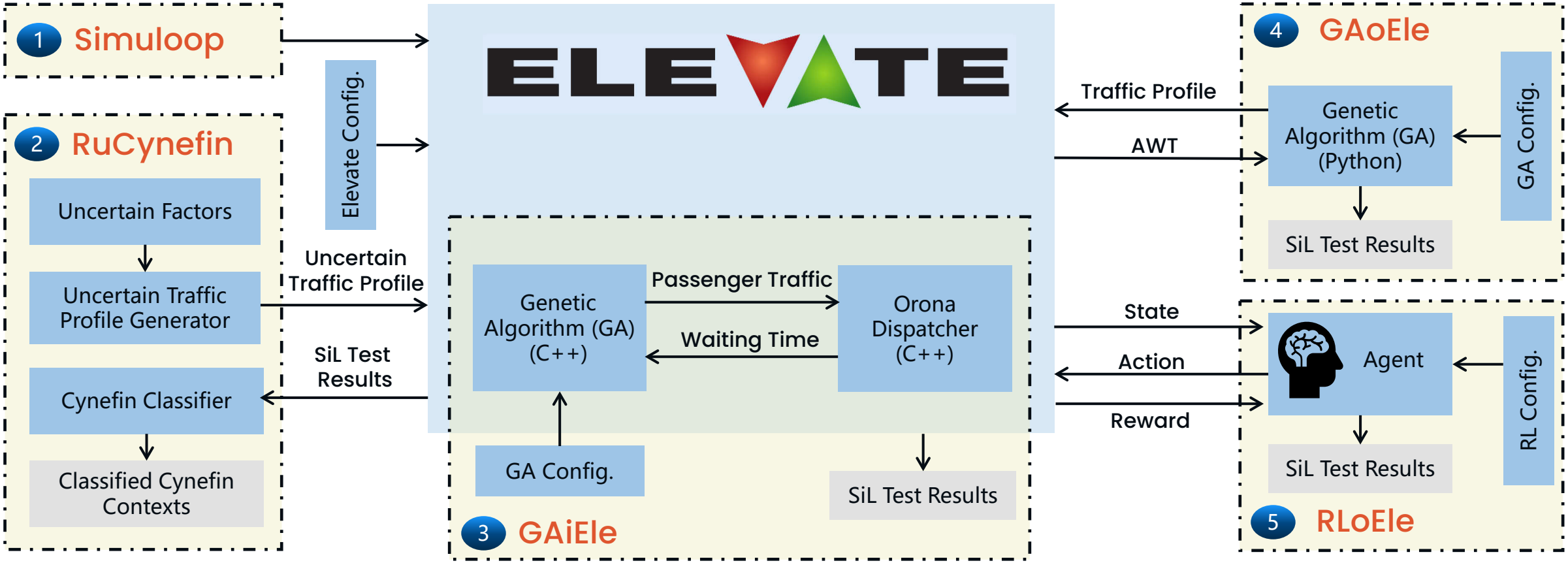
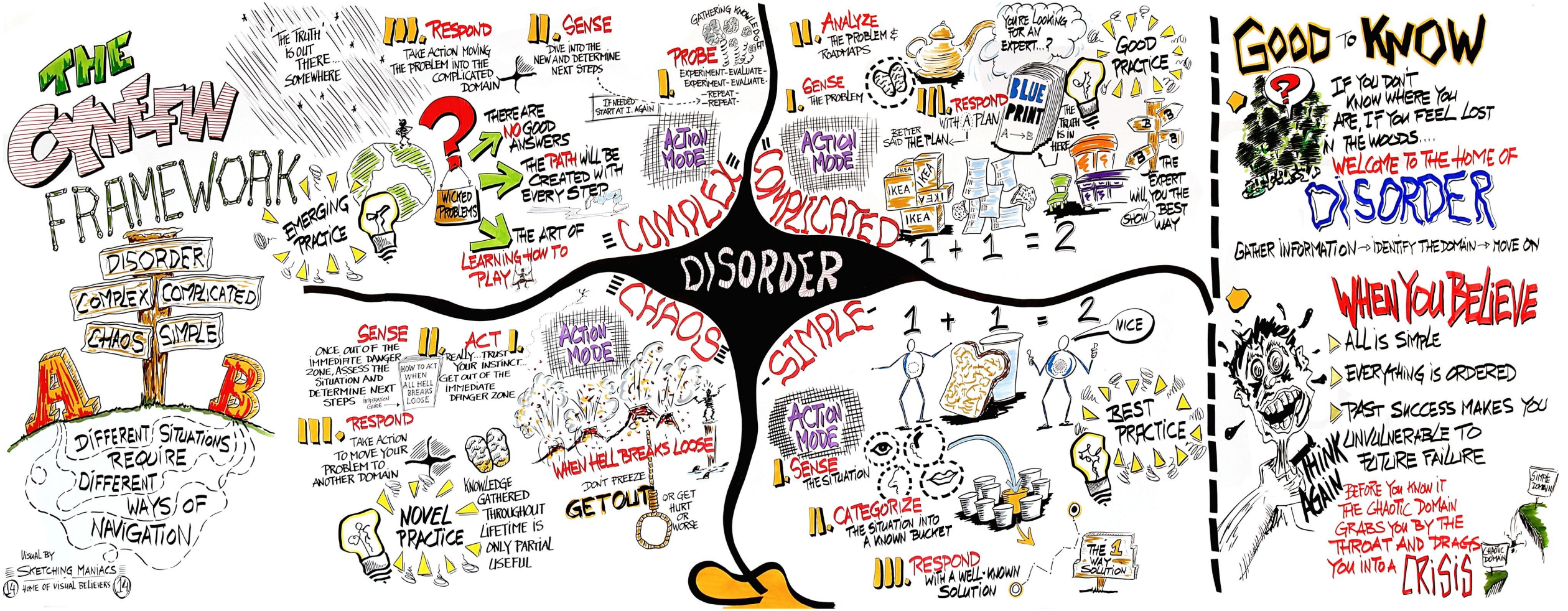
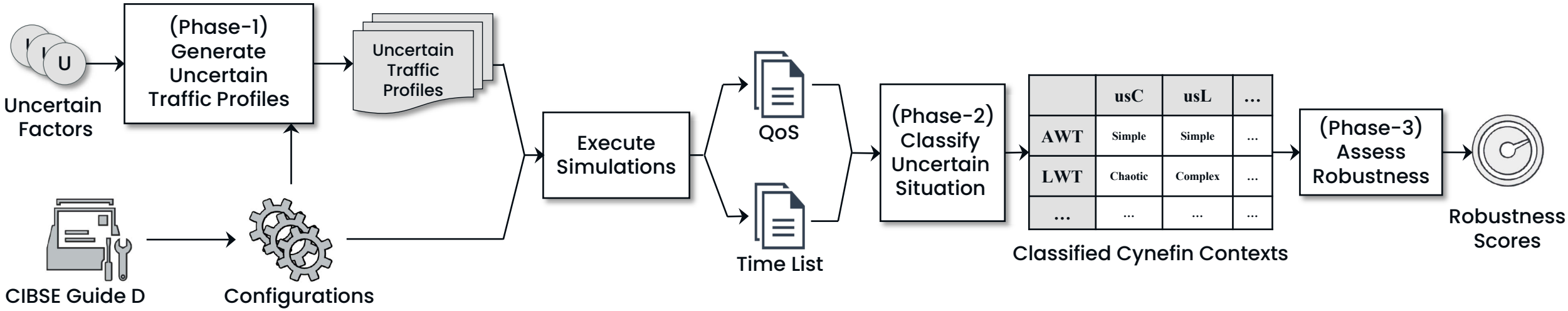


Cynefin: Decision Making under Uncertainty



Sketch of the Cynefin framework, by Edwin Stoop

RuCynefin : Cynefin-based uncertain situation generation and classification



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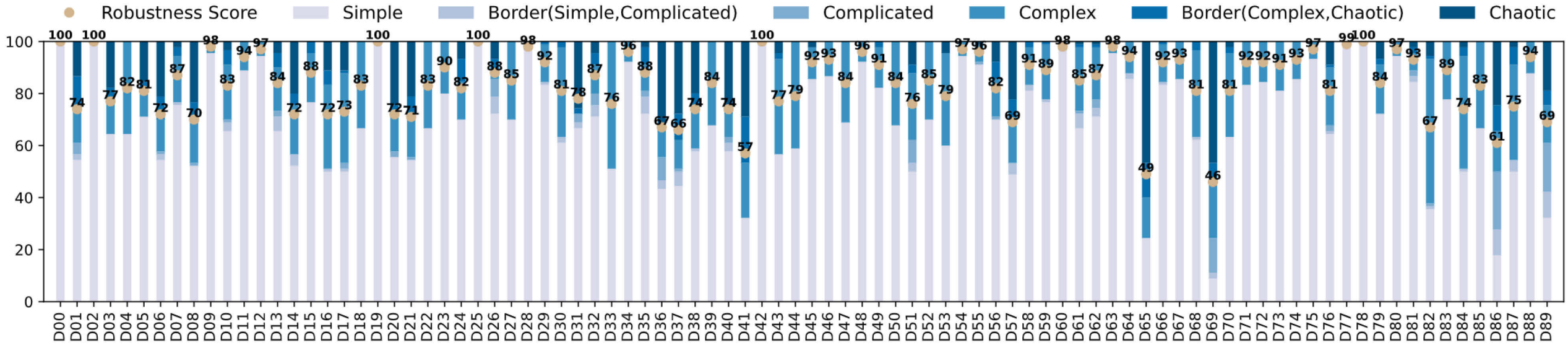
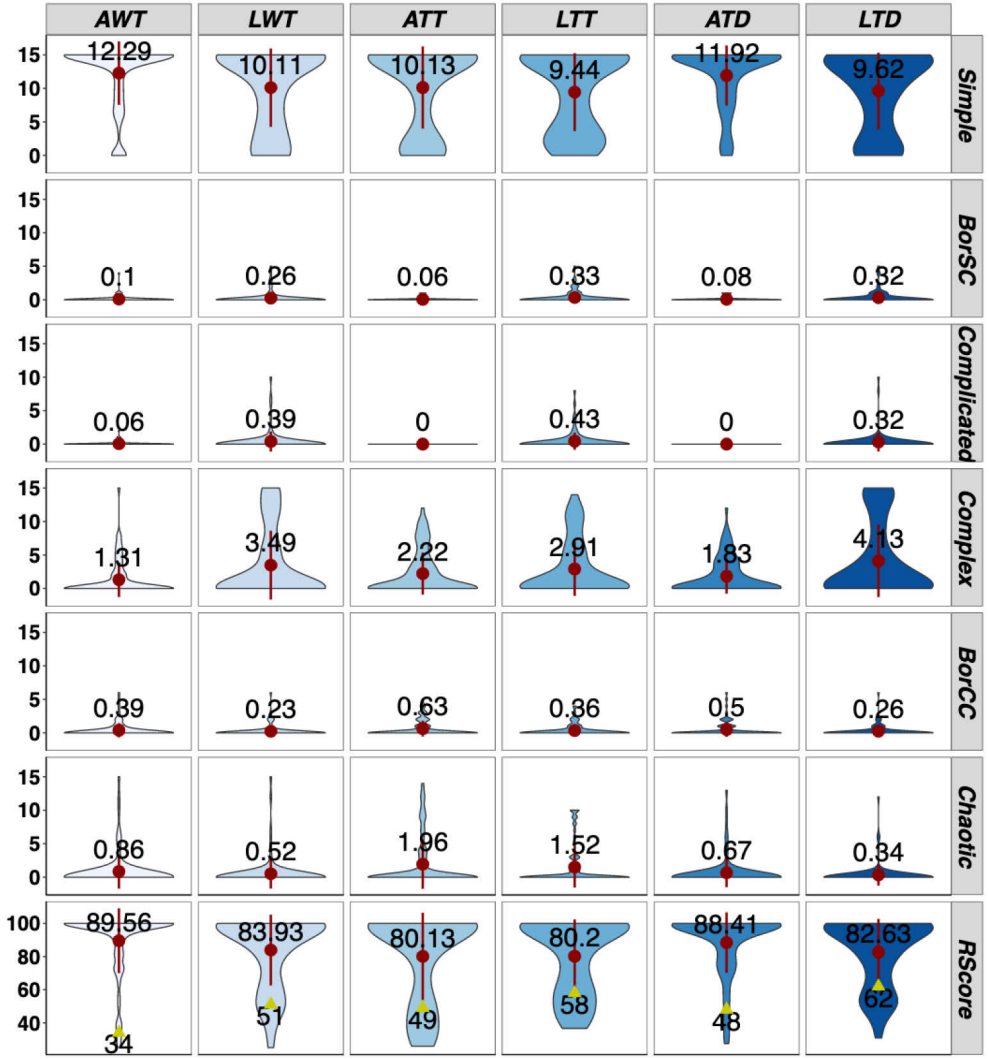


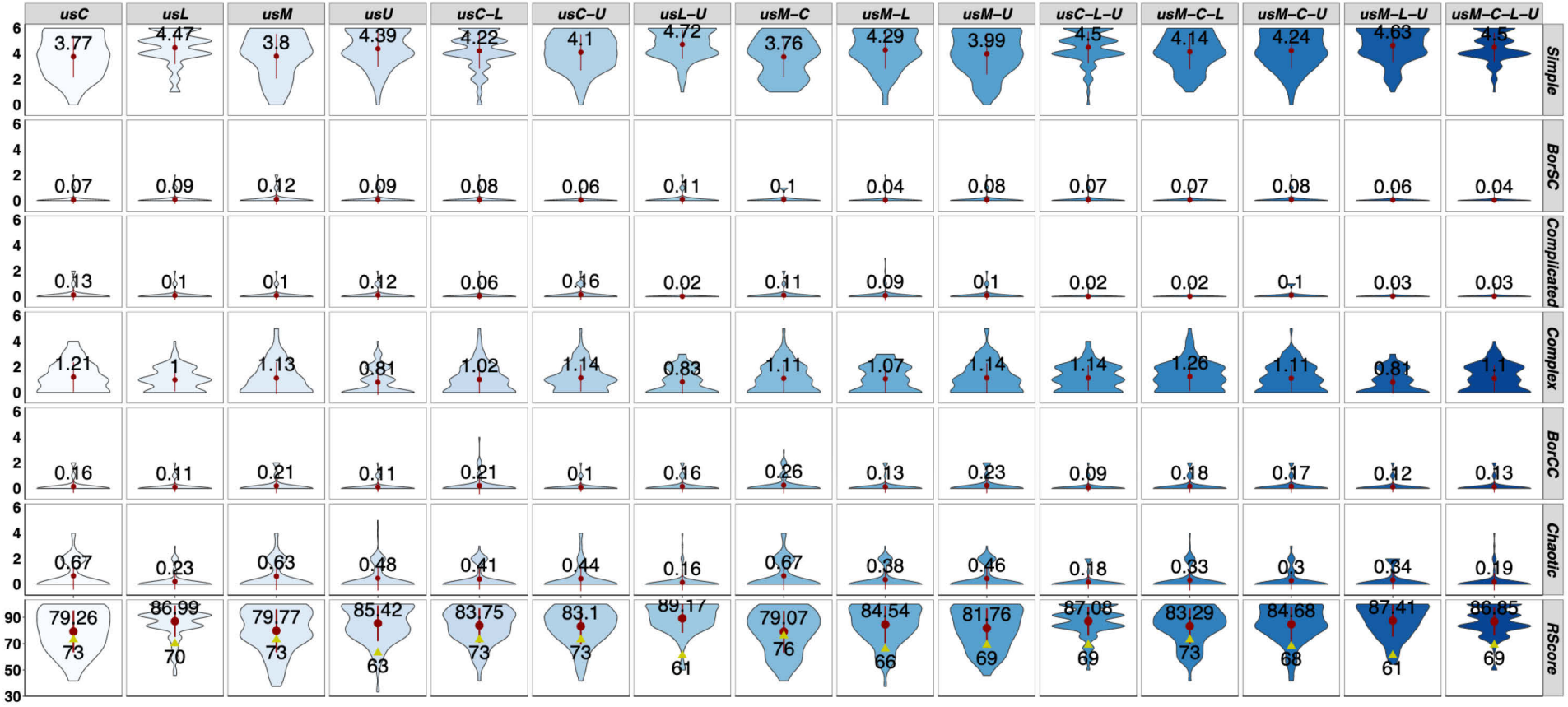
The 90 dispatchers exhibit diverse robustness in terms of dealing with uncertainties.

RuCynefin : Cynefin-based uncertain situation generation and classification



- AWT and ATD are impacted relatively less by uncertainties.
- Recommend to optimize a dispatcher's robustness under uncertainties with respect to a particular QoS of interest.

RuCynefin : Cynefin-based uncertain situation generation and classification



Different uncertain factors have different extents of impact on the robustness of the dispatchers.

Capacity Factor, Mass and their interaction have relatively higher impact on the dispatchers' robustness than the other uncertain factors.

RuCynefin : Cynefin-based uncertain situation generation and classification

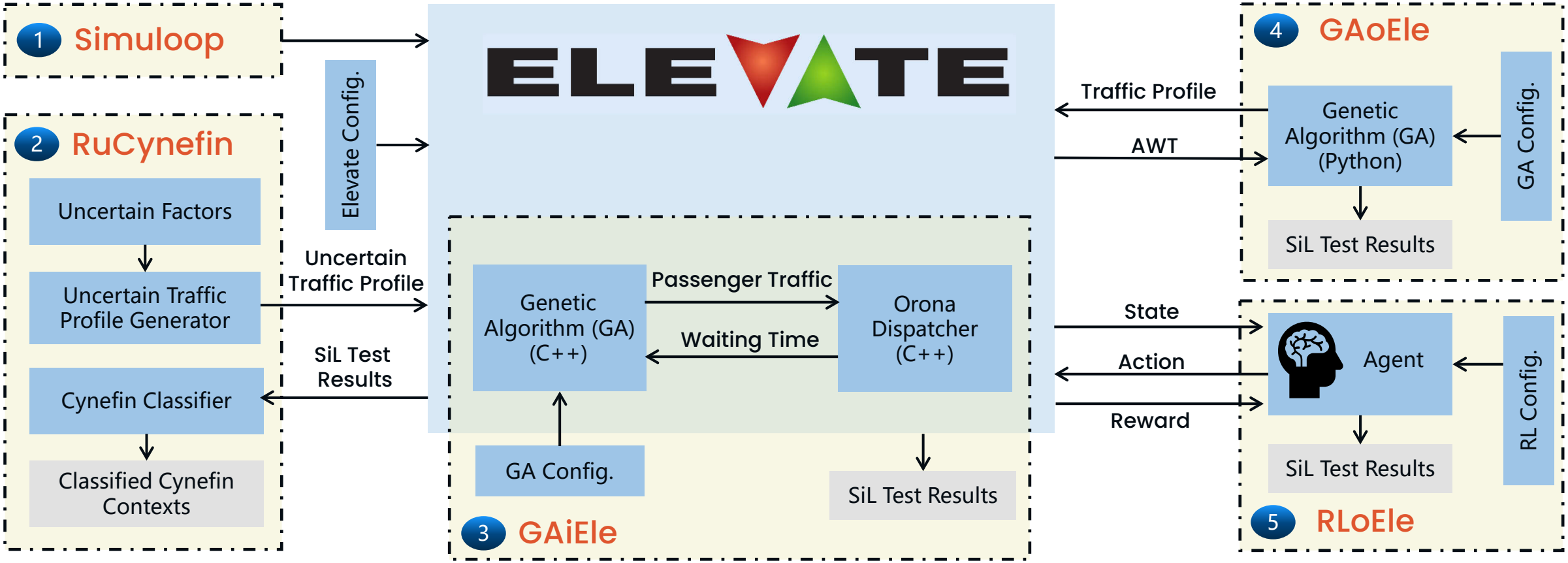
QoS	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15
AWT	69	69	73	76	75	71	73	73	76	72	77	76	74	76	76
LWT	57	57	59	62	62	62	61	59	63	59	62	58	59	68	62
ATT	55	64	51	60	59	57	69	52	61	56	65	62	63	71	67
LTT	51	66	**43**	59	50	60	74	50	55	53	58	55	62	59	55
ATD	60	**80**	64	74	76	64	78	58	75	62	**82**	68	71	79	**82**
LTD	**47**	66	52	64	58	55	70	**46**	56	57	61	54	53	64	63

#1 *usC* #2 *usL* #3 *usM* #4 *usU* #5 *usC-L* #6 *usC-U* #7 *usL-U* #8 *usM-C* #9 *usM-L*
#10 *usM-U* #11 *usC-L-U* #12 *usM-C-L* #13 *usM-C-U* #14 *usM-L-U* #15 *usM-C-L-U*

Provide feedback on which QoS against which uncertain situation should be prioritized for optimization.

- E.g., focus on LTD when facing uncertainties caused by Capacity Factor itself or its interactions with Mass.

Our SiL-based Methods

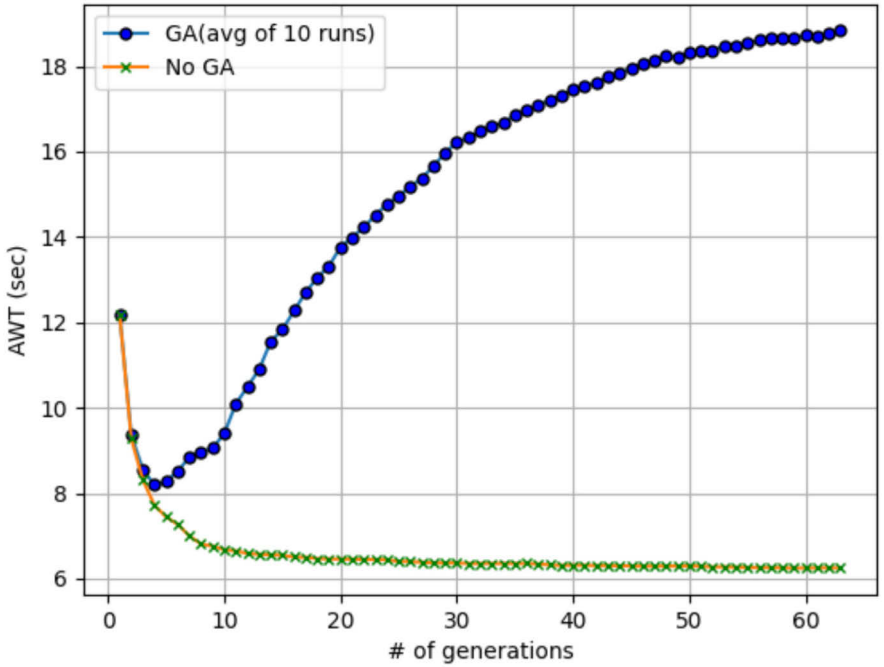


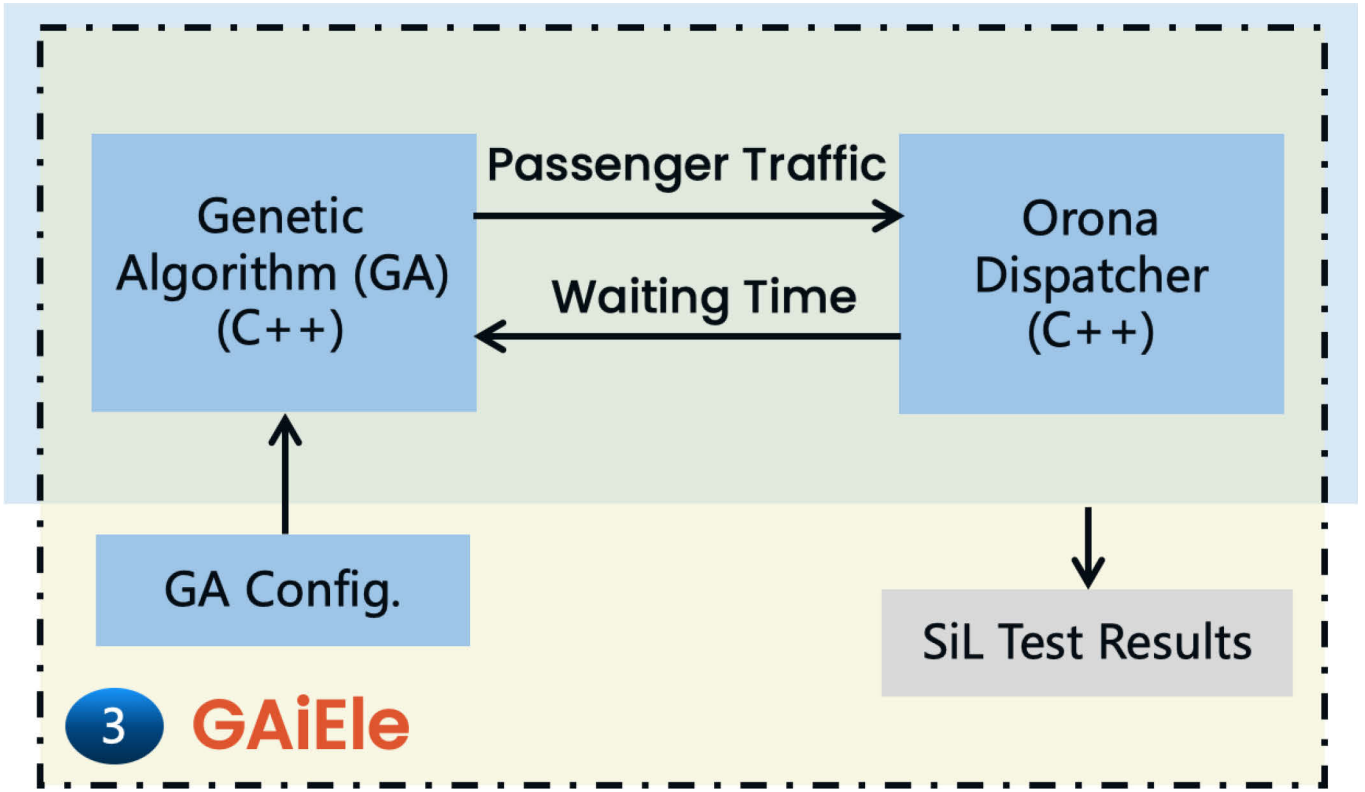
GAiEle: Search-based SiL testing

GAiEle generates passengers with specific attributes during SiL, for a given traffic profile, with GA, with the aim of maximizing AWT of passengers.

Arrival Time	Arrival Floor	Destination Floor	Mass	Capacity Factor	Loading Time	Unloading Time

Empirical study:



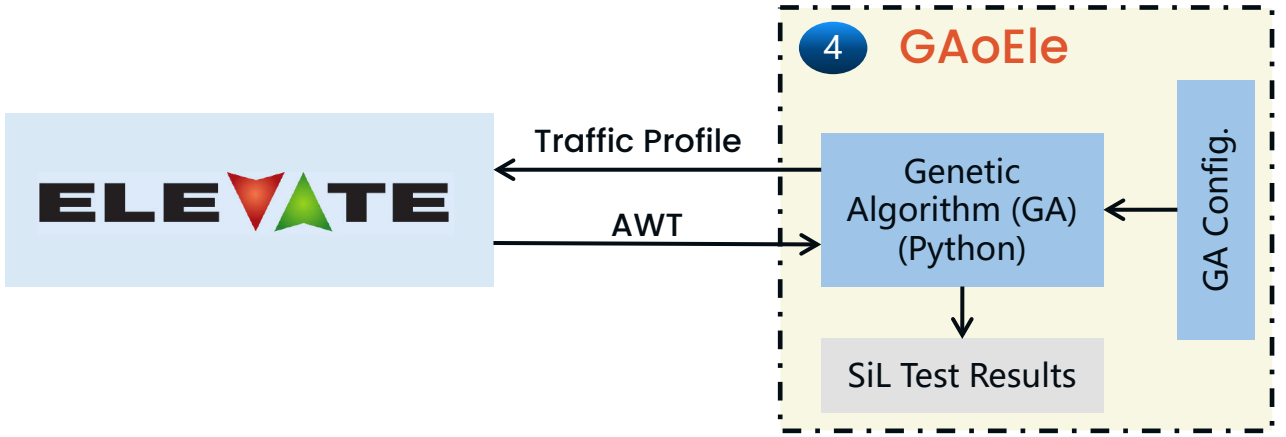


GAoEle: Search-based SiL testing

Objective: maximize AWT of passengers

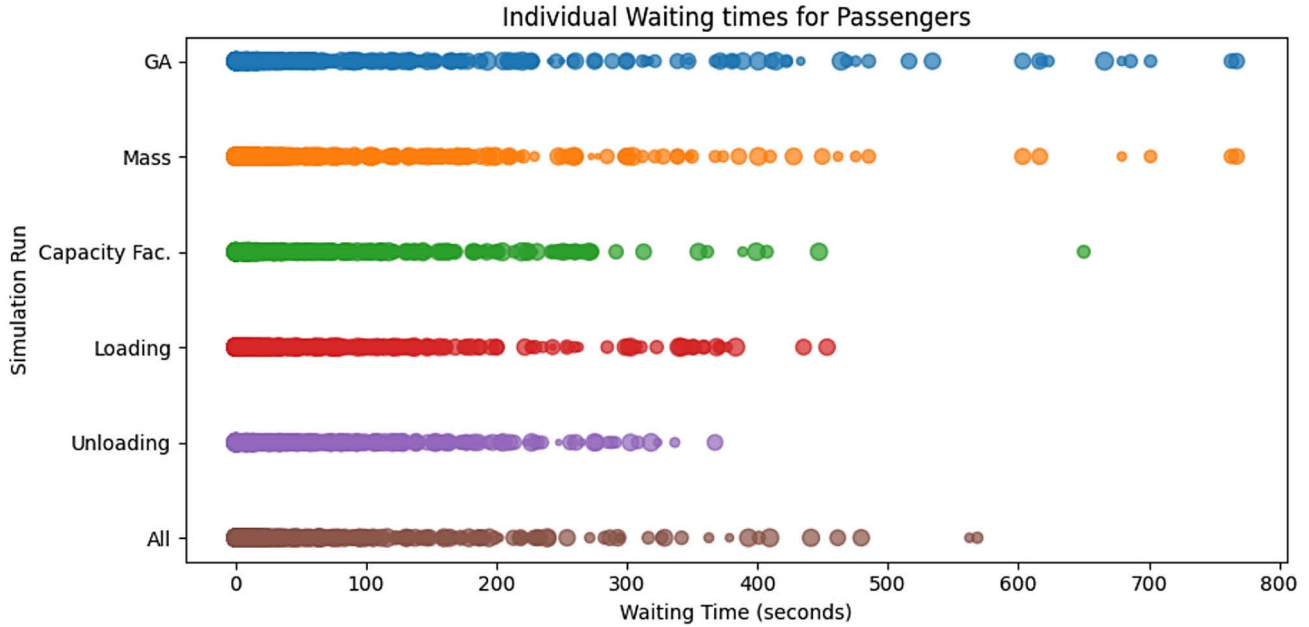
Difference with GAiEle:

- load standard profile at the beginning
- change all passengers at each generation
- outside of Elevate, not extra engineering work



Empirical study:

Attribute	GA	Mass	Cap.	Load.	Unload.	All
Mass (kg)	x	90	x	x	x	90
Cap Fac. Mass (%)	x	x	75	x	x	75
Loading time (s)	x	x	x	2	x	2
Unloading time (s)	x	x	x	x	2	2
AWT(s)	**44.5**	40.3	39.0	34.0	30.3	34.5



RLoEle: Reinforcement learning based SiL Testing

Environment

- Building configuration
- Elevator setup

State

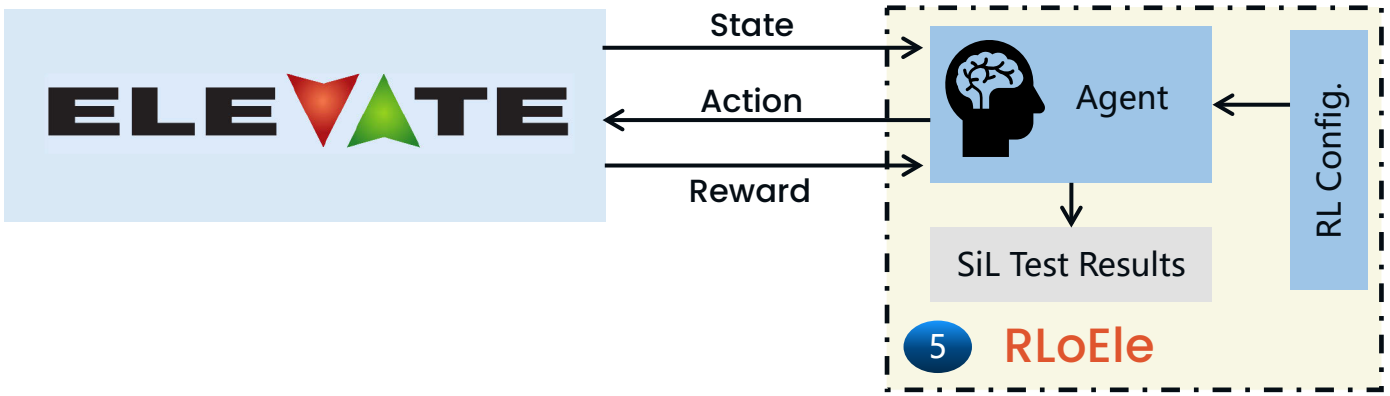
- Elevator and passenger positions and directions

Action

- Assign arrival and destination floors

Reward

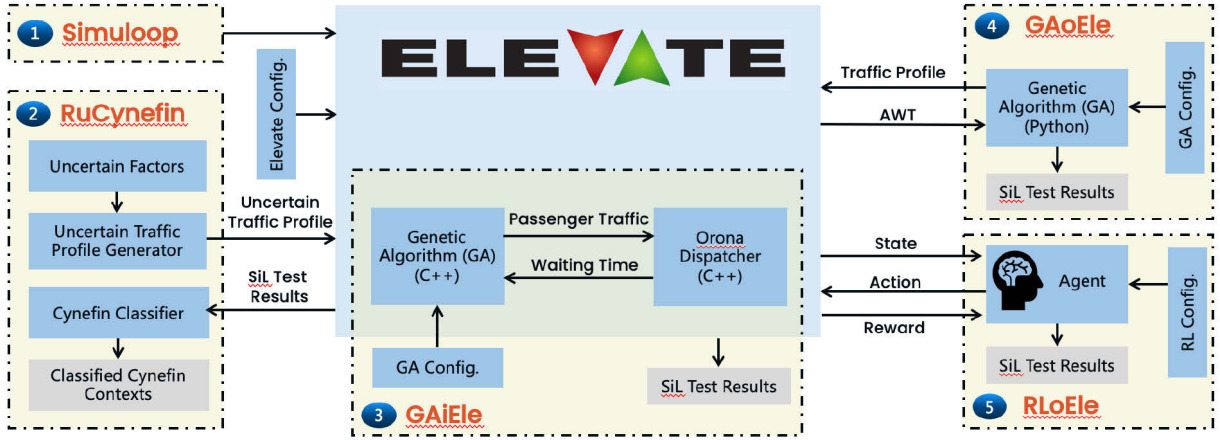
- AWT



Summary and Outlook

Follow-Up Works

- Industrial validation and technology transfer
- Generalize to other domains, e.g., train control



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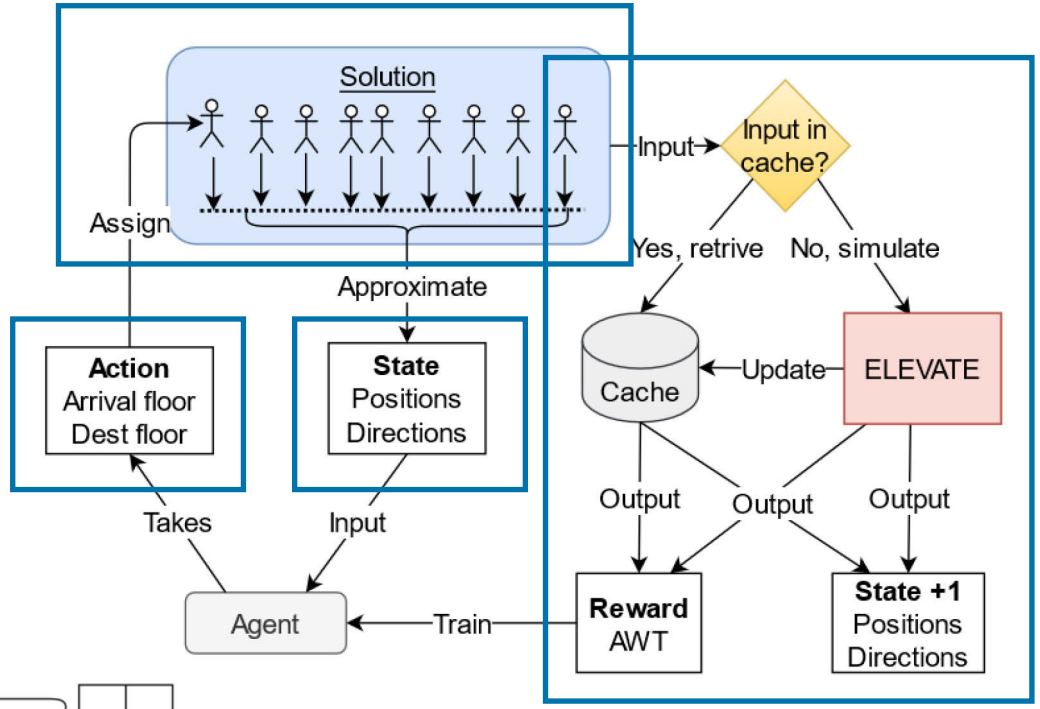
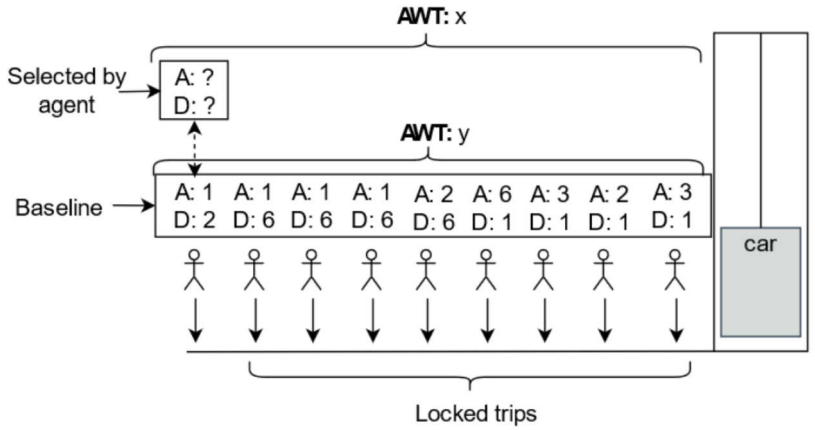
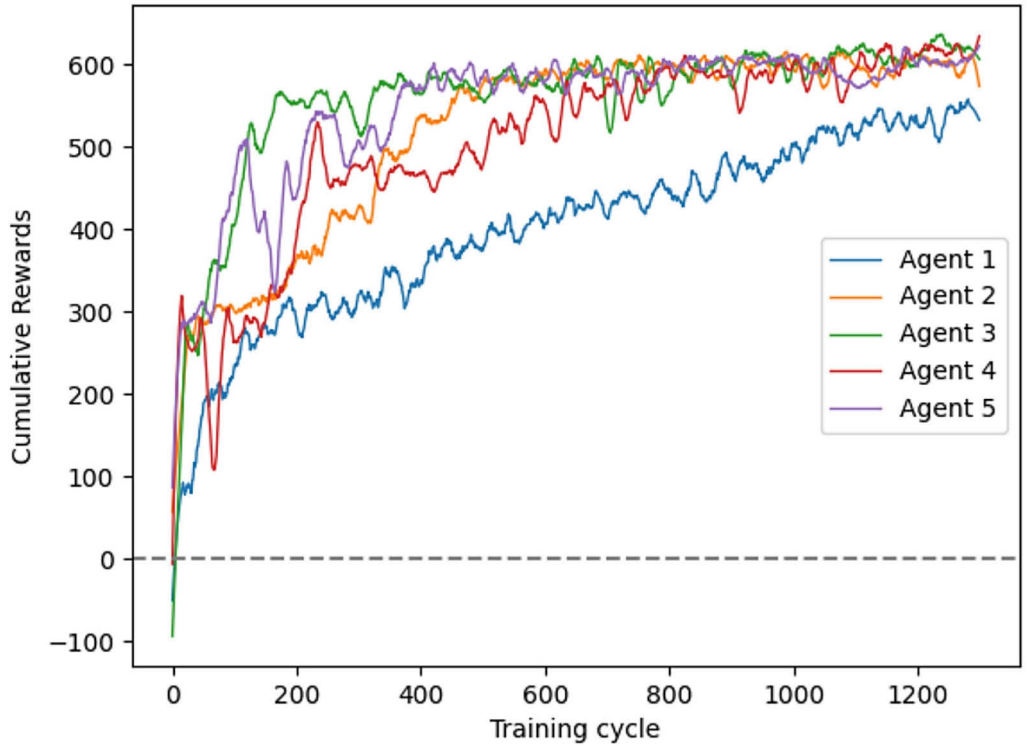
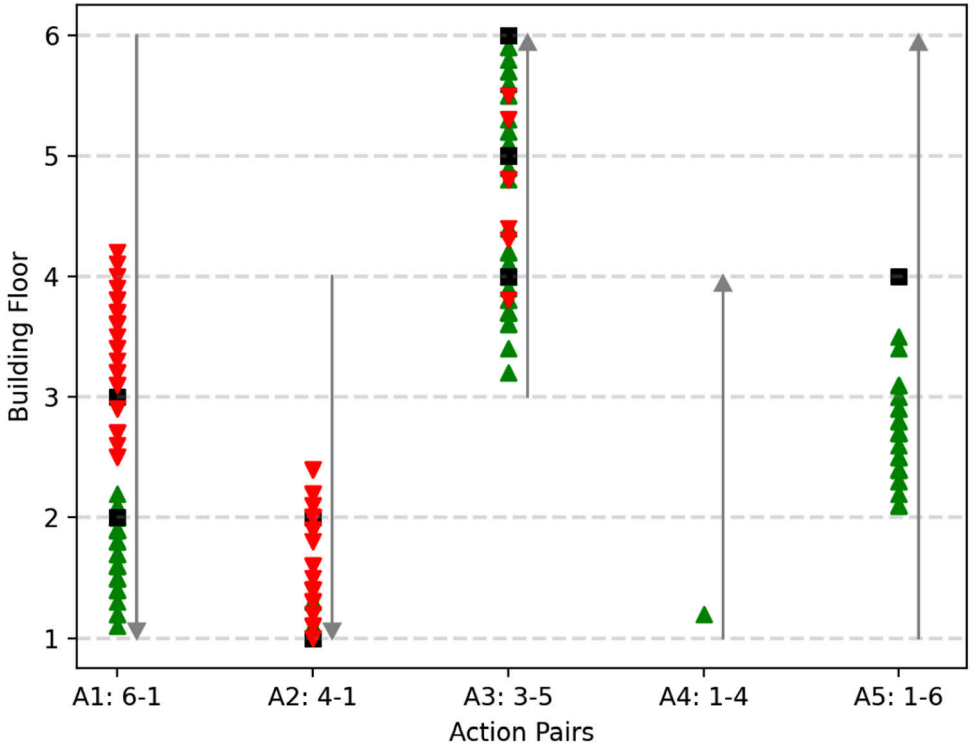




$$x - y = reward$$

RLoEle: Reinforcement learning based SiL Testing





Most models were converged after 1000 cycles.

Given a floor height and a direction, it is straightforward to conclude which action to select.