ATTRIBUTE REPAIR FOR THREAT PREVENTION

SAFECOMP 2023

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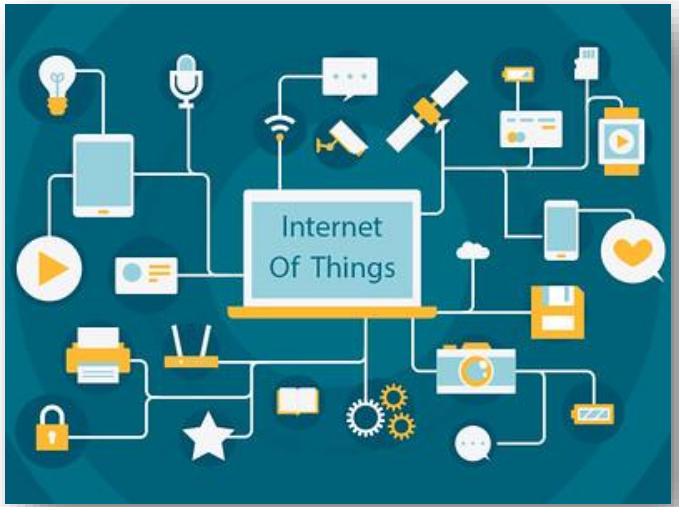
AIT Austrian Institute of Technology

Joint work with Thorsten Tarrach, Masoud Ebrahimi, Sandra König, Christoph Schmittner and Roderick Bloem

MOTIVATION



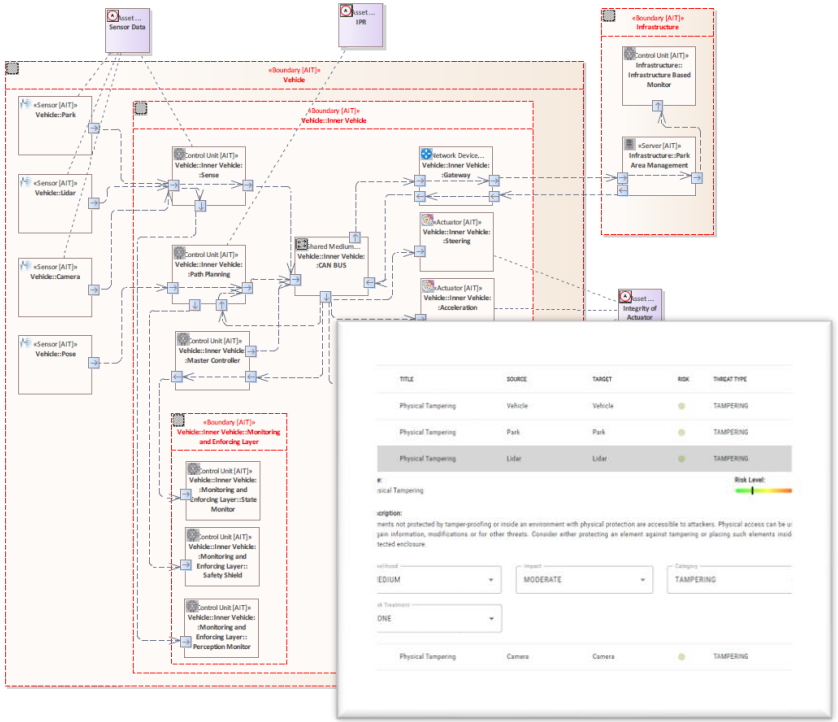
Larger attack surfaces

New security standards
ISO/SAE 21434

→ Security as first-class citizen from early stages of design

THREATGET

- THREATGET - tool for threat management and analysis
- Reusable analysis results
- Traceable mitigations and design decisions
- Up-to-date threat catalogue

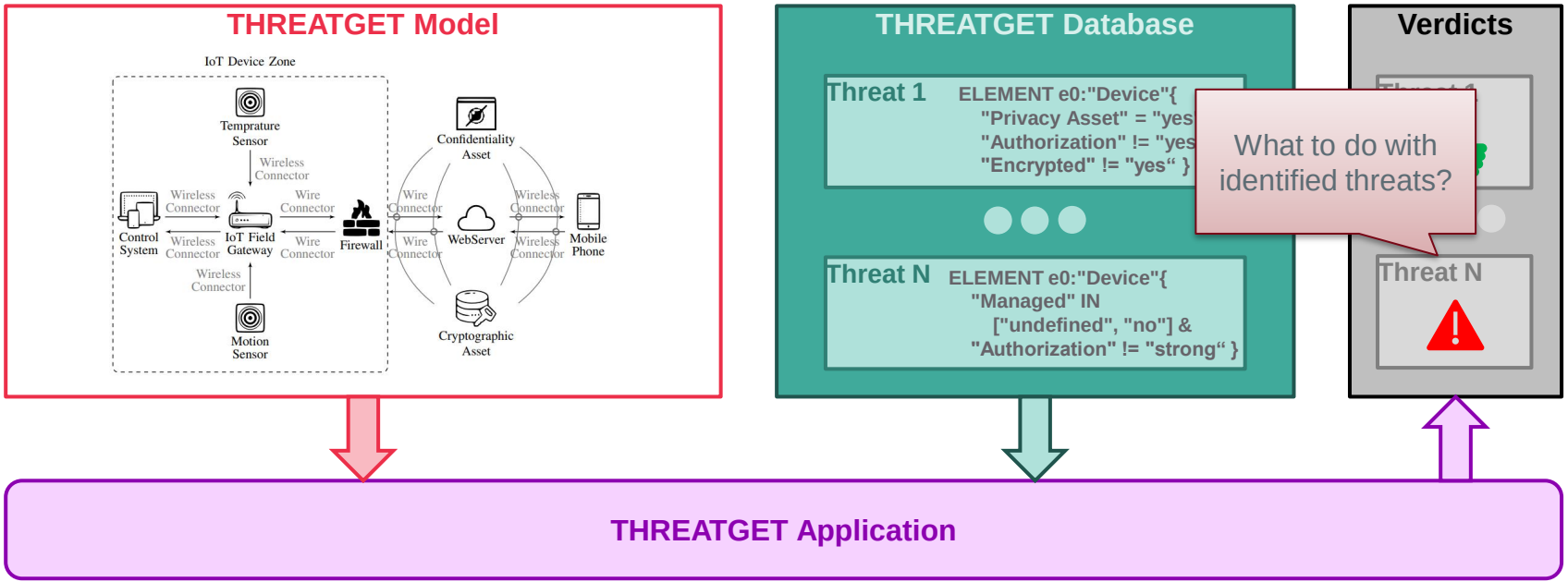


https://www.threatget.com/

Commercial tool, free academic license

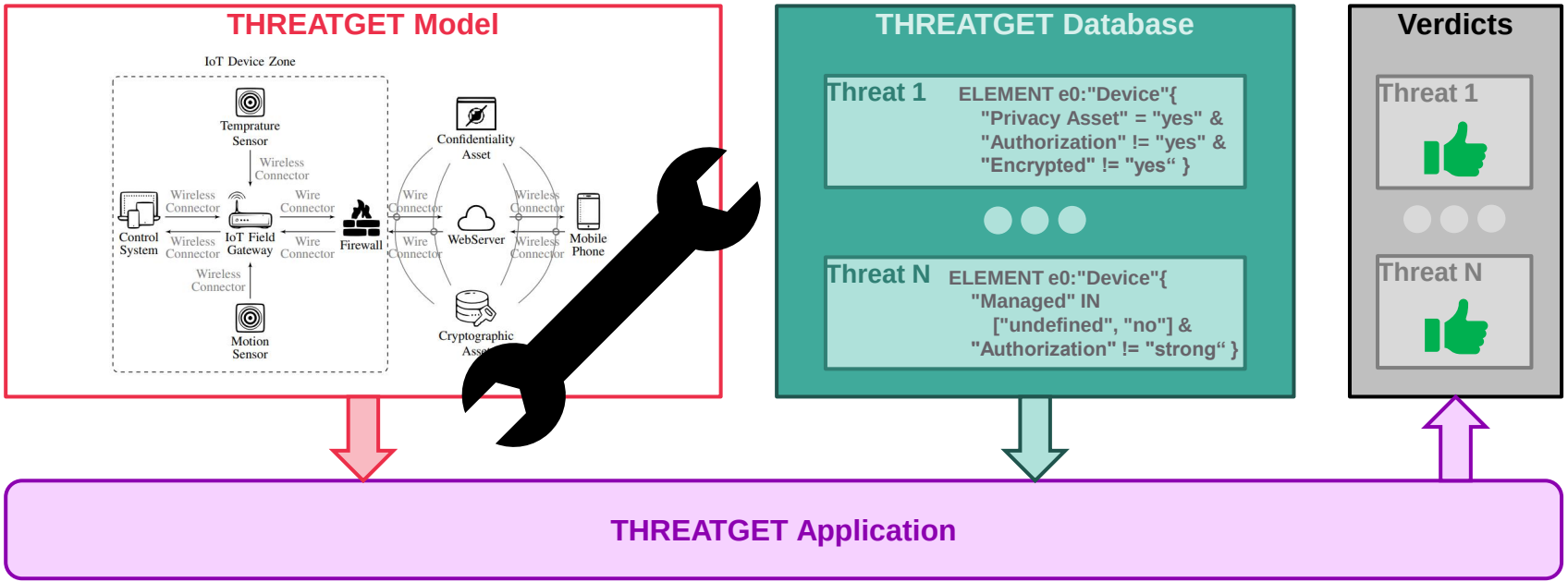
THREAT MODELING WITH THREATGET

https://www.threatget.com/



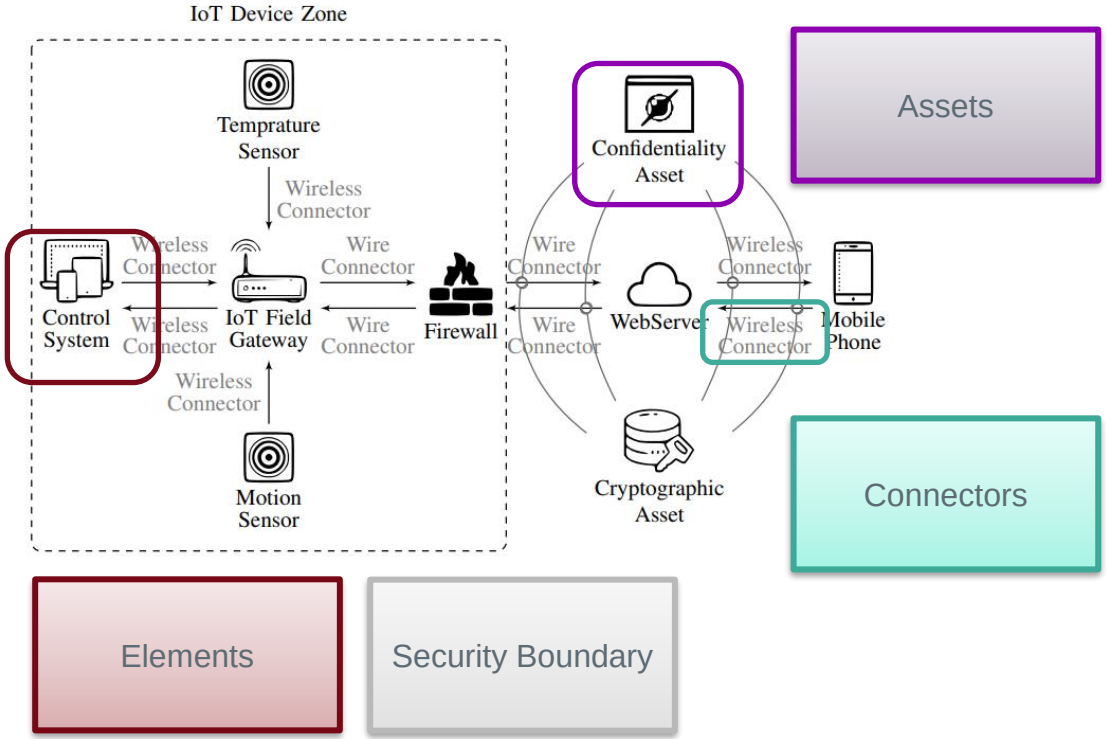
MODEL REPAIR

https://www.threatget.com/



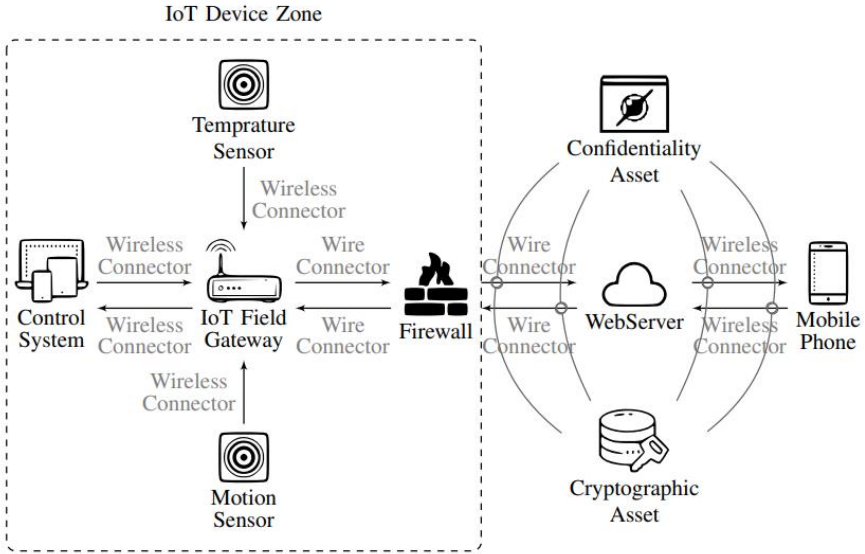
MODEL REPAIR

SYSTEM MODEL



Attribute	Value	Weight
Authentication	No	100
Encryption	Yes	10
…	…	

ATTRIBUTE REPAIR

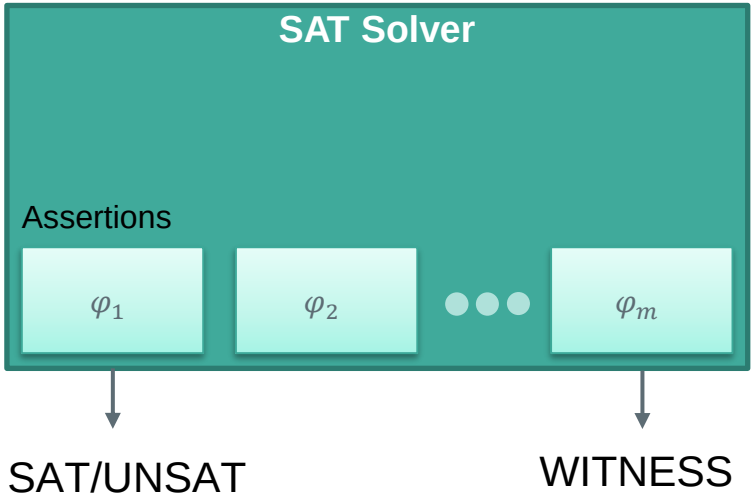


Attribute	Value	Weight
Authentication	No	100
Encryption	Yes	10
…	…	

- We repair **security attributes** of elements and connectors
- We are not allowed to changed the structure of the model

SAT

- Problem of determining if there exists an interpretation that satisfies a given Boolean formula

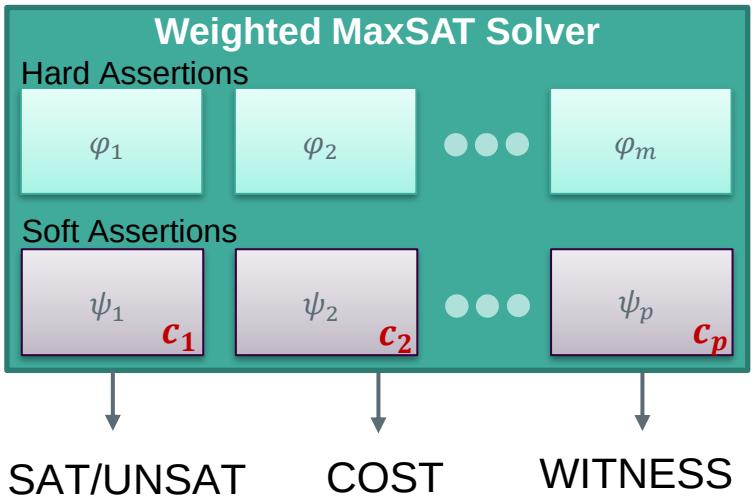


Example

$$\varphi_1 = p \wedge (q \vee r)$$
$$\varphi_2 = p \wedge (q \wedge r) \wedge (q \wedge \neg r)$$
$$solve(\varphi_1) = SAT$$
$$solve(\varphi_2) = UNSAT$$
$$witness(\varphi_1) = (p \rightarrow 1, q \rightarrow 1, r \rightarrow 0)$$

WEIGHTED MAXSAT

- Problem of determining the subset of clauses of a Boolean formula that can be made true by an interpretation and that minimizes the cost.



Weighted MaxSAT

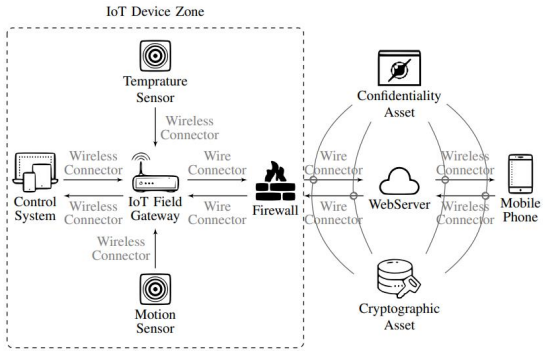
Given a set of formulas $\{\varphi_1, \dots, \varphi_m\}$ and $\{\psi_1, \dots, \psi_p\}$ and a set of real-valued costs $\{c_1, \dots, c_p\}$, weighted MaxSAT consists in finding $K \subseteq \{1, \dots, p\}$ such that:
(1) $\wedge_{i \in \{1,\dots,m\}} \varphi_i \ \wedge \ \wedge_{i \in K} \psi_i$ is SAT
(2) $\Sigma_{i \in \{1,\dots,p\}-K} \ c_i$ is minimized

$$\varphi_1 = (p \wedge q) \vee \neg r$$
$$\psi_1 = r, c_1 = 5$$
$$\psi_2 = p \wedge \neg q, c_2 = 2$$
$$solve(\varphi_1 \wedge \psi_1 \wedge \psi_2) = UNSAT$$
$$\text{max}sat\_solve(\varphi_1 \wedge \psi_1 \wedge \psi_2) = SAT$$
$$K = \{1\}$$
$$cost(\varphi_1 \wedge \psi_1 \wedge \psi_2) = 2$$
$$witness(\varphi_1 \wedge \psi_1 \wedge \psi_2) = (p \rightarrow 1, q \rightarrow 1, r \rightarrow 1)$$

ATTRIBUTE REPAIR AS WEIGHTED MAXSAT

System Model

Model Structure



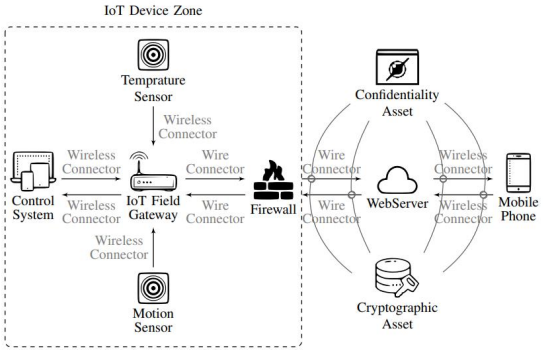
ATTRIBUTE REPAIR AS WEIGHTED MAXSAT

System Model

Model Structure

(Item, Attribute) Valuation 1

(Item, Attribute) Valuation M



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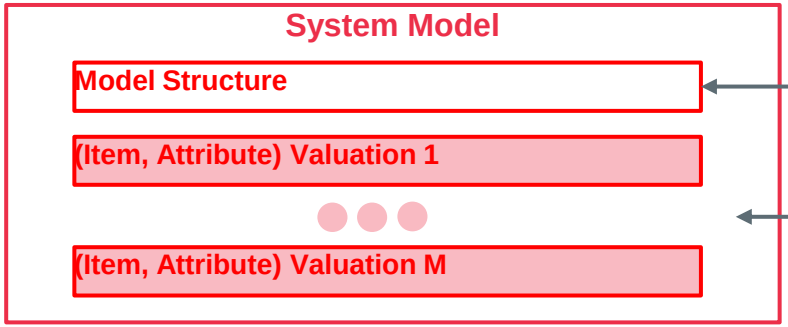
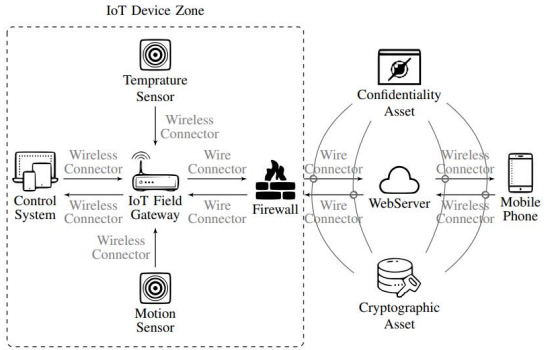
ATTRIBUTE REPAIR AS WEIGHTED MAXSAT





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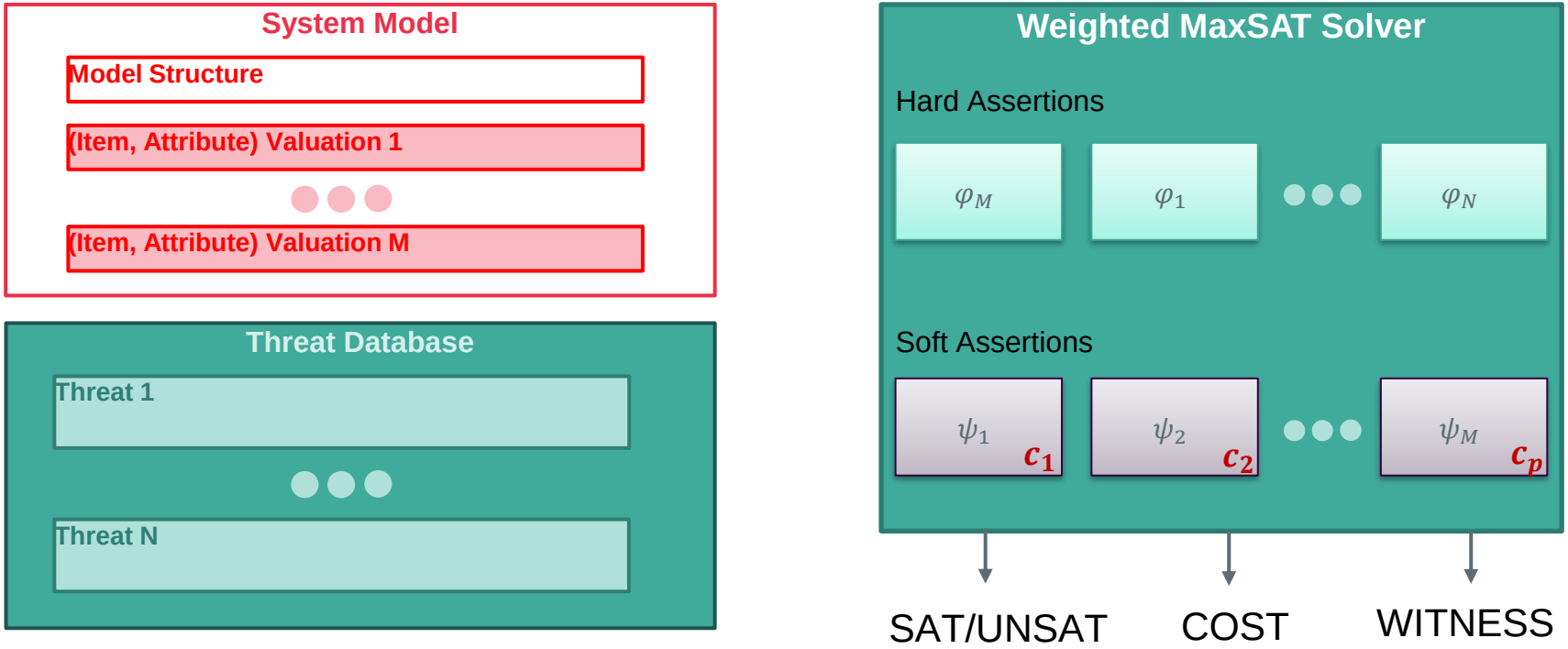

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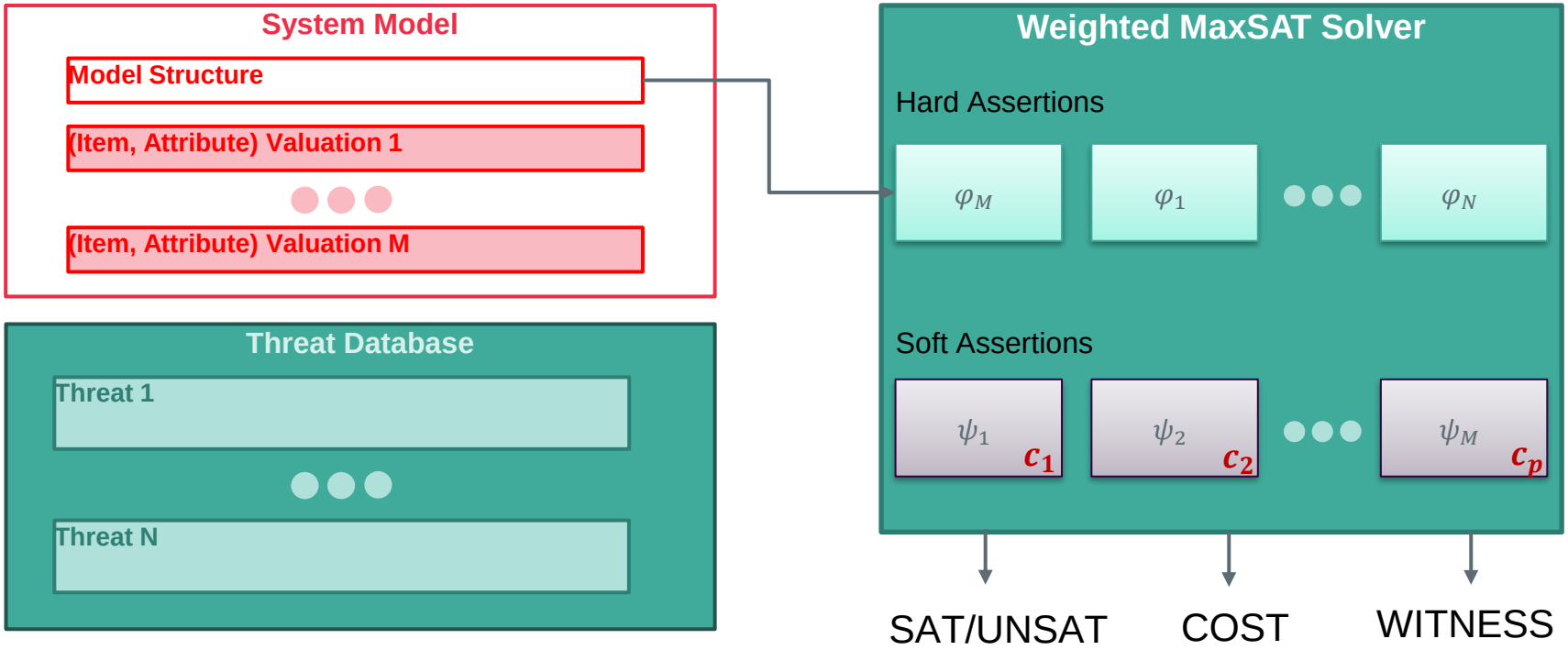

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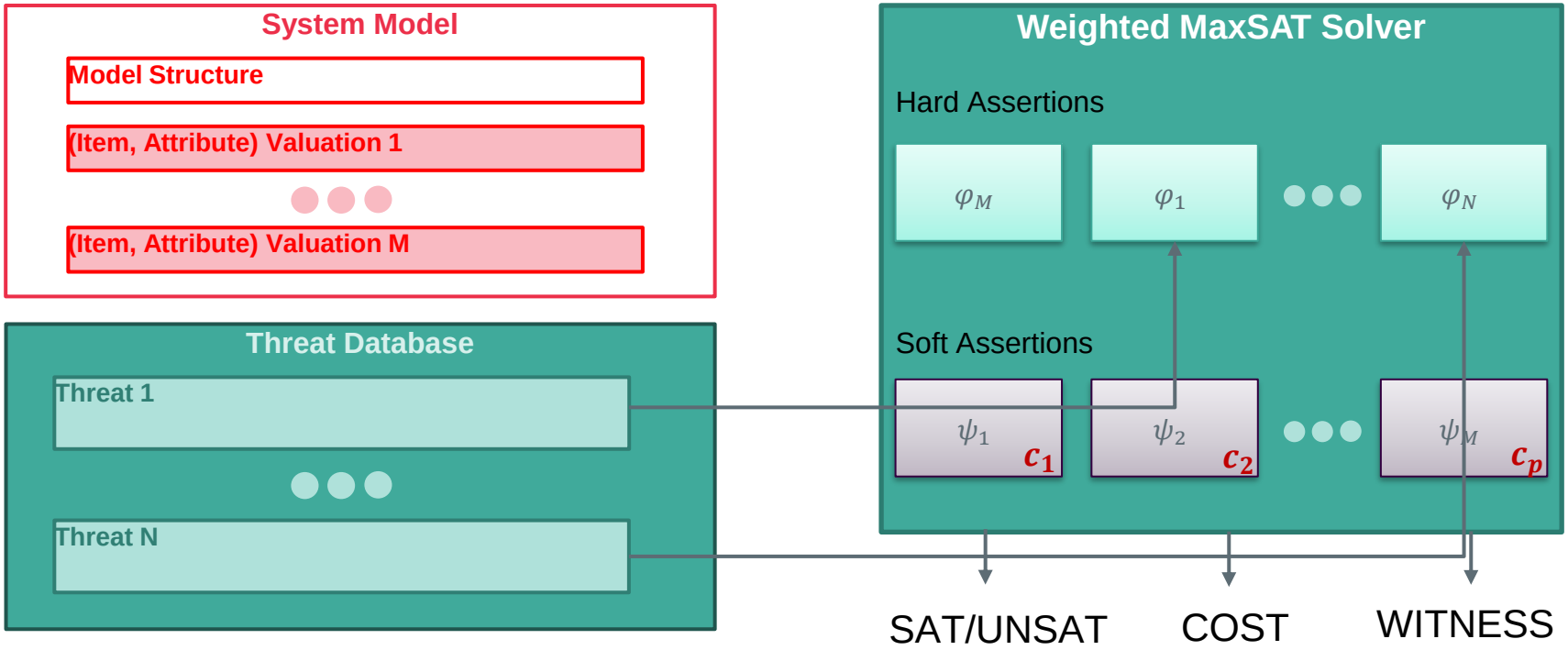
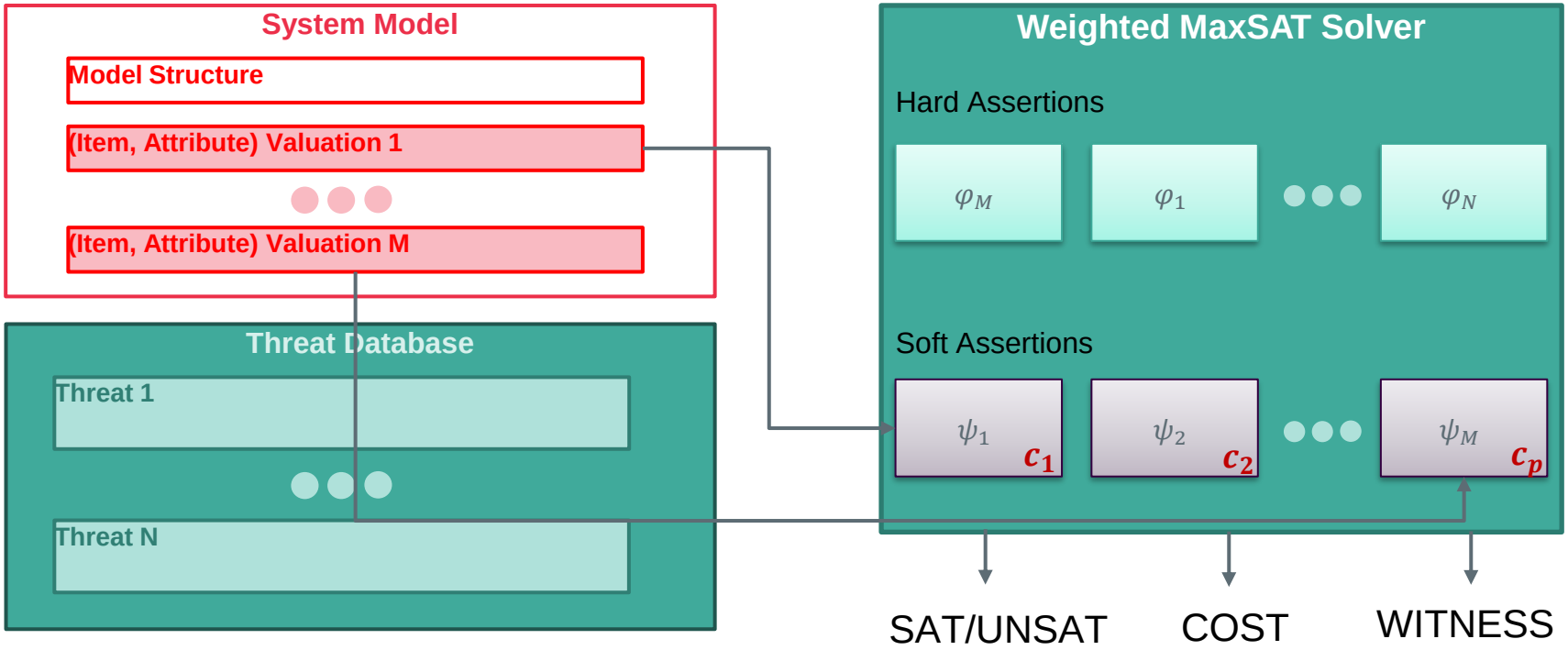
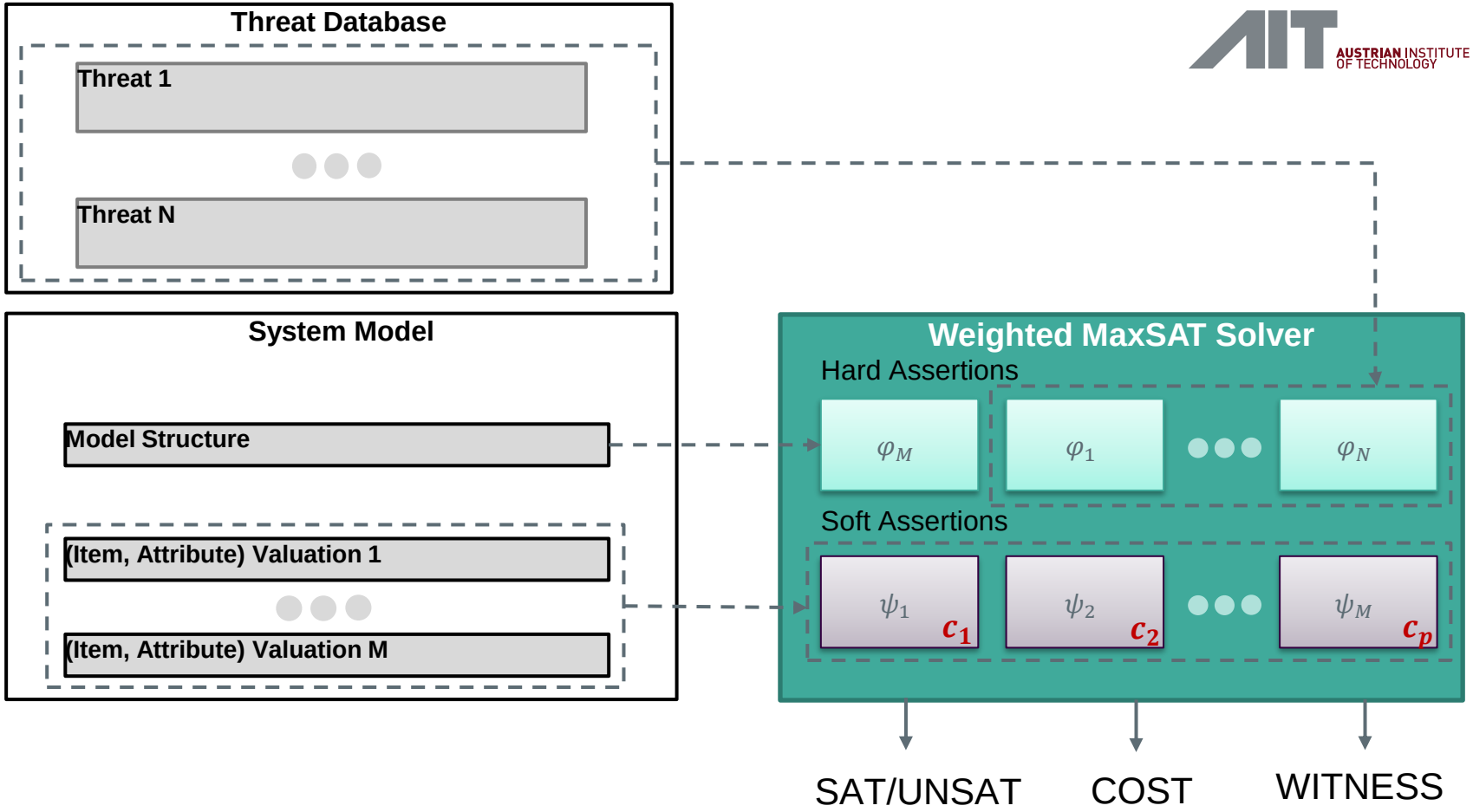
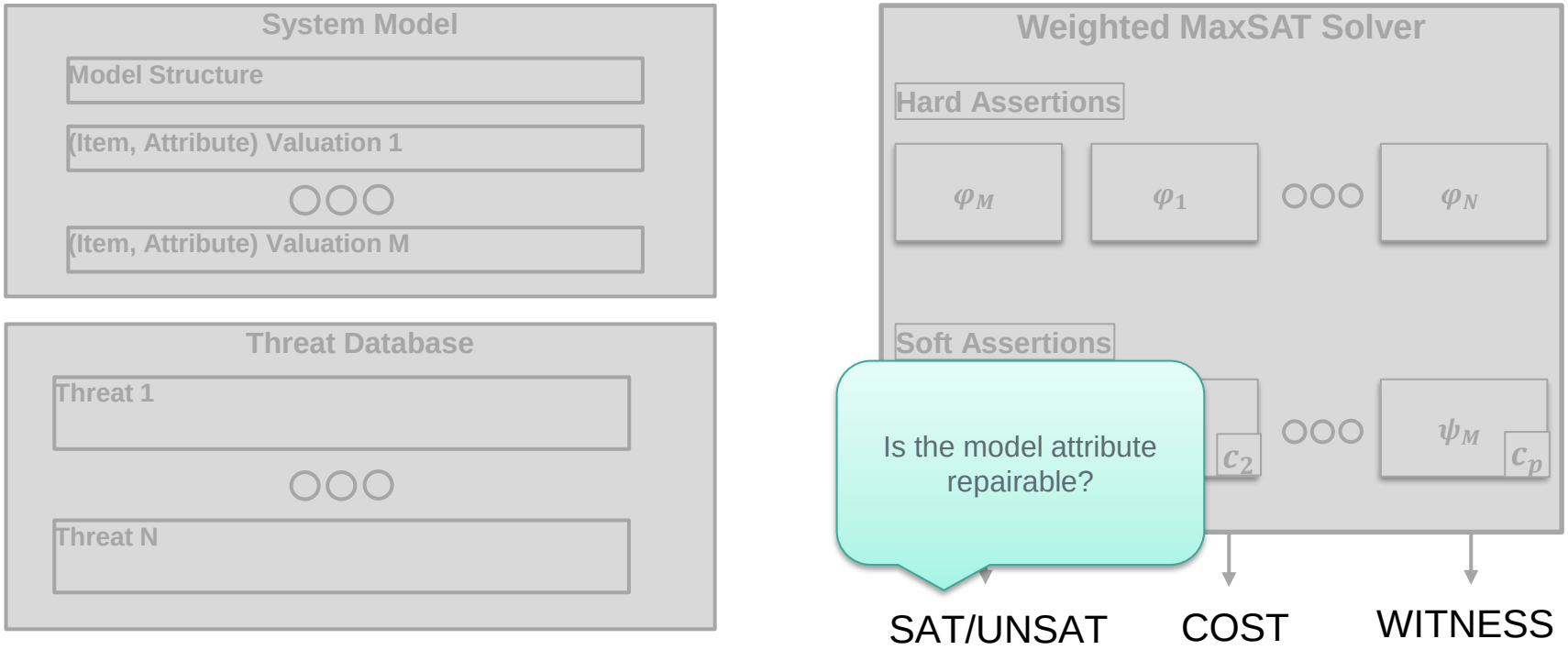


ATTRIBUTE REPAIR AS WEIGHTED MAXSAT




Threat Database
Threat 1
Threat N
System Model
Model Structure
(Item, Attribute) Valuation 1
(Item, Attribute) Valuation M
Weighted MaxSAT Solver
Hard Assertions
φ_M
φ_1
φ_N
Soft Assertions
ψ_1 c_1
ψ_2 c_2
ψ_M c_p
SAT/UNSAT
COST
WITNESS

ATTRIBUTE REPAIR AS WEIGHTED MAXSAT



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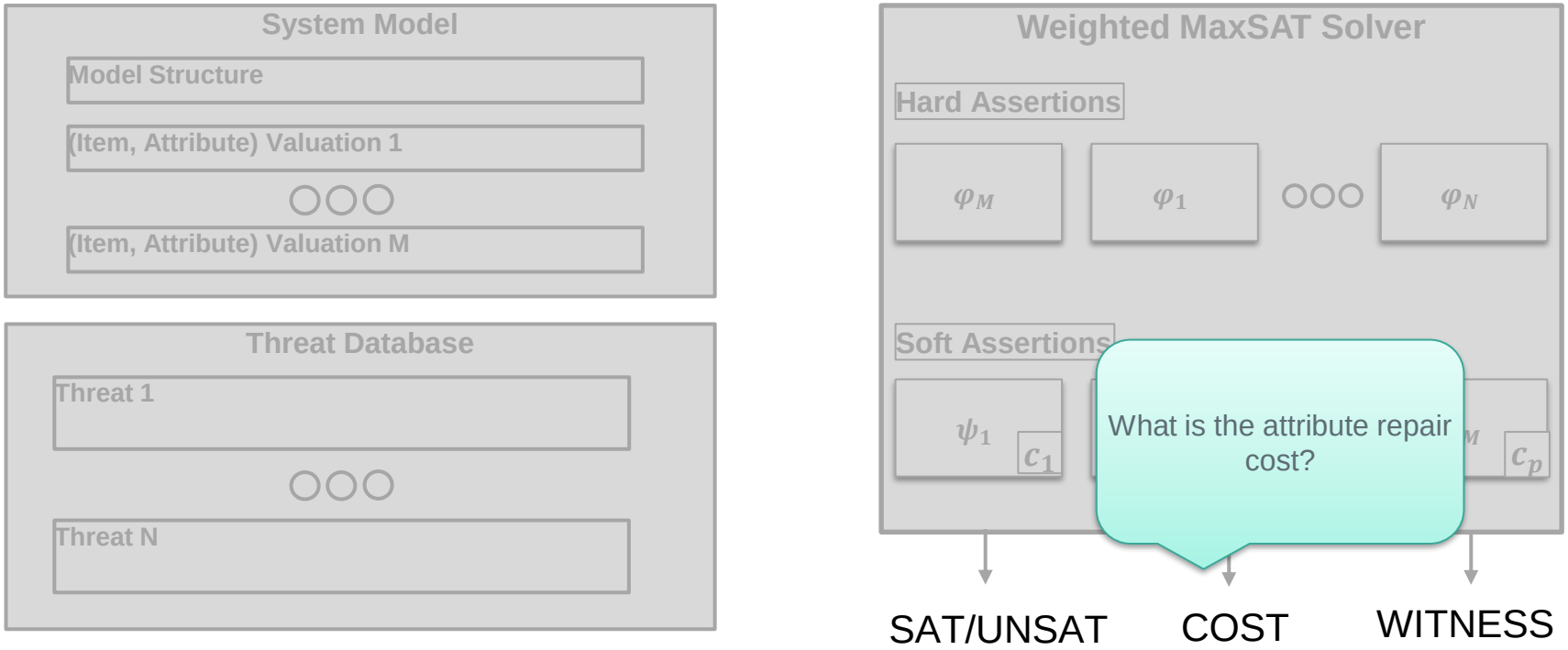

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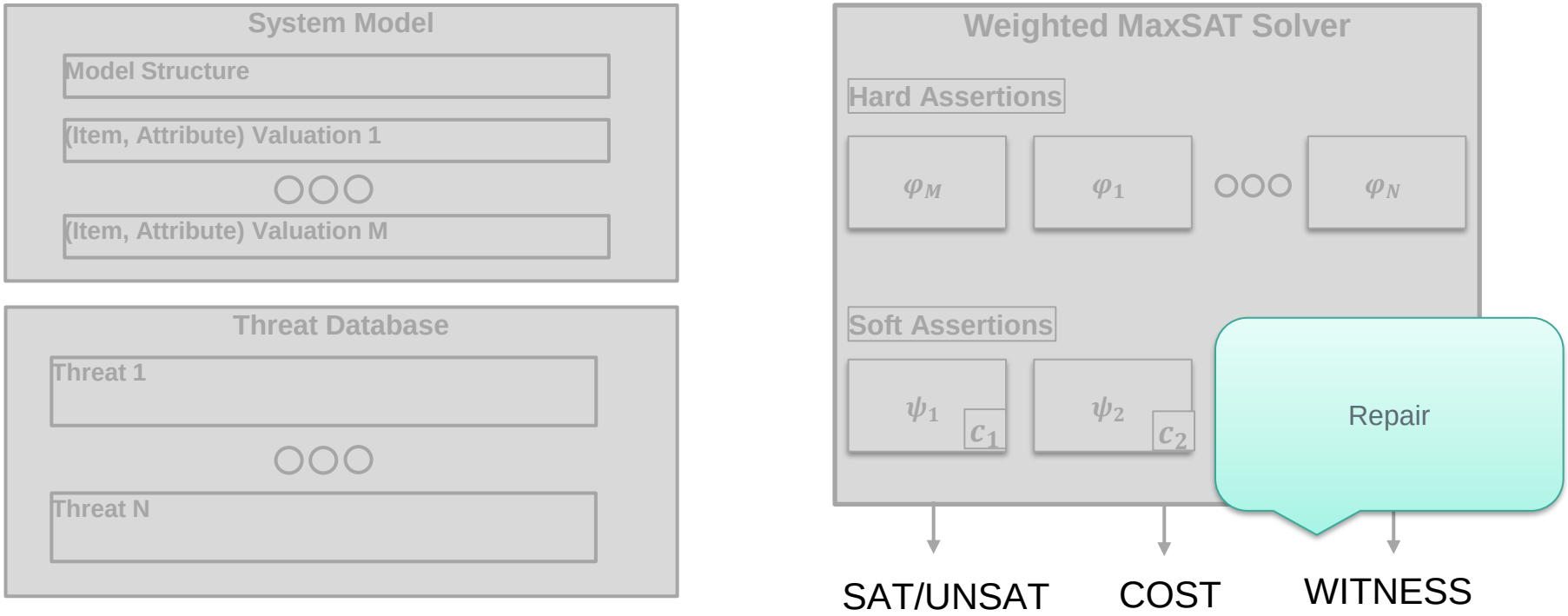

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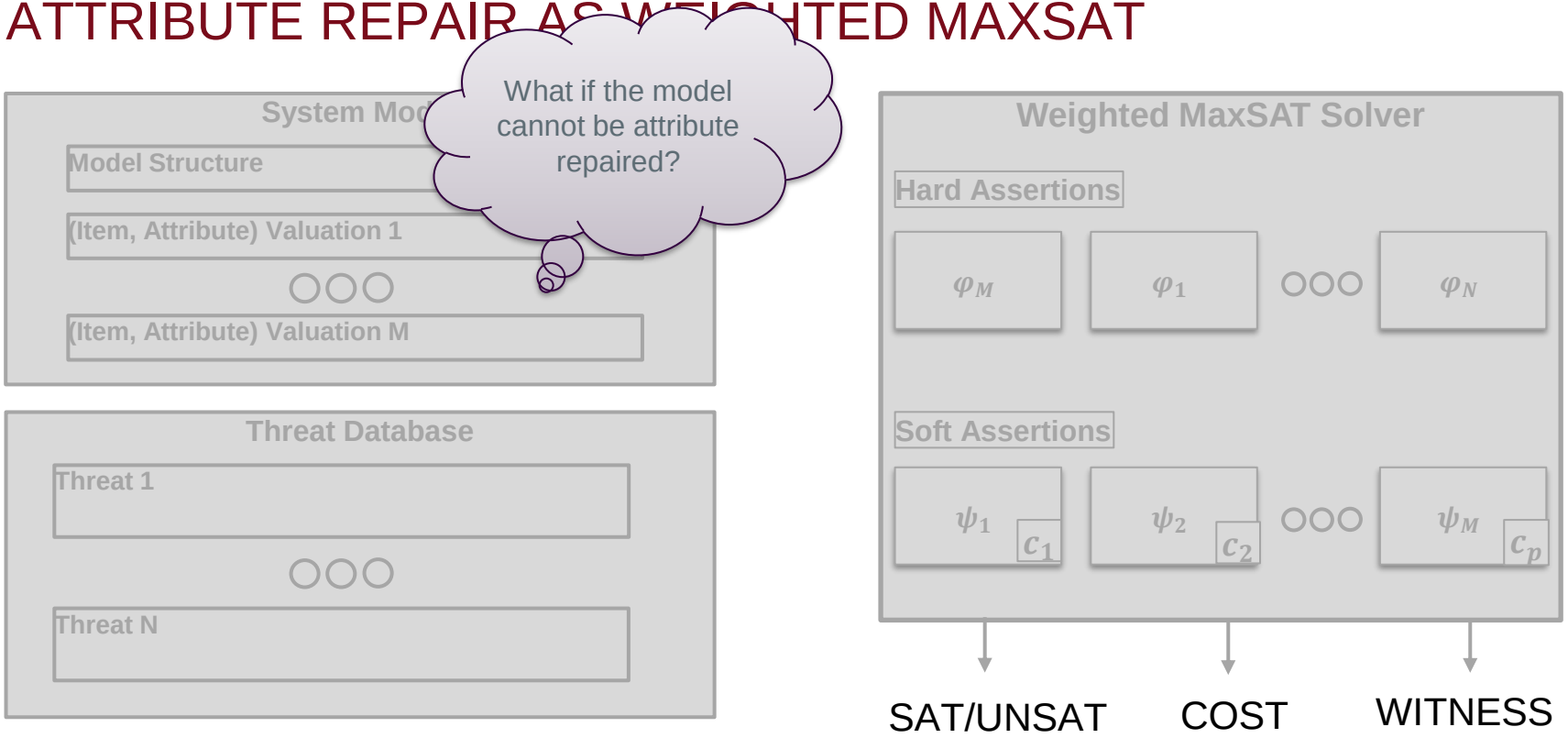

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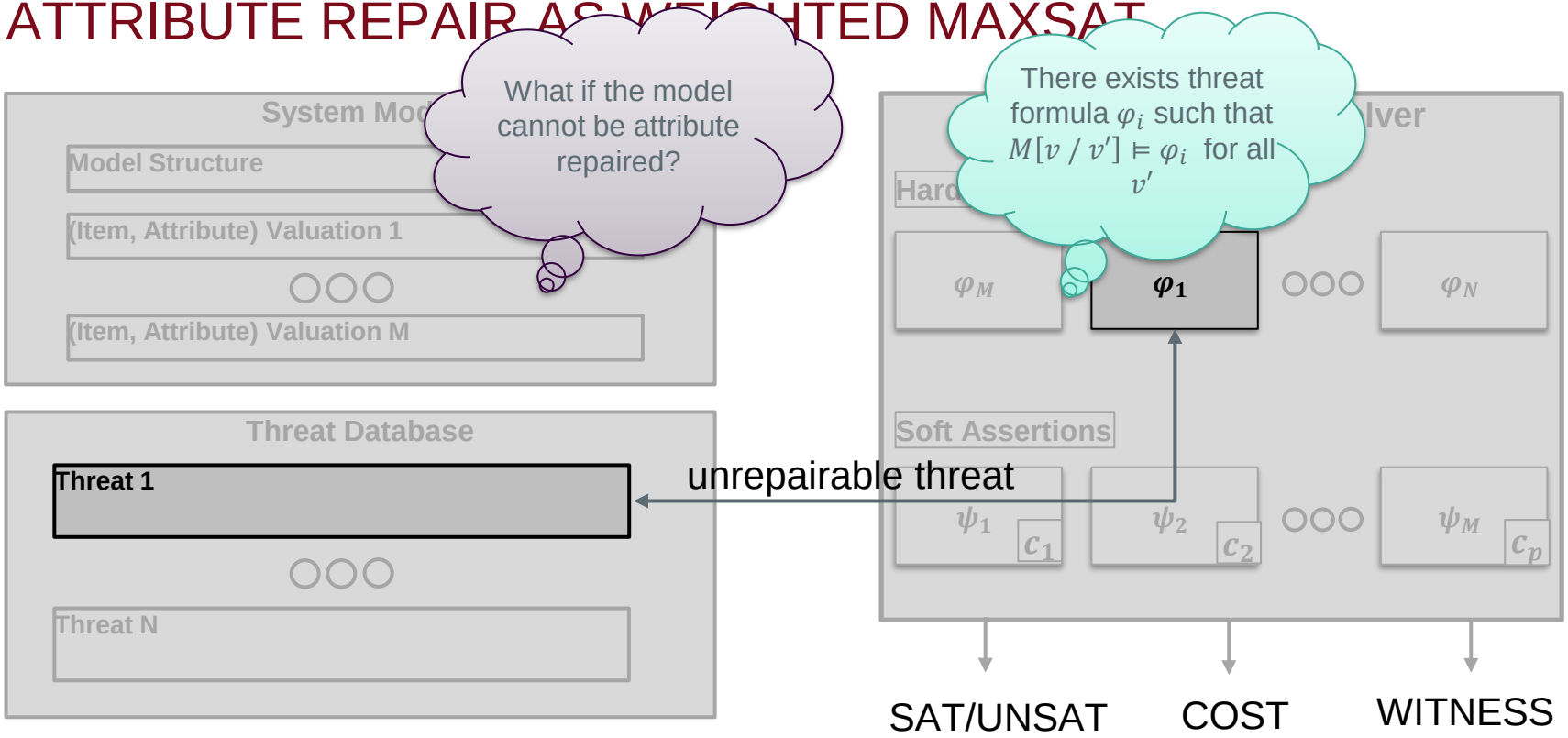

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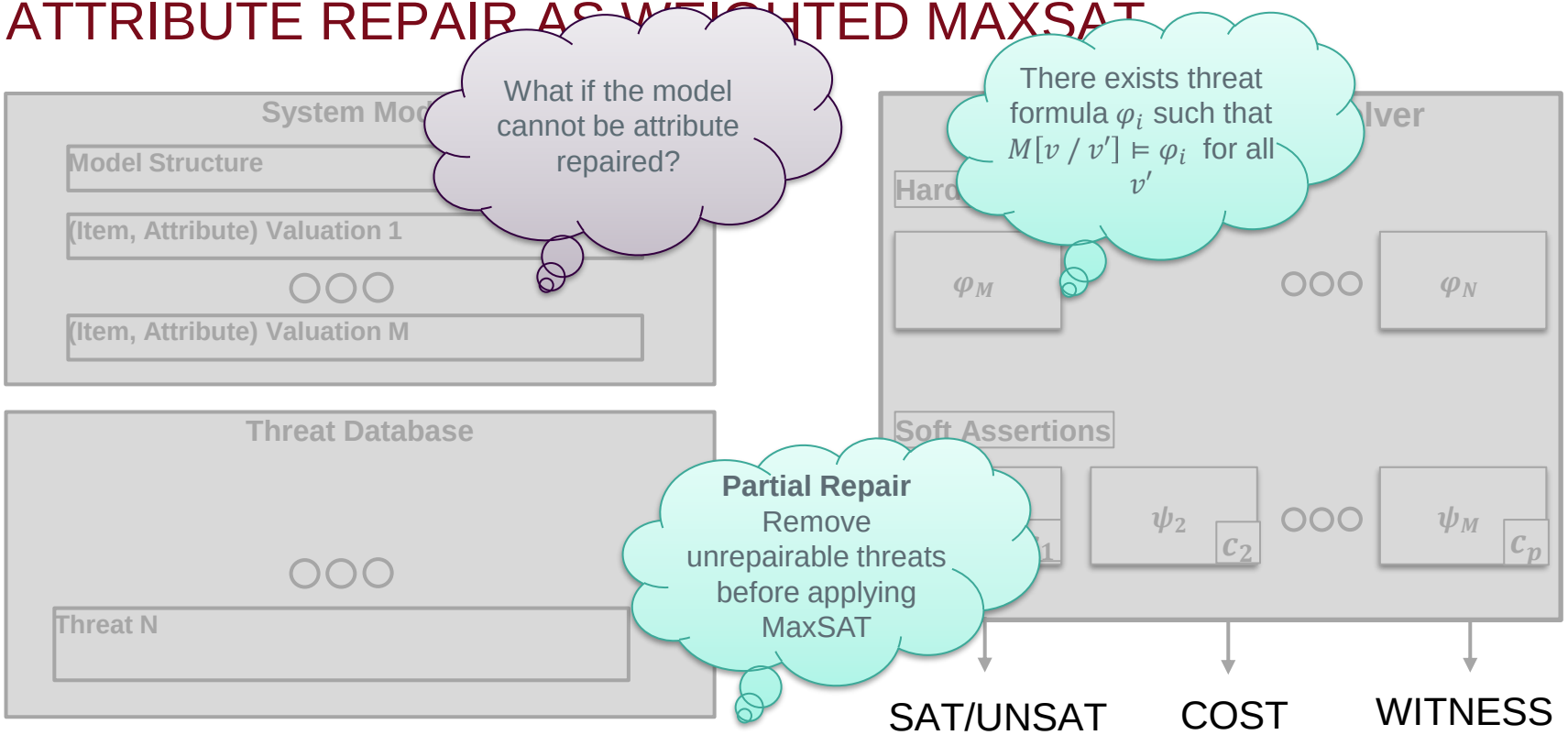

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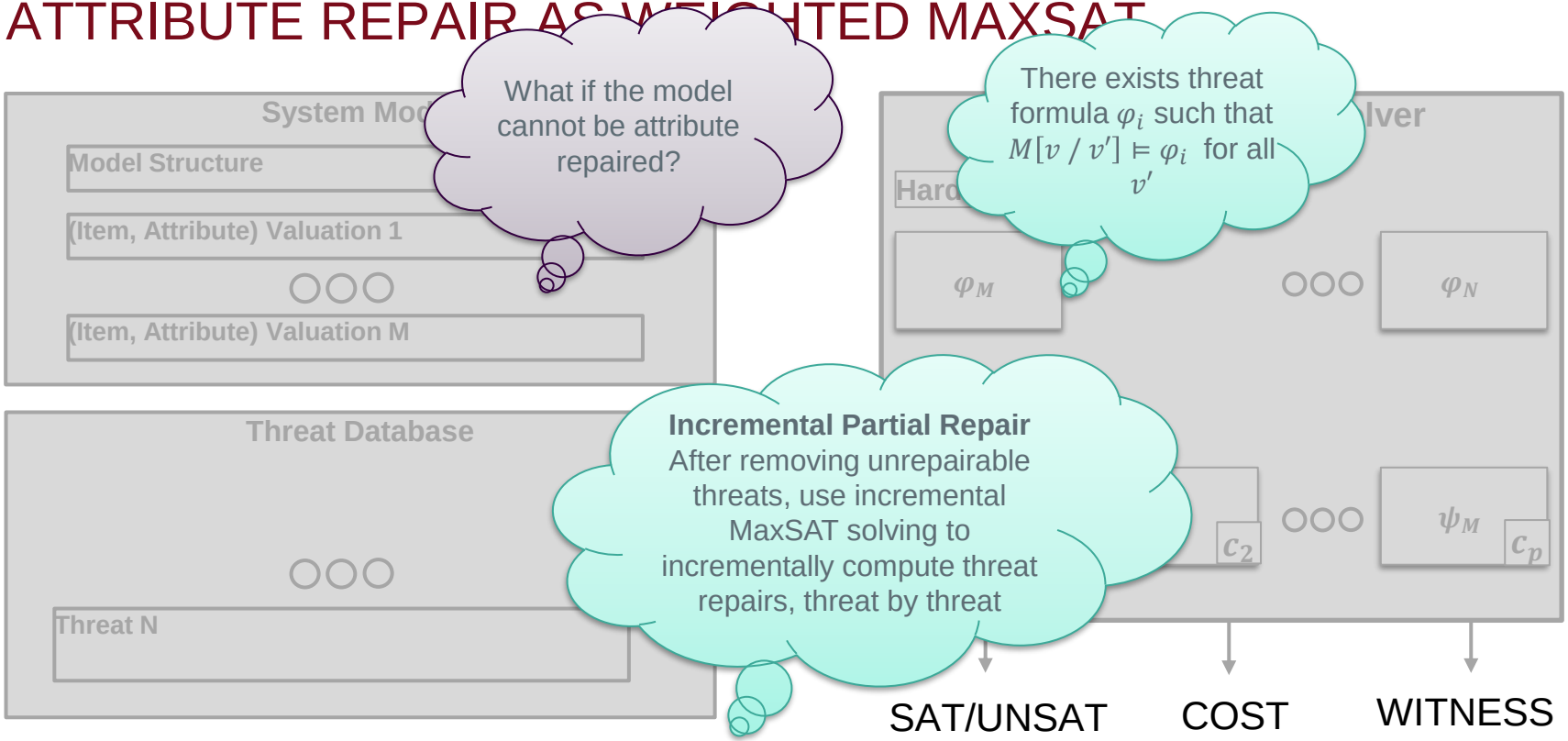
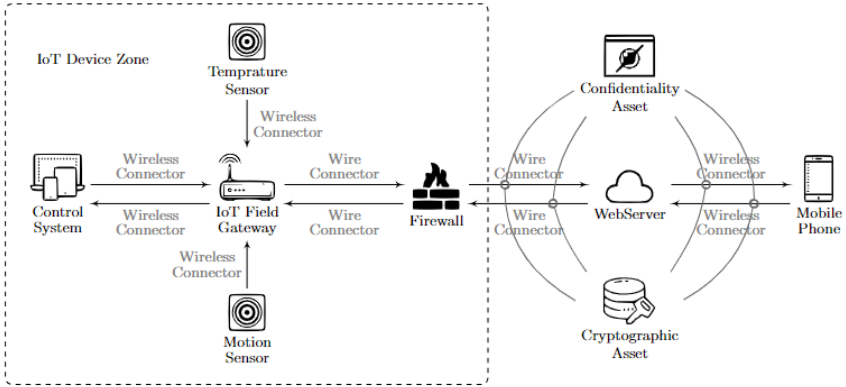


IMPLEMENTATION AND CASE STUDIES

IMPLEMENTATION

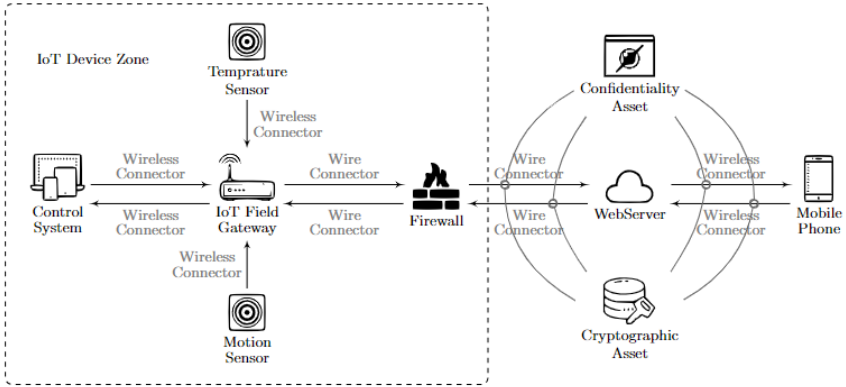
- Java implementation as an external module to THREATGET
- Z3 SMT solver used for MaxSAT

SMART HOME IOT



Verdict	SAT
# formulas (F)	169
# rep Fs	27
# unrep Fs	9
# Fs wo threat	133
Total cost	77
Time	47

SMART HOME IOT



Verdict	SAT
# formulas (F)	169
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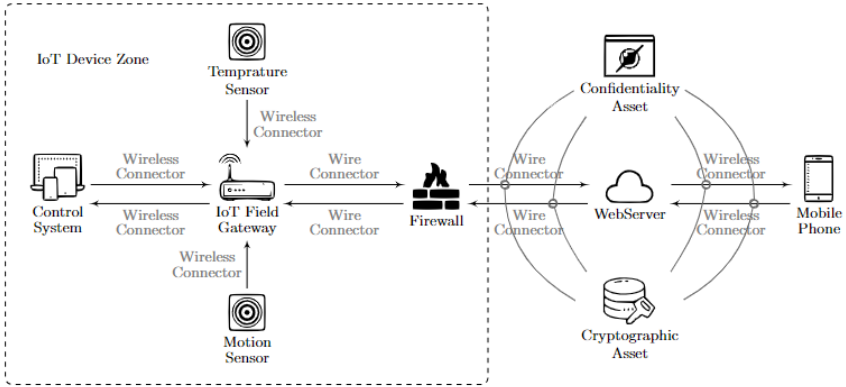
Example of repairable threat:

"Attacker can deny the malicious act and remove the attack footprints leading to repudiation issues"

$$\exists e.\, type(e) = Firewall \wedge v(e, Activity\ Logging) \in \{Missing, Undefined\}$$

Repair: set Activity Logging to Yes

SMART HOME IOT



Verdict	SAT
# formulas (F)	169
# rep Fs	27
# unrep Fs	9
# Fs wo threat	133
Total cost	77
Time	47

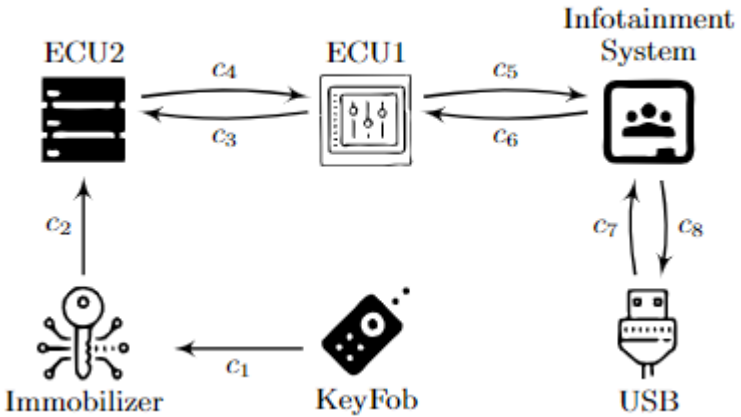
Example of unrepairable threat:

"Spoof IP"

$$\exists e_1, e_2, c.\, type(c) = Internet\ Connection \wedge src(c) = e_1 \wedge tgt(c) = e_2$$

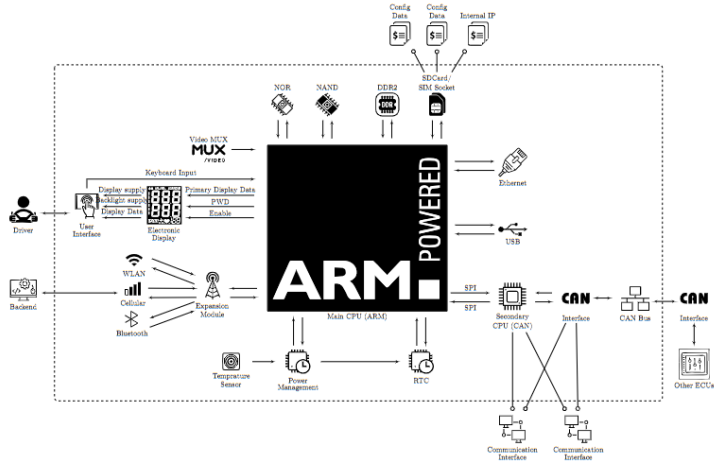
Cannot remove the internet connection with attributes

KEYFOB



	All threats		Subset	
	Full	**Heur**	**Full**	**Heur**
Verdict	UNSAT	SAT	SAT	SAT
Total # Fs	165	165	21	21
# rep Fs	n/a	25	4	4
# unrep Fs	n/a	7	0	0
# Fs wo threat	n/a	133	17	17
Cost	n/a	33	9	11
Time (s)	4	103	10	26

VEHICULAR TELEMATIC GATEWAY



Threat rule with flow (path) property

	With flow	WO flow
Verdict	SAT	SAT
Total # Fs	95	82
# rep Fs	19	18
# unrep Fs	23	21
# Fs wo threats	53	43
Cost	57	57
Time (s)	497	118

CONCLUSIONS

- Automated threat prevention
  - Repairing security-related system attributes
- Widely applicable
- SAT formulation of flows not optimal

- Model repair
  - Address limitation of attribute repair
  - Define a set of meaningful repair patterns

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TOMORROW TODAY

THANK YOU!

Lecturer, Date