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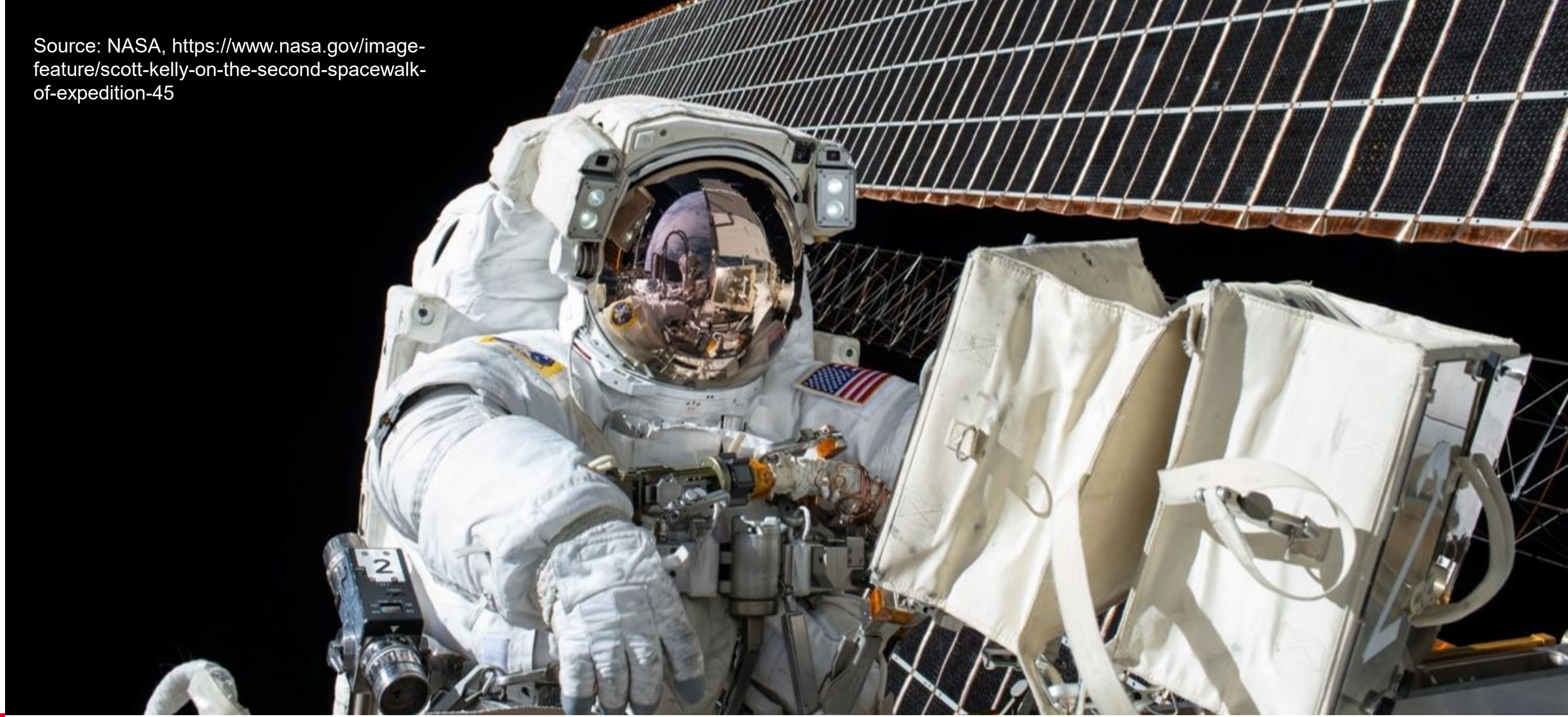
Collins Aerospace

USC Viterbi School of Engineering
Center for Cyber-Physical Systems and the Internet of Things

Presented by Timothy E. Wang and Prof. Pierluigi Nuzzo

Source: NASA, https://www.nasa.gov/image-feature/scott-kelly-on-the-second-spacewalk-of-expedition-45



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Computer-Aided Generation of Assurance Cases

SafeComp 2023, SASSUR 2023

September 19th-22nd, 2023

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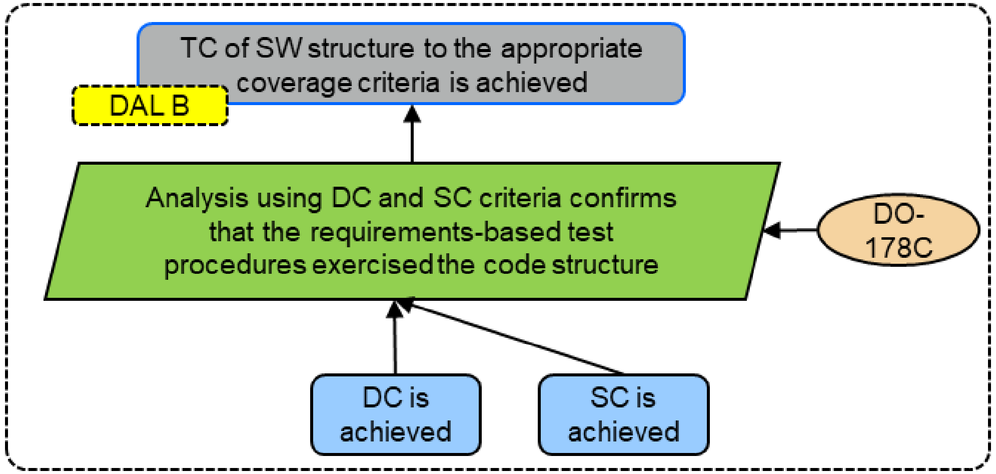
Motivation

"Moving from current process to an argument-based process…"

What is an assurance case?

Assurance cases (ACs) are explicit arguments that desired properties (safety, security, standards compliance,..) have been adequately established for a given system.



Assurance case elements: Claim, argument, and evidence or other sub-claims

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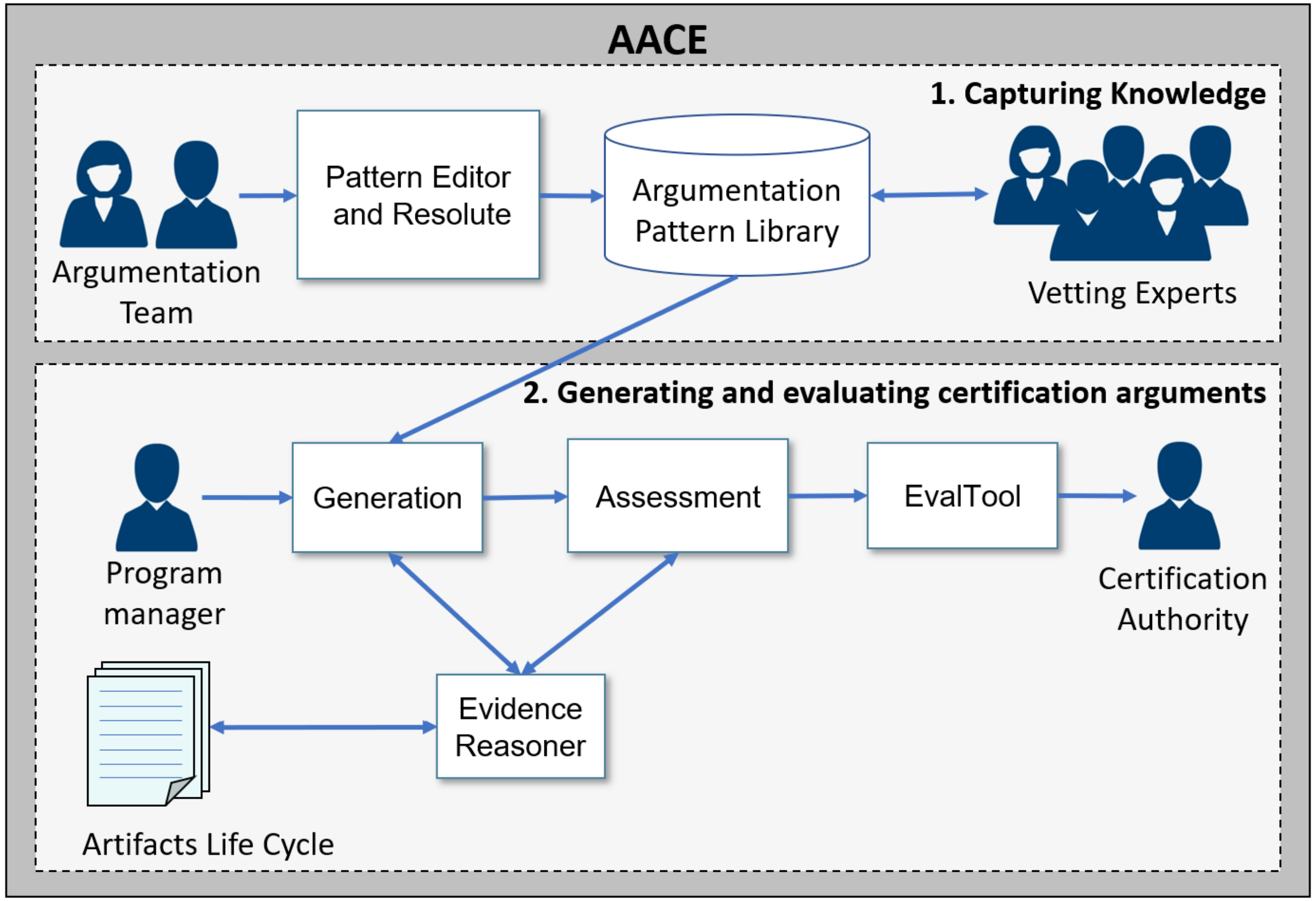
AACE: Automated Assurance Case Environment



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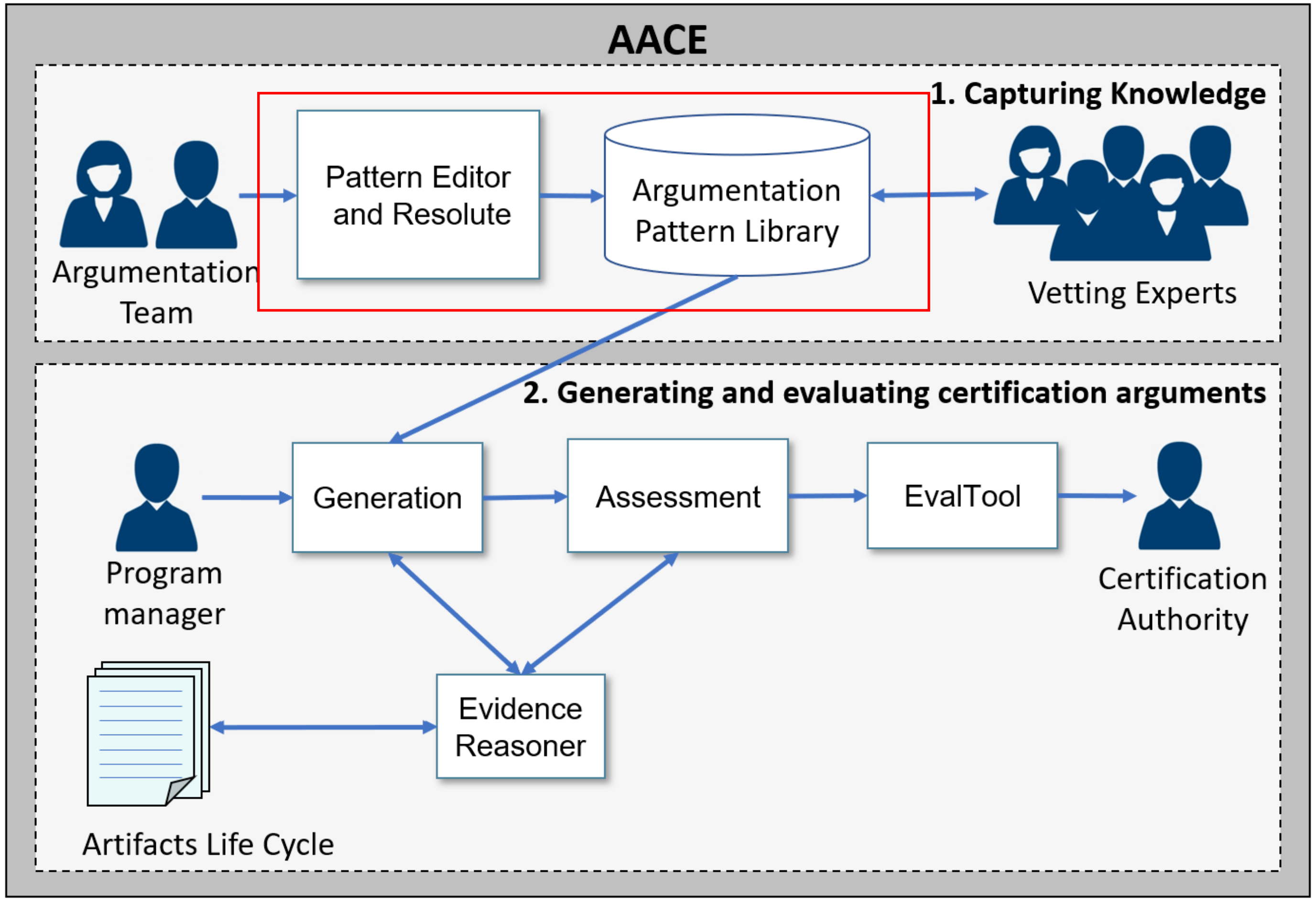

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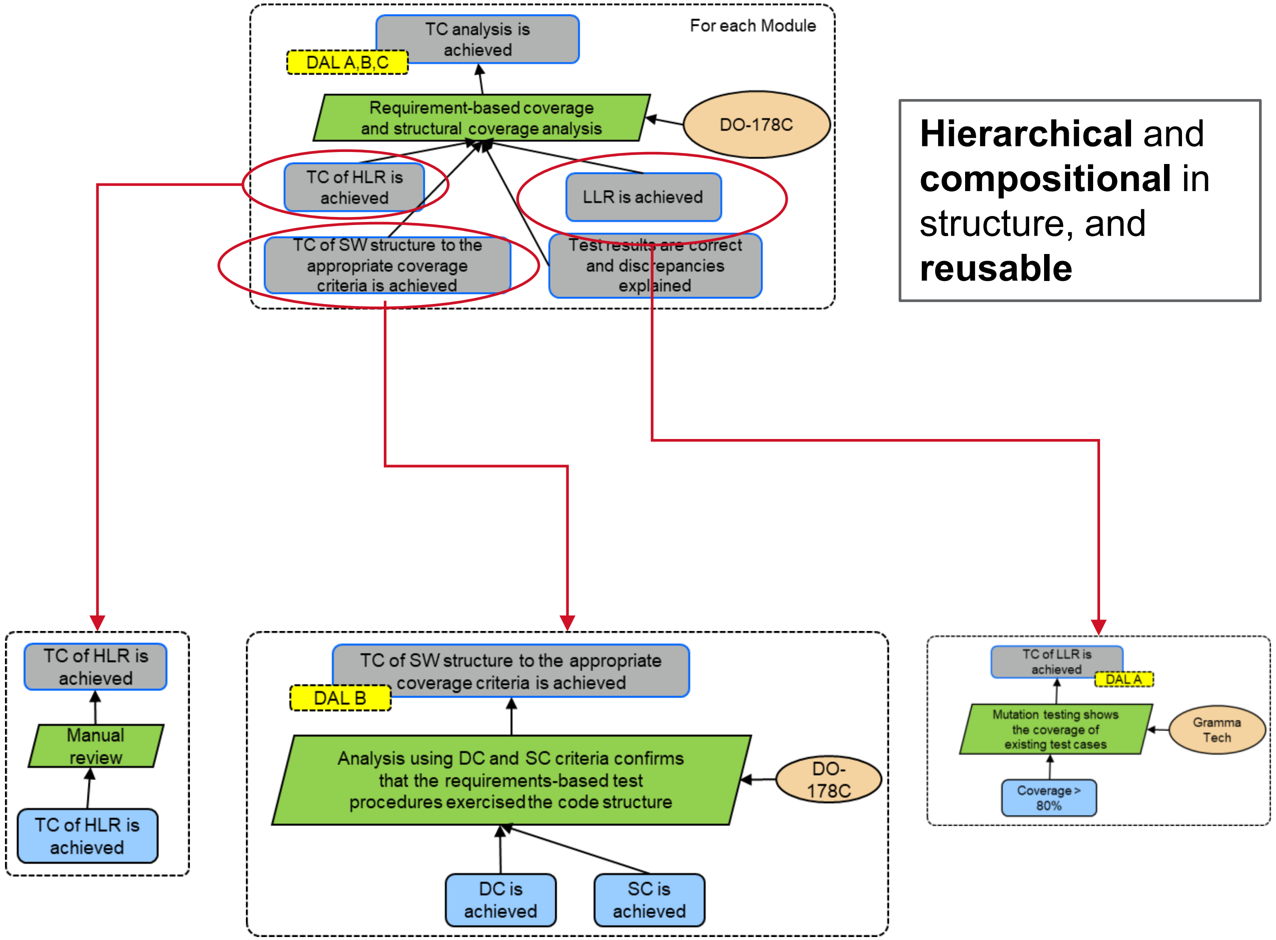
Assurance Case Patterns



Hierarchical and **compositional** in structure, and **reusable**

Assurance case argumentation pattern:

- An argumentation pattern consists of a given **claim** (or conclusion), the associated **evidence** or sub-claims and the **argument** for why the claim could be concluded in a given context or given restrictions
- Context information can be categorized into User Domain, Rationale, and Restriction, and used for automatic selection of patterns

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Formalizing Assurance Case Patterns

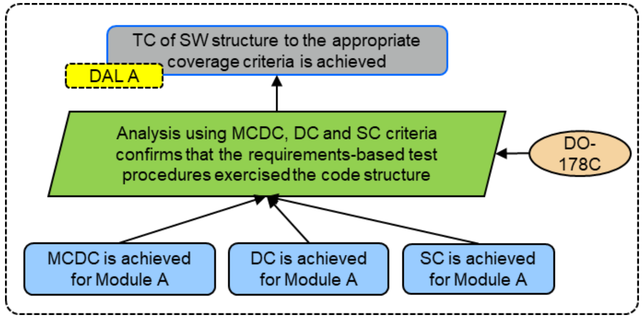
Hierarchical Contract Nets (HCN)

Human-Understandable (FAN Notation and Justification)

Believing
Structure TC of software Module A to the appropriate criteria is achieved.

Is justified by applying
DO-178C standard for DAL A software

To these premises
1. MCDC is achieved for Module A
2. DC is achieved for Module A
3. SC is achieved for Module A



Claims and restrictions

Strategy and user domain

$claim_1$
A: exists(moduleA)
G: *stc(moduleA)*

$\varphi_1 := dal(moduleA) = DALA$
$\varphi_2 := \forall\ module\ dal(module) = DALA \Rightarrow (sc(module) \wedge dc(module) \wedge mcdc(module) \Rightarrow stc(module))$

$\preccurlyeq_{\varphi_1 \wedge \varphi_2}$

$argument_1$

$subclaim_1$
A: exists(moduleA) $\wedge$ $\mathrm{dal(moduleA)} = \mathrm{DALA}$
G: *mcdc(moduleA)*

$subclaim_2$
A: exists(moduleA)
G: *dc(moduleA)*

$subclaim_3$
A: exists(moduleA)
G: *sc(moduleA)*

Argument: evidence or subclaims and relations between them

Timothy E. Wang, Zamira Daw, Pierluigi Nuzzo, and Alessandro Pinto. *Hierarchical Contract-Based Synthesis for Assurance Cases*. In NASA Formal Methods Symposium, 2022.

Capturing Knowledge

Argumentation patterns and models for uncertainty quantification and decision making

```
goal p1_testsCoverCode(s : system) <=
     ** "Tests cover the software structure for DAL A" **
     claim: testsCoverCode(s) = DALA;

     justification: "The combination of MDCDC, DC and SC coverage metrics
     guarantee that the software structure of the code is covered by the
     provided tests as required by DALA (DO-178C Table 6)";

     defeater: validSourceCode(s) and validTestCases(s);
     confidence :  coveredByMutation_GT(s, 95) and inputCoveredBy(s, 80);
     s_coveredByMCDC(s) and s_coveredByDC(s) and s_coveredBySC(s)
```

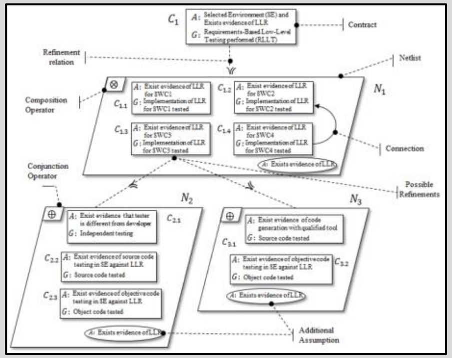
Human-Understandable Argument

Believing
Tests cover source code

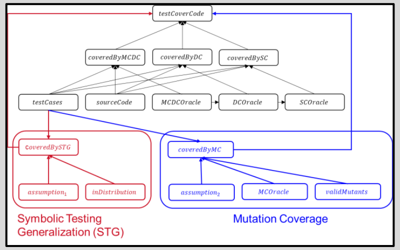
To these premises
1. MCDC is achieved
2. DC is achieved
3. Statement coverage is achieved

Confidence affected by
1. Input space is covered
2. Testing mutation coverage

Logic Argument (HCN)



Confidence Argument (BN)



- Make knowledge **reusable**
- **Vetting process** involves consensus among different experts
  - Elicitation process
  - Validation process
  - Formal methods to verify validity of the patterns

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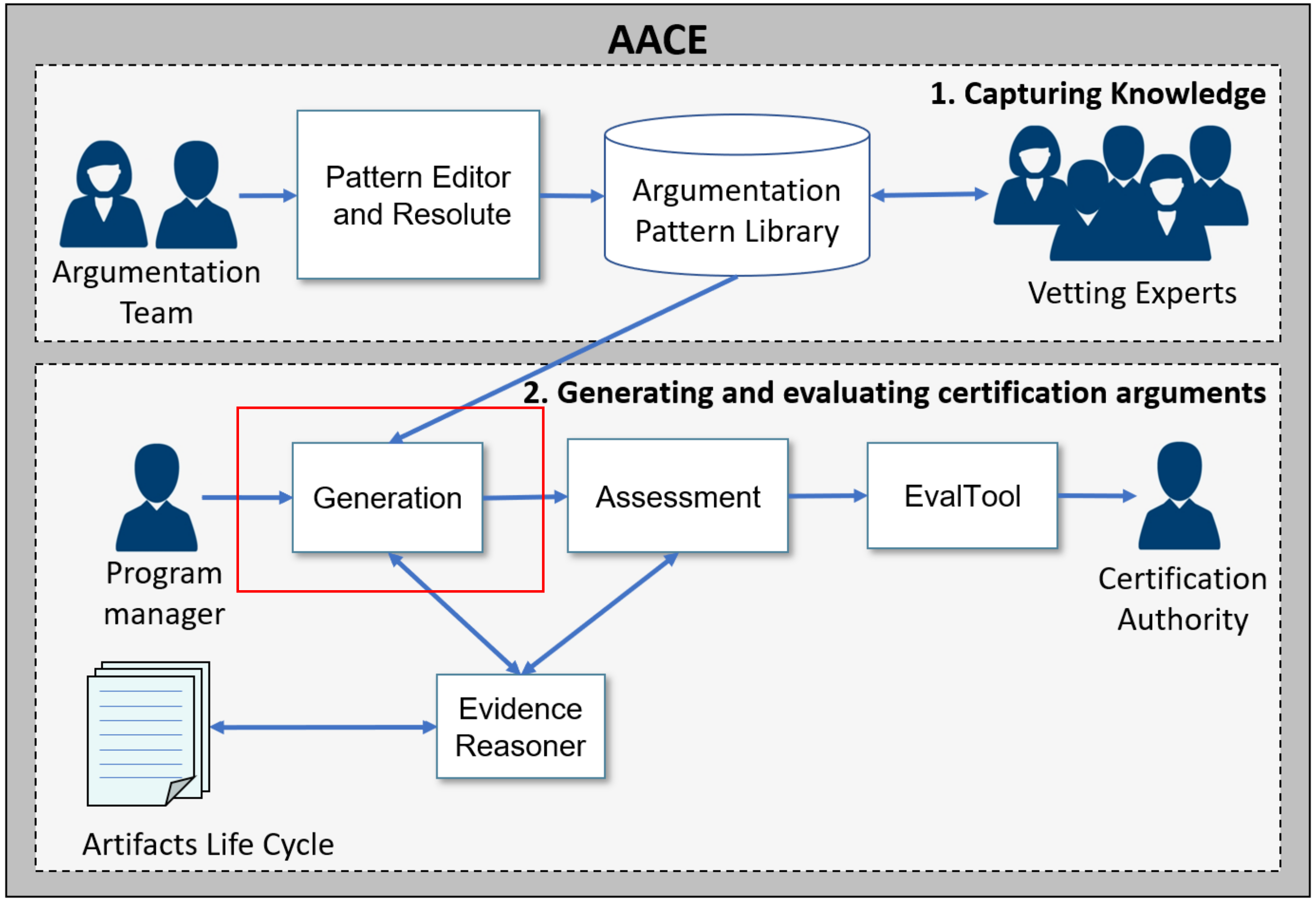

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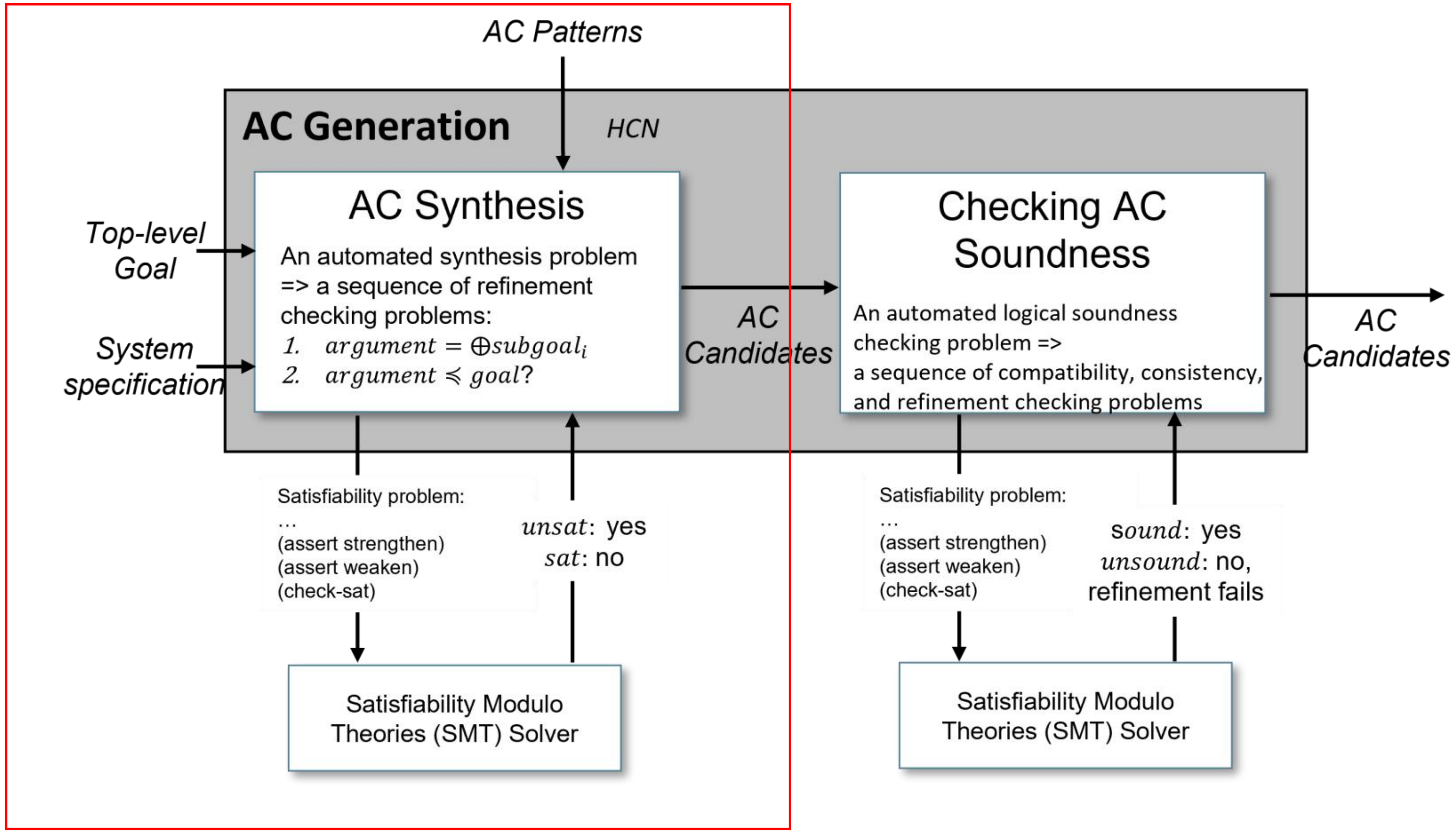
Generating Certification Arguments



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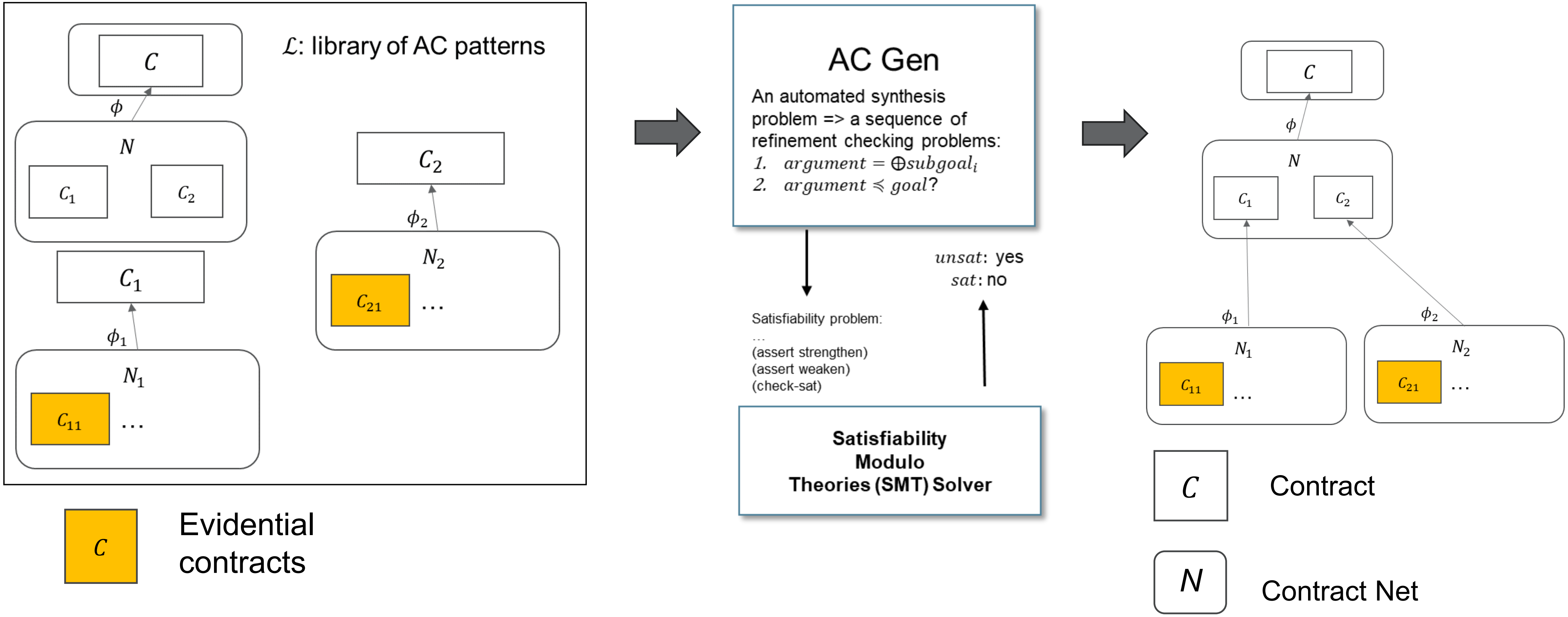
Automatic Synthesis



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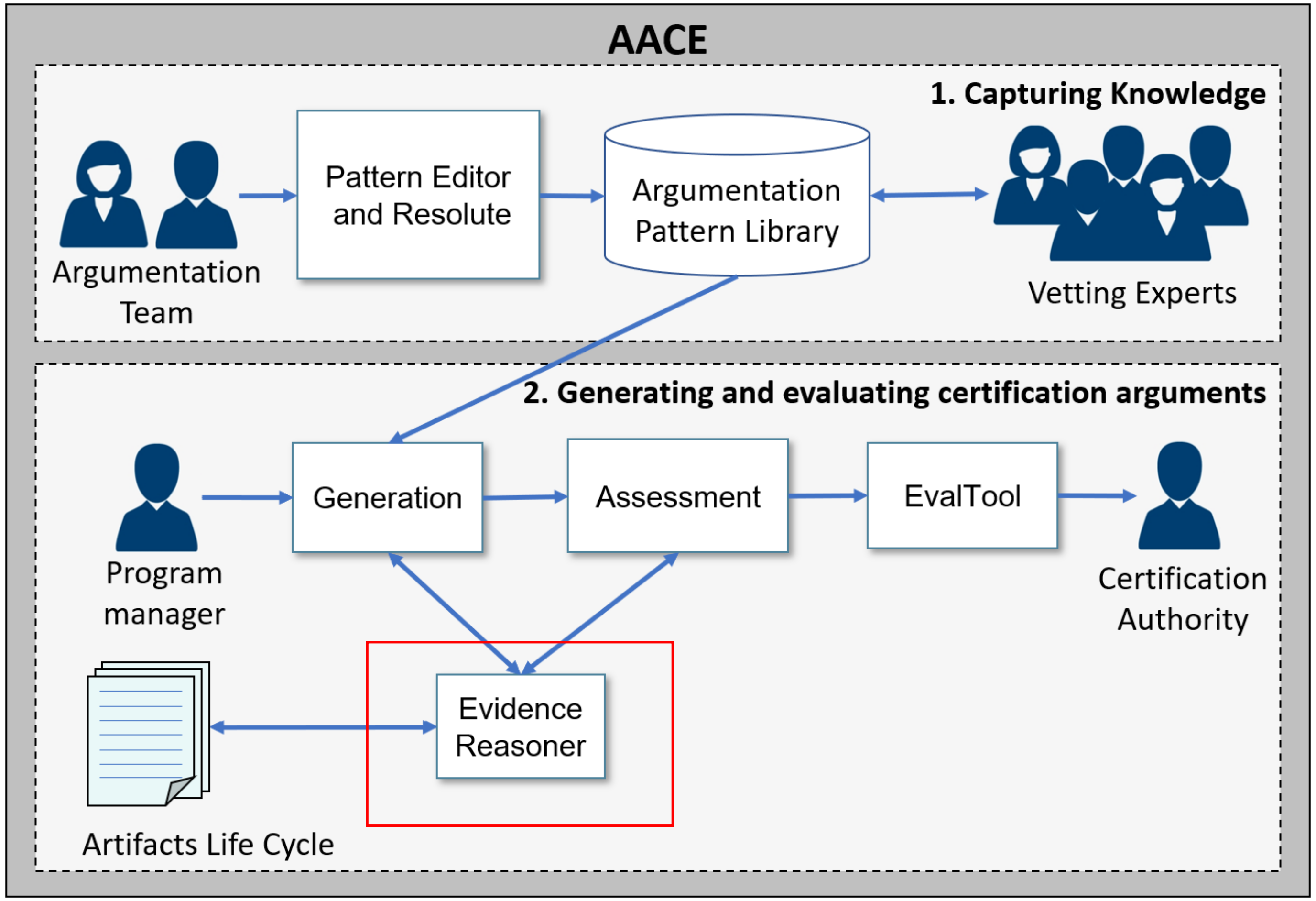

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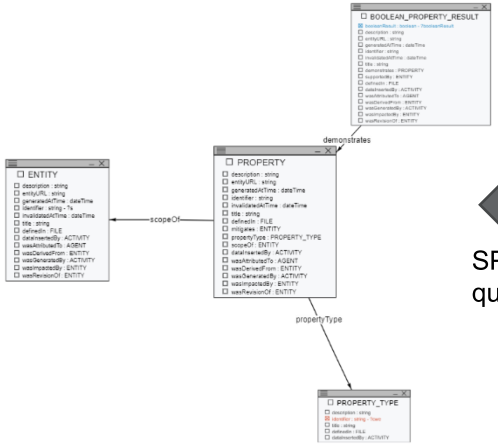
Reasoning About Certification Artifacts

- Evidence produced during the entire lifecycle is captured in an ontology database
- The ontology defines key software certification concepts such as Component, Requirement, Tests,…
- An ontology reasoner between the assurance case generation and the evidence extraction allows a varied source of evidence and pre-analysis to identify inconsistencies and conflicts
- Currently, we are using as ontology-based database known as RACK

Heterogeneous evidence extraction

Ontological model of evidence (GE RACK)



SPARQL queries

Evidence as premises, defeaters, and sources of doubt

Add

Index	Description
1	MCDC Coverage for module is achieved.
2	SC Coverage for module is achieved.
3	DC Coverage for module is achieved.
4	Absence of buffer overflows in the module.
5	Unless the hardware encryption is not secure.
6	Requirement A-7 is satisfied.
7	Requirement coverage is satisfied.
8	The analysis is sound and complete.

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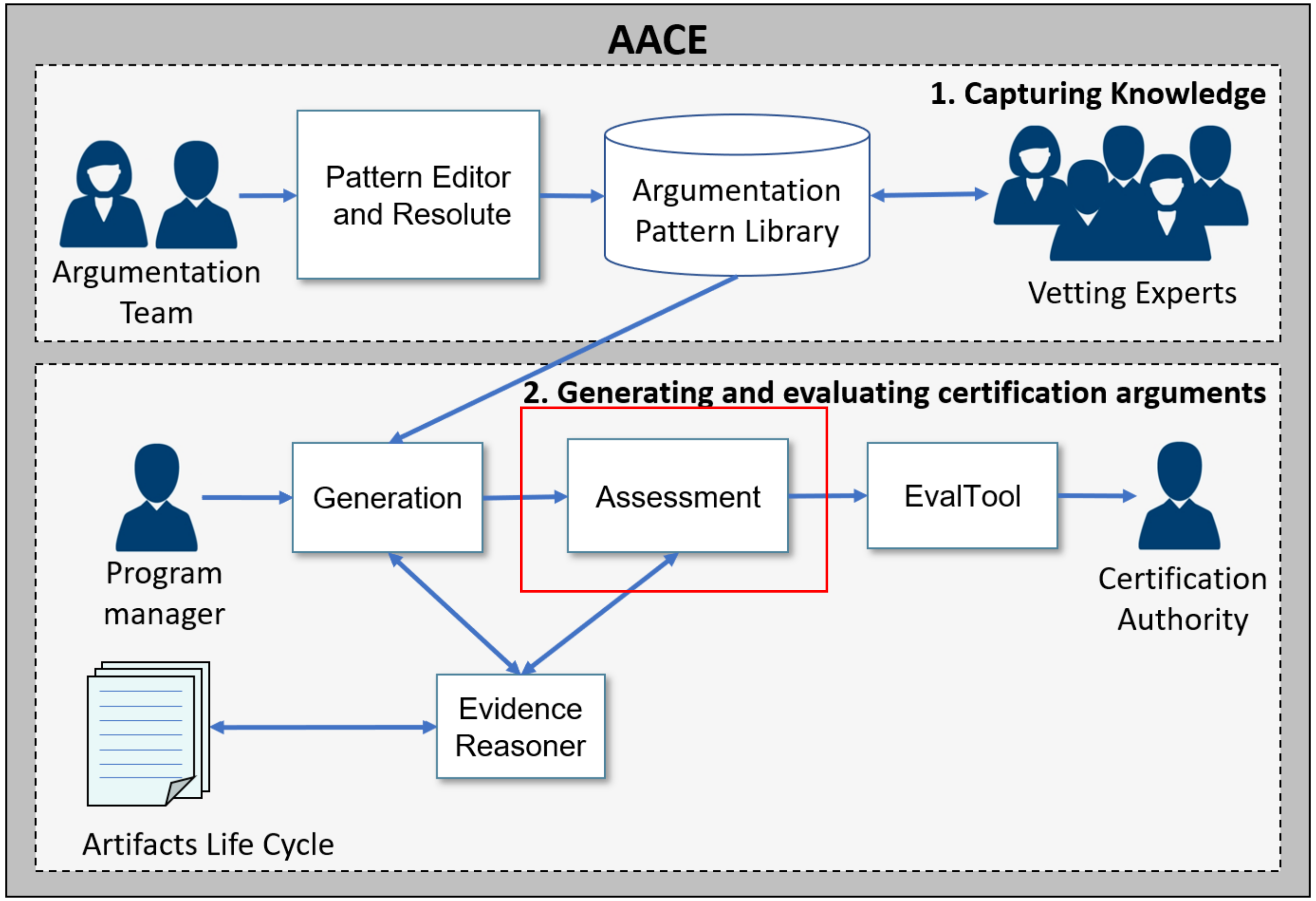

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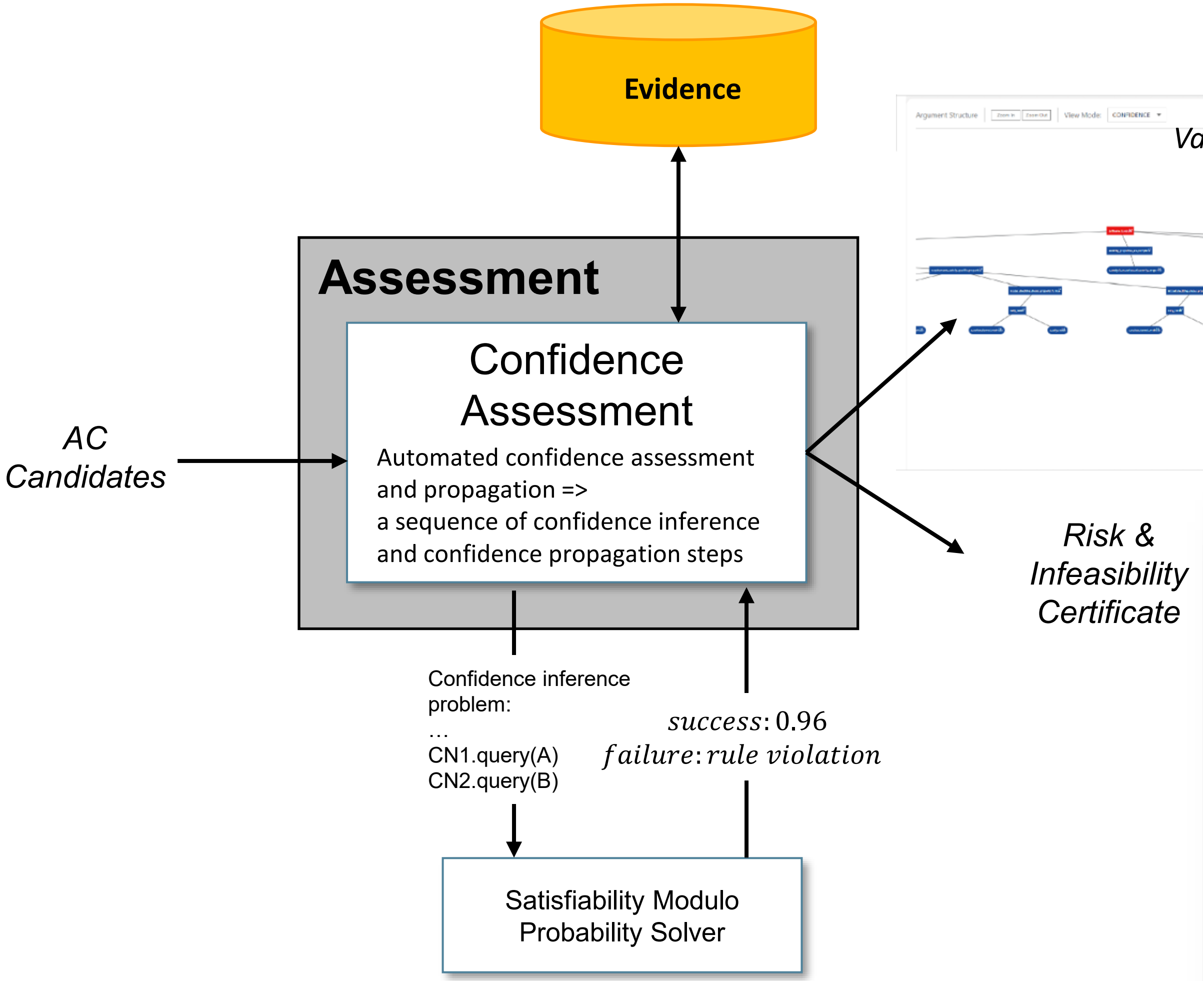
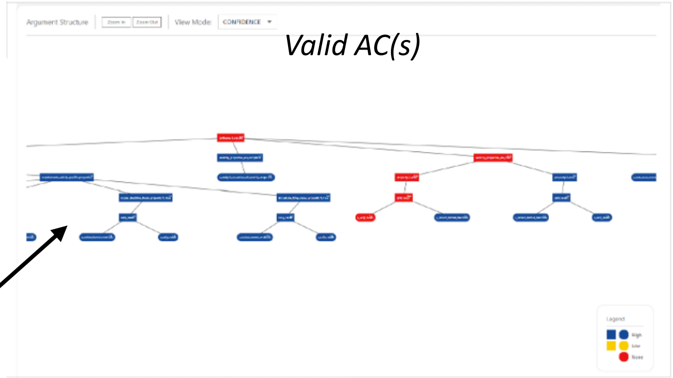
Assessing Certification Arguments





Completion Metric:
Select valid arguments with minimum number of ”missing” evidence items

Algorithm 1: $\textsc{AssessConf}(T, \mathcal{E}, \mathcal{W}, \mathbf{R})$

input : Top-level refinement $T = (C_r, \varphi_r, N_r)$; library of confidence networks $\mathcal{E}$; library of decision rules $\mathcal{W}$; set $\mathbf{R}$ of HCN refinements.

output: Confidence $\mathcal{P}(C_r)$, $\perp$ if assessment fails; infeasibility certificate *cert*.

$cert \leftarrow \perp$ and $\mathcal{P}, Q \leftarrow \perp$
for $C \in N_r$ **do**
  $R_{curr} \leftarrow \perp$
  for $R = (C_u, \varphi, N_l) \in \mathbf{R}$ **do**
    if $C = C_u$ **then** $R_{curr} \leftarrow R$; break;
  if $R_{curr} = \perp$ **then**
    $\mathcal{P}(C) \leftarrow \textsc{InferConf}(C, \mathcal{E})$
  else
    $\mathcal{P}(C), certificate \leftarrow \textsc{AssessConf}(R_{curr}, \mathcal{E}, \mathcal{W}, \mathbf{R})$
    if $\mathcal{P}(C) = \perp$ **then** **return** $\perp$, *cert*
$Q \leftarrow \textsc{DecideConf}\ (\mathcal{P}, \mathcal{E}, \mathcal{W})$
if $Q = \perp$ **then** **return** *null*, *cert*
else **return** $\textsc{PropagateConf}(\mathcal{P}, R_{curr})$, *cert*

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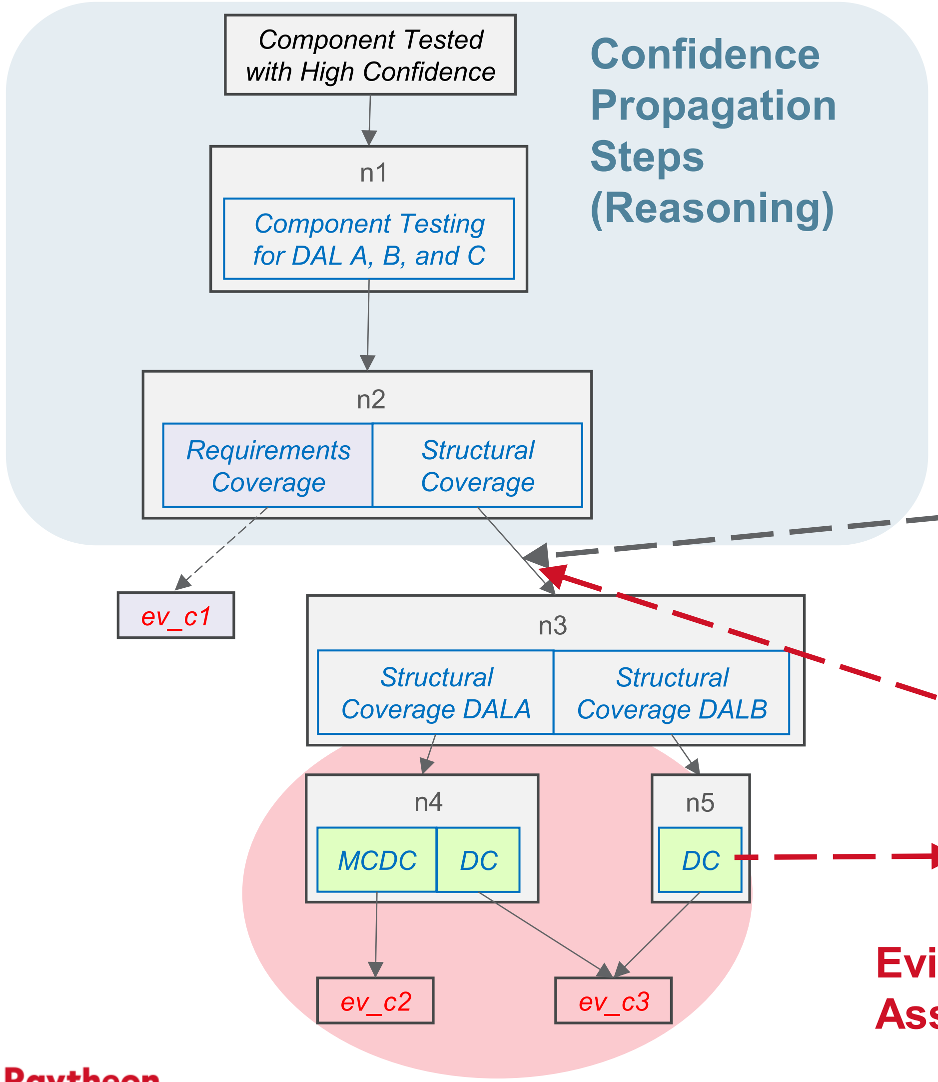
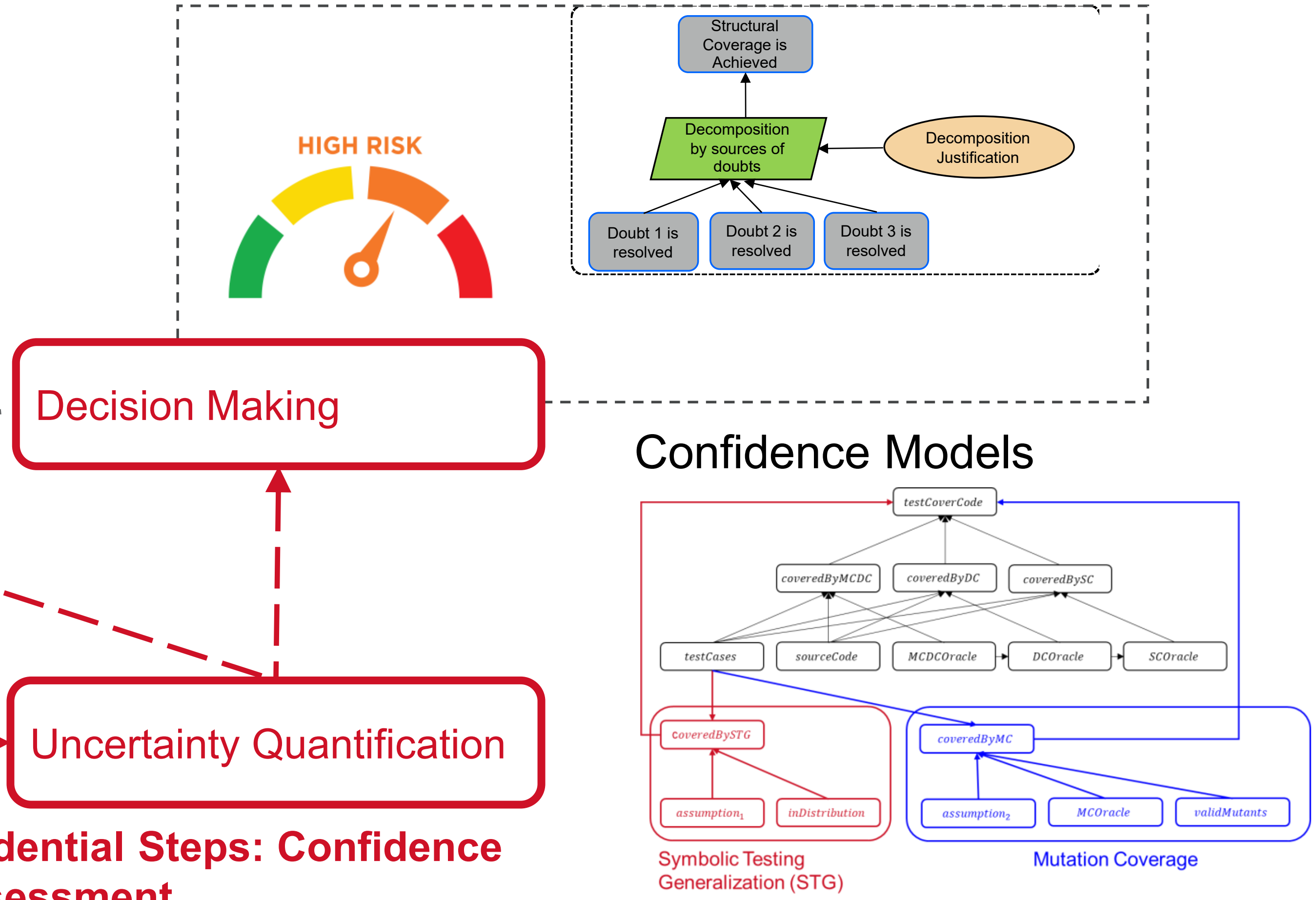
Assessing Certification Arguments

Hierarchical Stochastic Contract Nets (HSCN)

Chanwook Oh, Nikhil Vijay Naik, Zamira Daw, Timothy E. Wang and Pierluigi Nuzzo. *ARACHNE: Automated Validation of Assurance Cases with Stochastic Contract Networks,* SafeComp 2022.





Evidential Steps: Confidence Assessment

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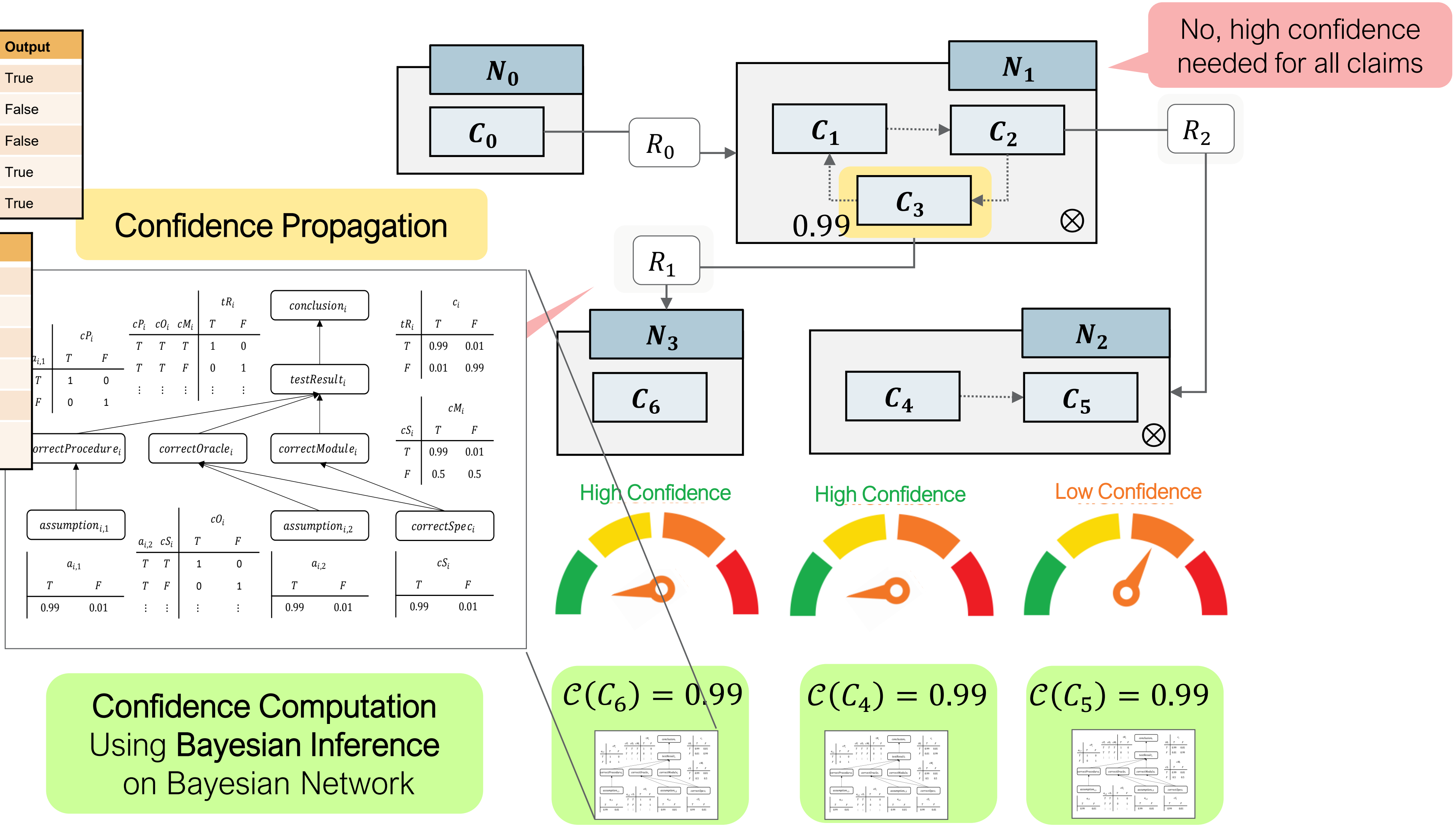
Assessing Certification Arguments: Example

LLR	HLR	Analysis	Output
LLR-1	HLR-1	Manual Review	True
LLR-3	HLR-2	Model Checking Verification	False
LLR-4	HLR-2	Model Checking Verification	False
LLR-5	HLR-3	Simulink verification	True
LLR-6	HLR-3	Simulink verification	True

SW-Comp	Analysis	Output
Comp-1	MCDC	True
Comp-1	DC	True
Comp-1	SC	True
Comp-1	Mutation > 80%	True
Comp-1	Input Space Covered	True
Comp-1	Requirements address robustness	False



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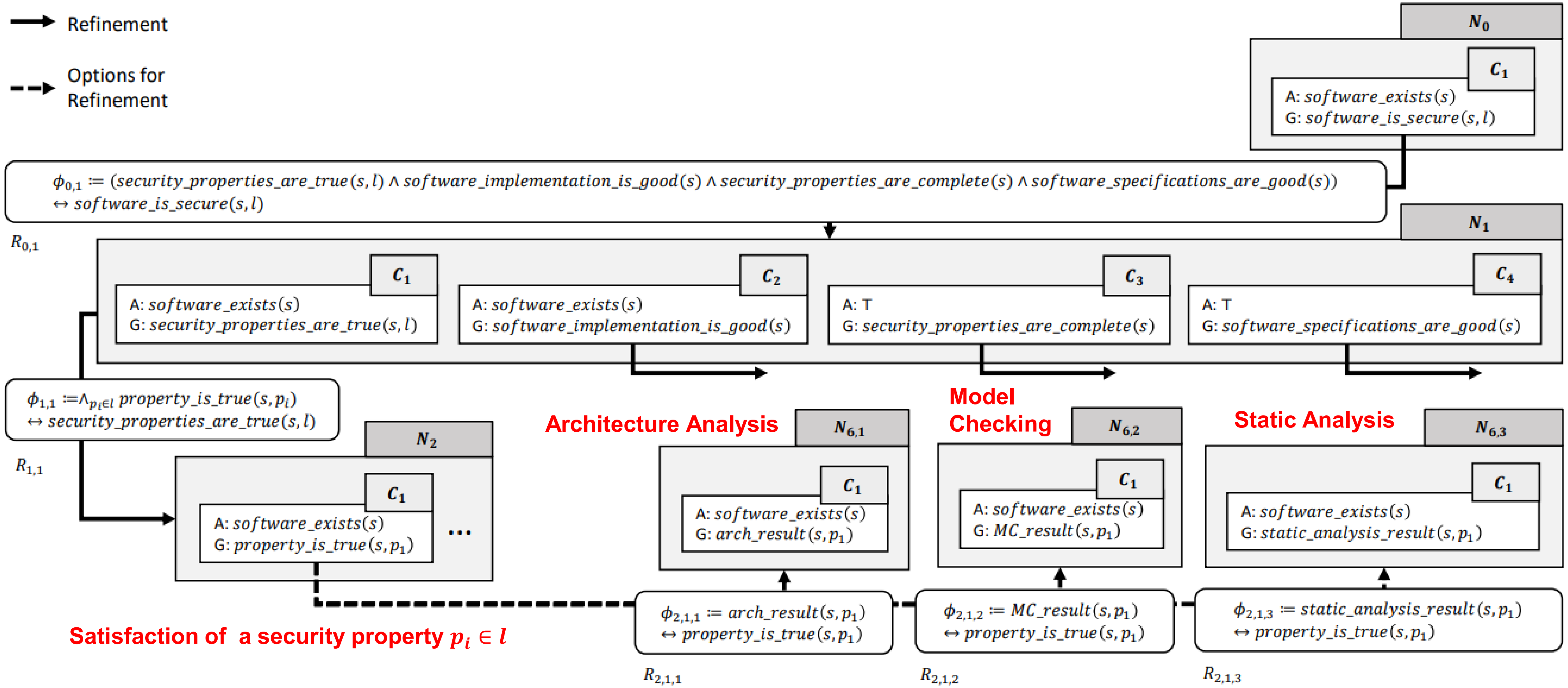
ArduCopter Security Assurance



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Synthesized and Evaluated over 10^5 Arguments in <100 min

Case Study	Pattern Library Size	Security Property Count	Total Candidates	Average Claims per Candidate	Synthesis (s)	Validation (s)		Total (s)
						Selection	Assessment	
ArduCopter	17	2	3^2	43	10	18	69	97
	17	4	3^4	50	12	21	82	115
	17	6	3^6	58	16	26	92	134
	17	8	3^8	66	18	41	102	161
	17	10	3^{10}	73	21	152	119	292
	17	12	3^{12}	81	25	3,143	832	4,000
Industrial Case Study	91	N/A	6×10^5	652	819	1,683	3,322	5,824

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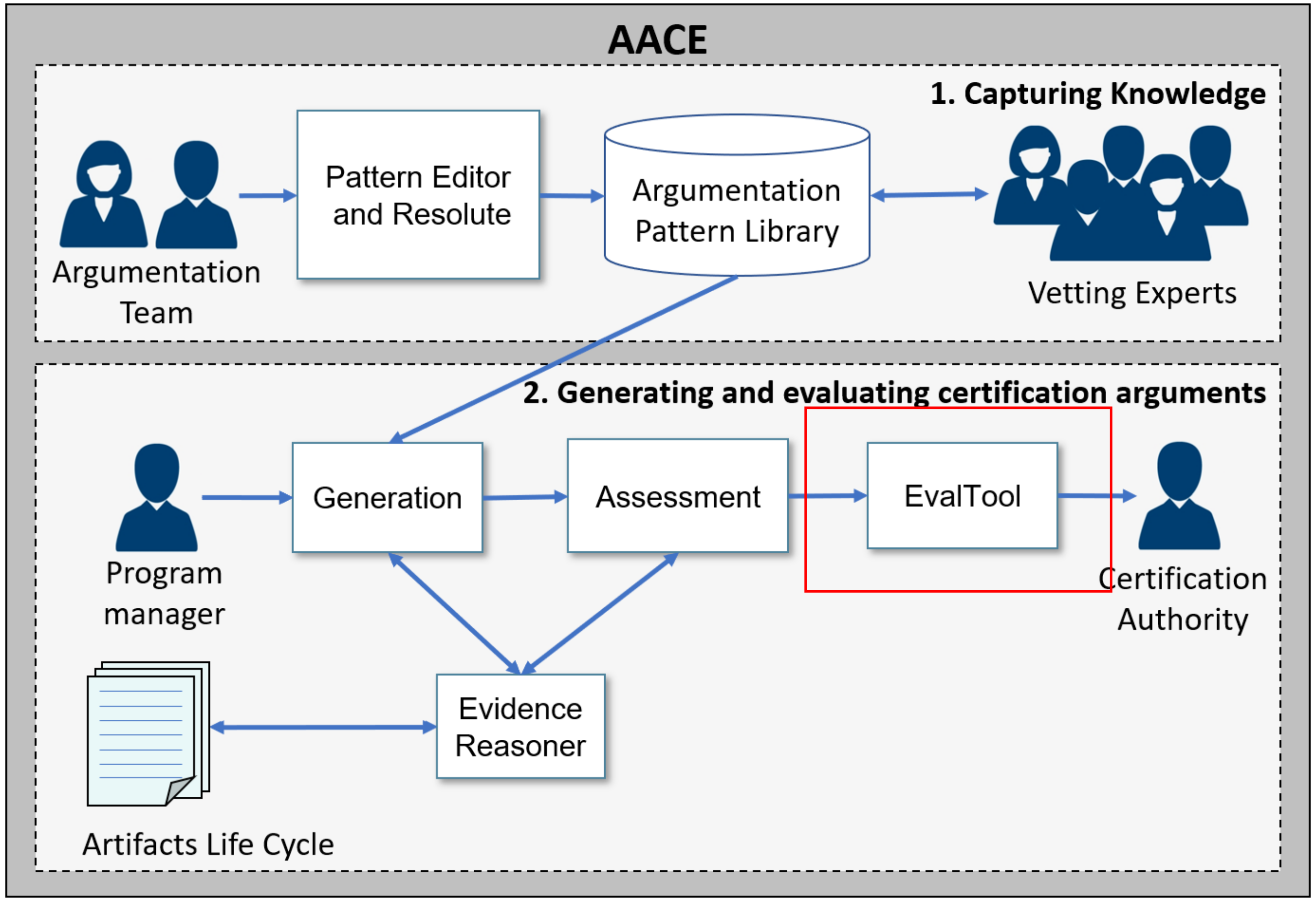

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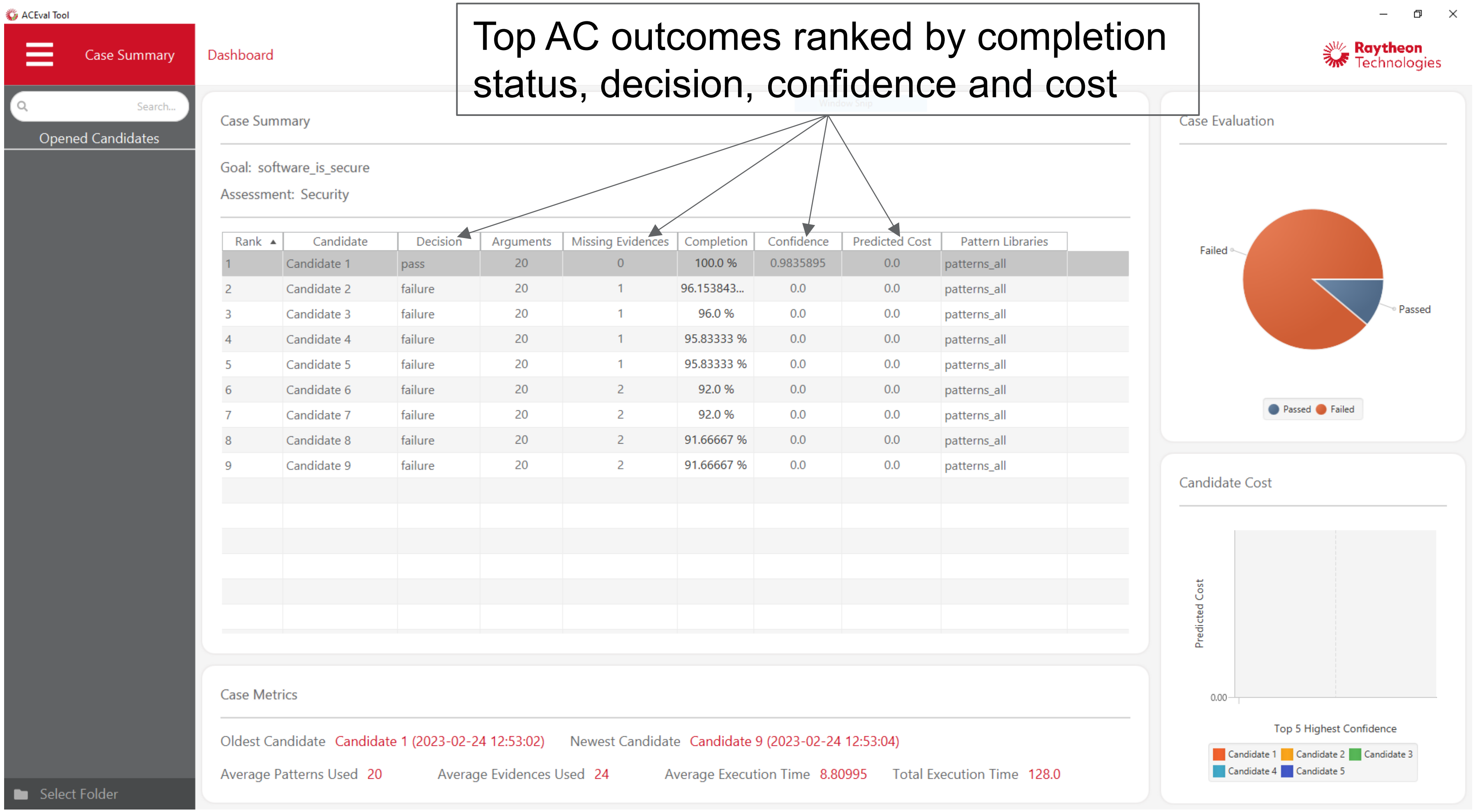
Eval Tool

Top AC outcomes ranked by completion status, decision, confidence and cost



Rank	Candidate	Decision	Arguments	Missing Evidences	Completion	Confidence	Predicted Cost	Pattern Libraries
1	Candidate 1	pass	20	0	100.0 %	0.9835895	0.0	patterns_all
2	Candidate 2	failure	20	1	96.153843...	0.0	0.0	patterns_all
3	Candidate 3	failure	20	1	96.0 %	0.0	0.0	patterns_all
4	Candidate 4	failure	20	1	95.83333 %	0.0	0.0	patterns_all
5	Candidate 5	failure	20	1	95.83333 %	0.0	0.0	patterns_all
6	Candidate 6	failure	20	2	92.0 %	0.0	0.0	patterns_all
7	Candidate 7	failure	20	2	92.0 %	0.0	0.0	patterns_all
8	Candidate 8	failure	20	2	91.66667 %	0.0	0.0	patterns_all
9	Candidate 9	failure	20	2	91.66667 %	0.0	0.0	patterns_all

Cost may consist of actual dollar cost, time, or any other limited or scarce resource

Z. Daw, T. Wang, C. Oh, M. Low, I. Amundson, G. Wang, R. Melville, and P. Nuzzo, “Computer-aided evaluation for argument-based certification,” in 42nd AIAA/IEEE Digital Avionics Systems Conference, 2023

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Thank You.

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