RESEARCH REVIEW 2022

Carnegie Mellon University Software Engineering Institute

Maturing Assurance Contracts in Model-Based Engineering

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DoD Digital Engineering Challenges

Model-Analyze-Build

Late Discovery of Design Errors in DoD Systems is very costly.

Architecture modeling and analysis can **detect** design **error early**

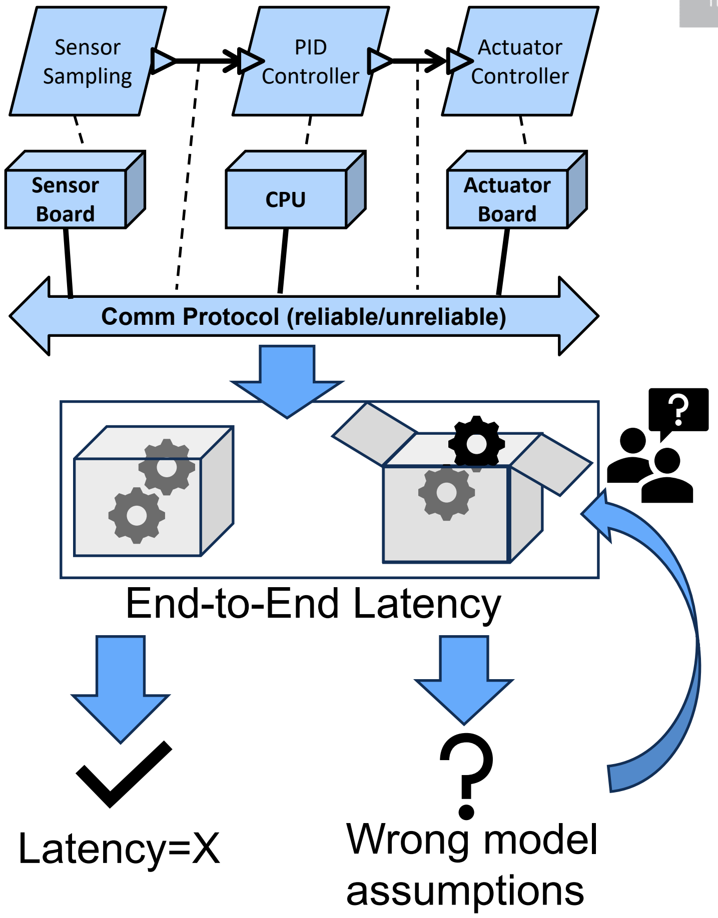
BUT:

Analysis assumptions are often implicit

if analysis **assumptions not met**: analyses break down for reasons not clear to users of analysis tools.

E.g., e2e Latency Assumption: periods multiple of each other (harmonic)

DoD barrier for adoption

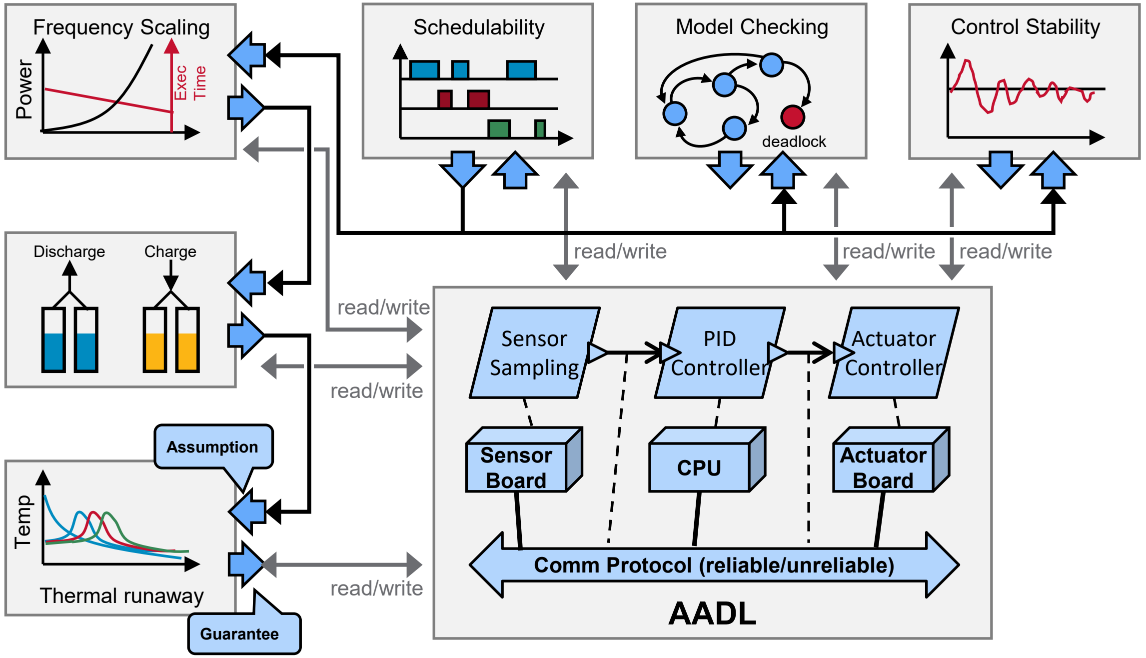


Digital Engineering: Multiple Claims – Multiple Analyses

Different Assurance Claims

- Combine multiple analysis
- Validate assumptions
- Resolve assumption conflicts

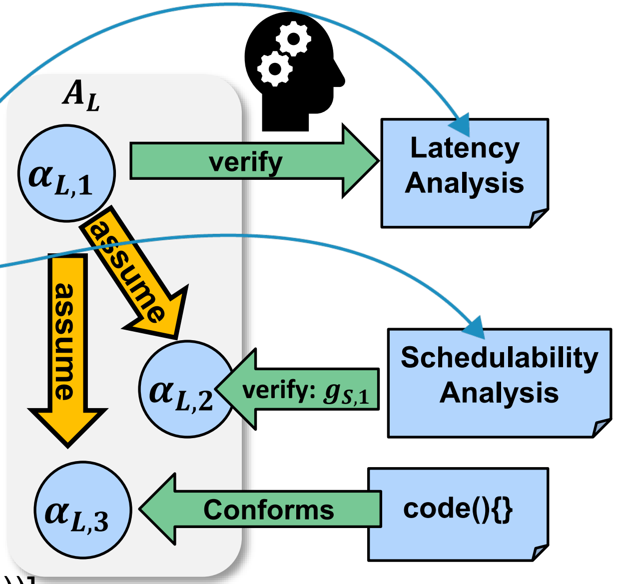
Integrate into arguments to satisfy claims



Analysis Contract: Tracking Assumptions and Guarantees

$$C_L = (A_L, G_L) \text{ with } A_L = \{\alpha_{L,1}, \alpha_{L,2}, \alpha_{L,3}\}$$

```
contract {
  input:
        E2ELatancies
  assumptions:
        areConnectionsDelayed()
        areDeadlinesConstrained()
        areTasksSchedulable()
        areAllThreadsPeriodic()
  analysis:
        meetEndToEndLatencies()
  guarantee:
        [E2EResponses[i] <= E2ELatencies[i]  for i in range(len(Responses))]
}
```



Shift Left And Down to the Implementation

Early Analysis

- Evaluate design decisions with partial information
- E.g., latency analysis before periods
  - periods of tasks must be multiples of each other

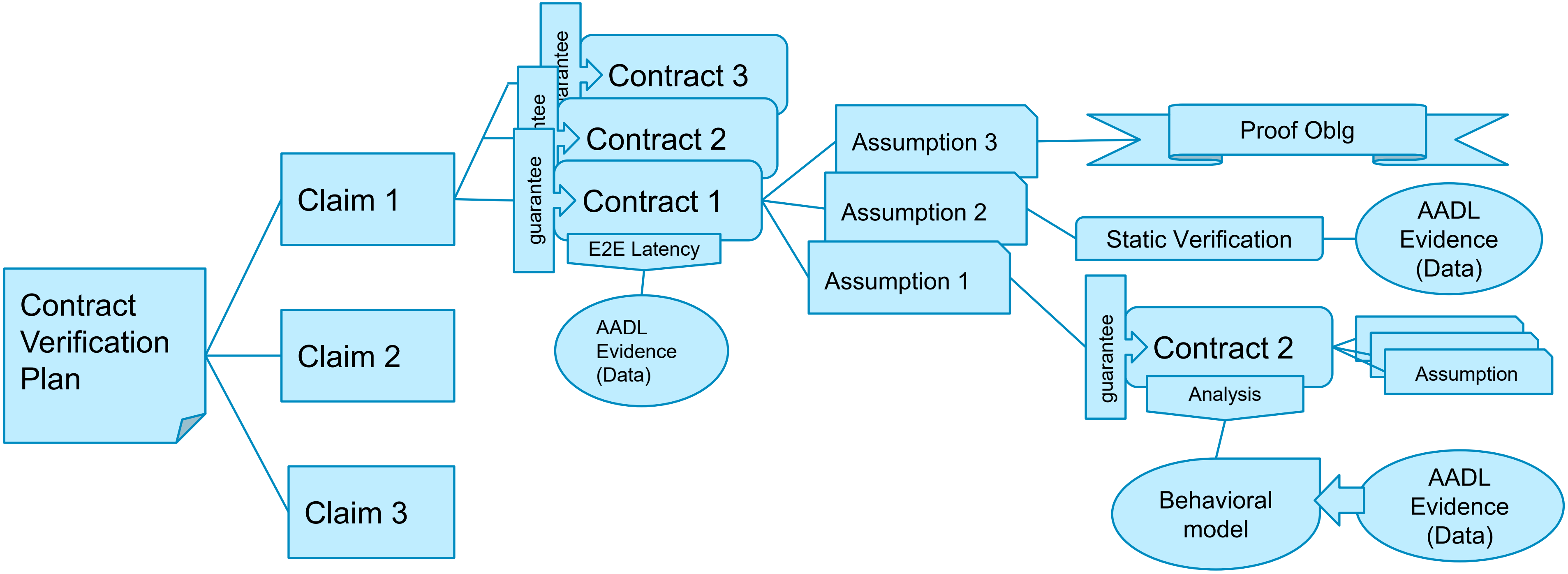
Refinement

- Track pending information
  - periods
- Track and execute pending verification
  - Schedulability

Conformance

- Track implementation assumption
- Verify implementation conformance
  - Task executed strictly periodic $\alpha_{L,3}$

Assurance Contract Argumentation (1)



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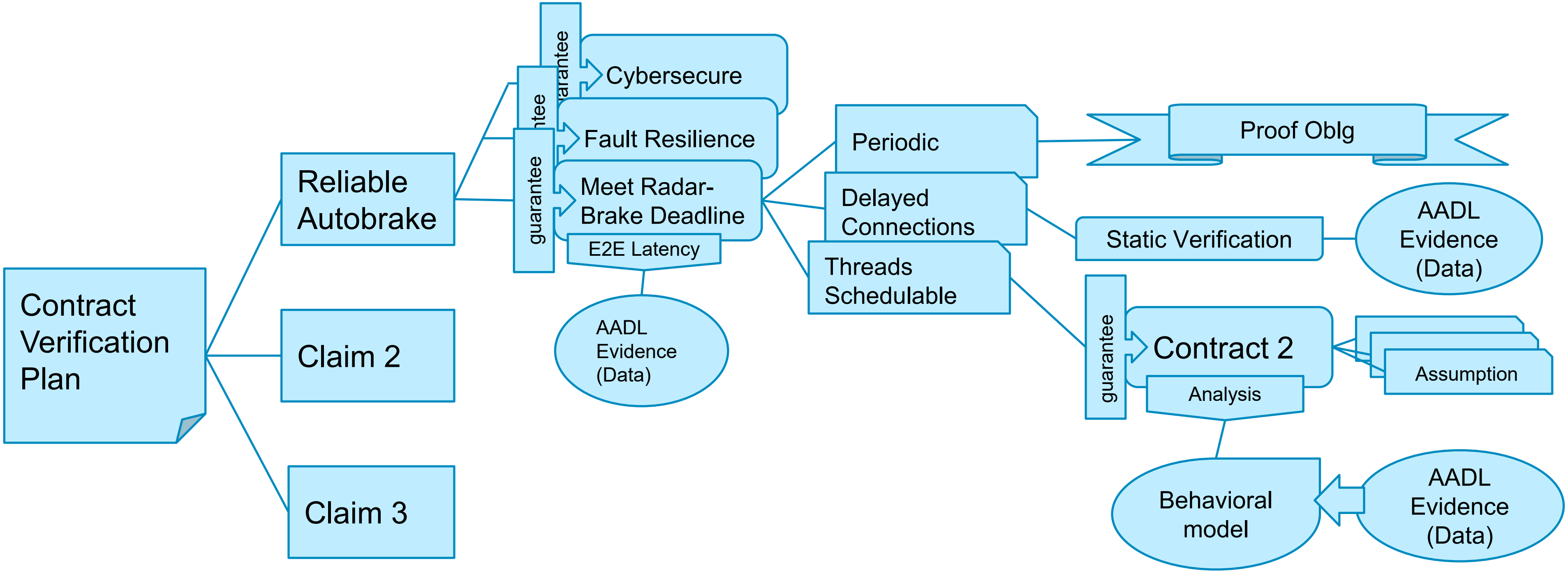
Assurance Contract Argumentation (2)



Contract Argumentation in the Development Lifecycle

Integrity of Analysis

- Verify assumptions
  - Detect violation
  - Suggest repairs
- Offer alternative analysis that satisfy assumptions

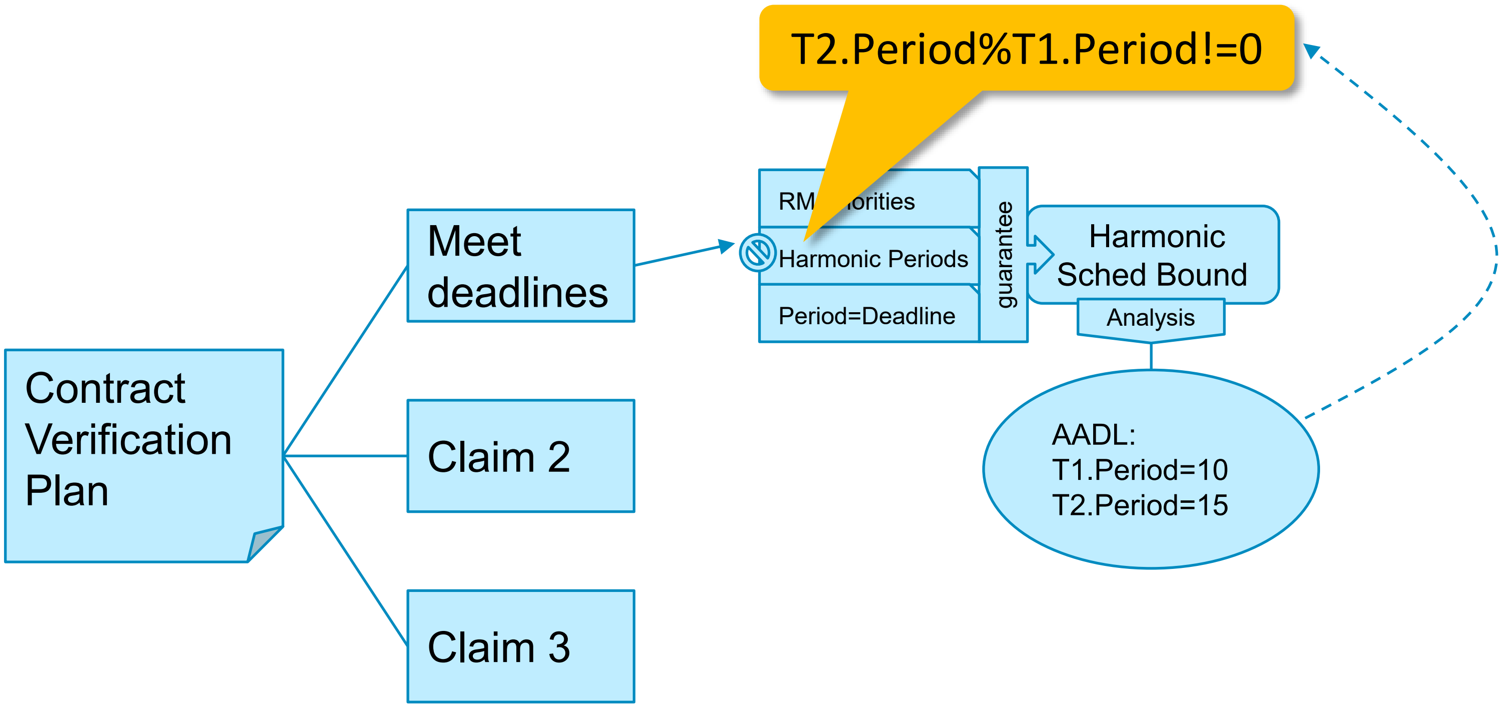
Refine Design

- When enough new data for new analysis
- When new data affects proof obligations

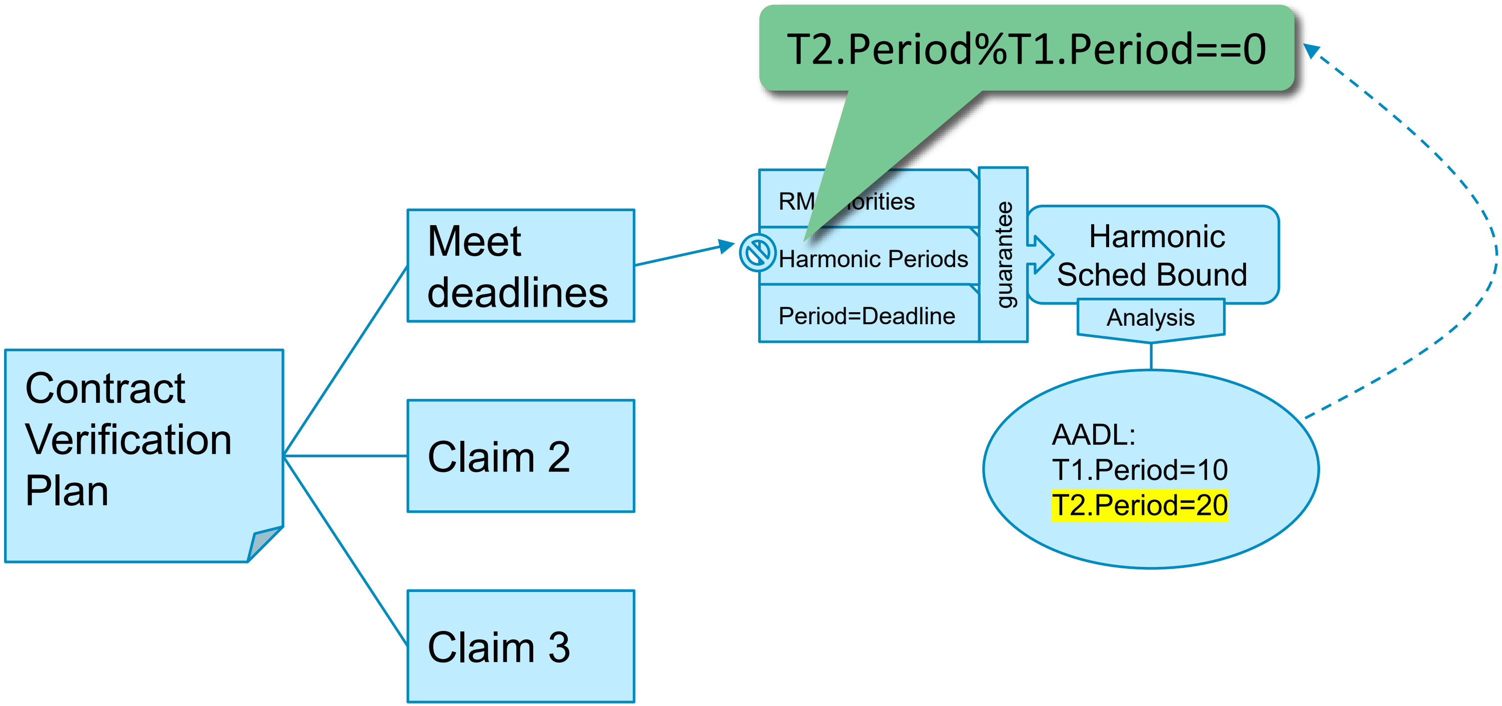
Argument reusability

- Self-contained modular analysis contracts

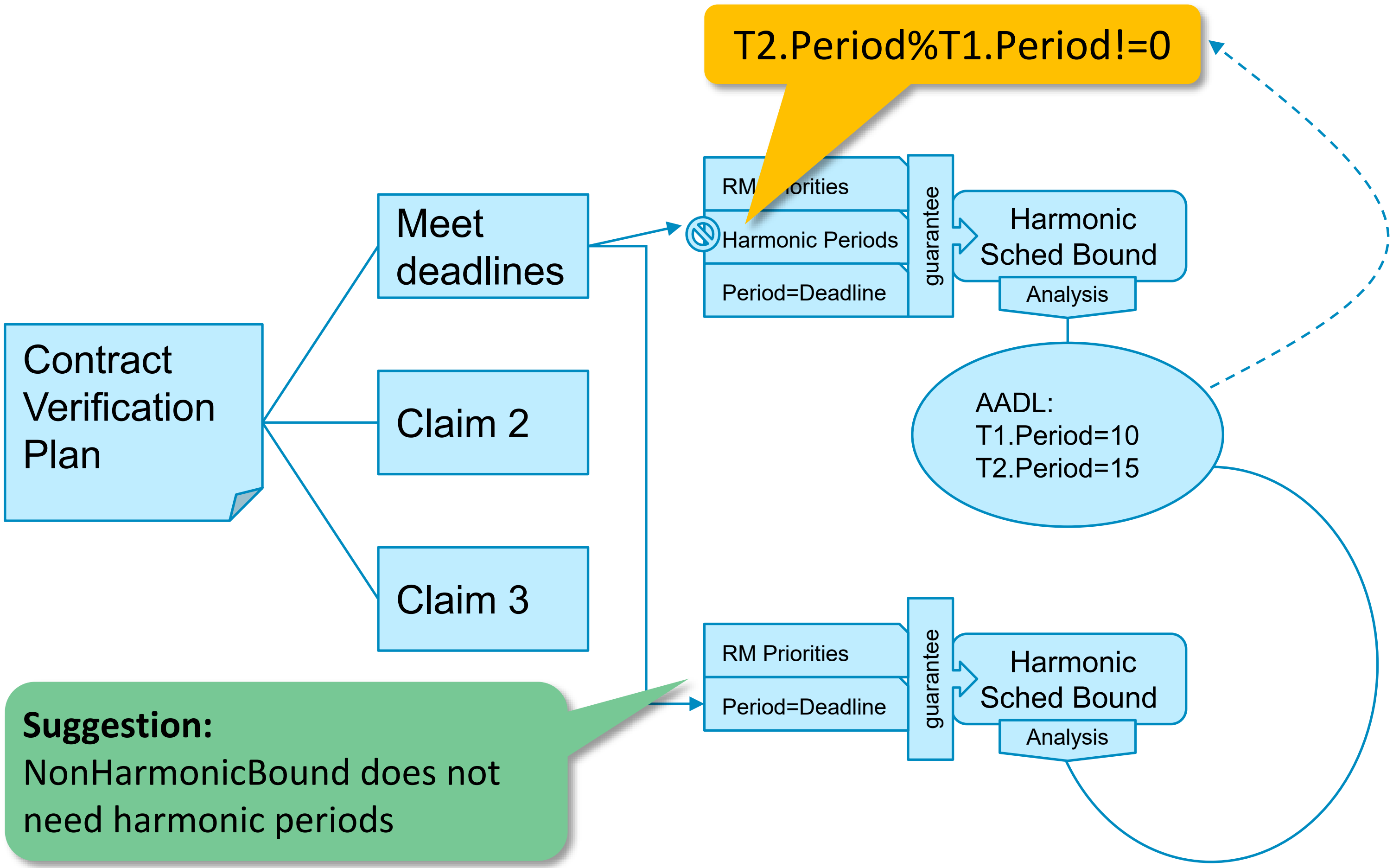
Integrity of Analysis: Repairing Assumptions (1)



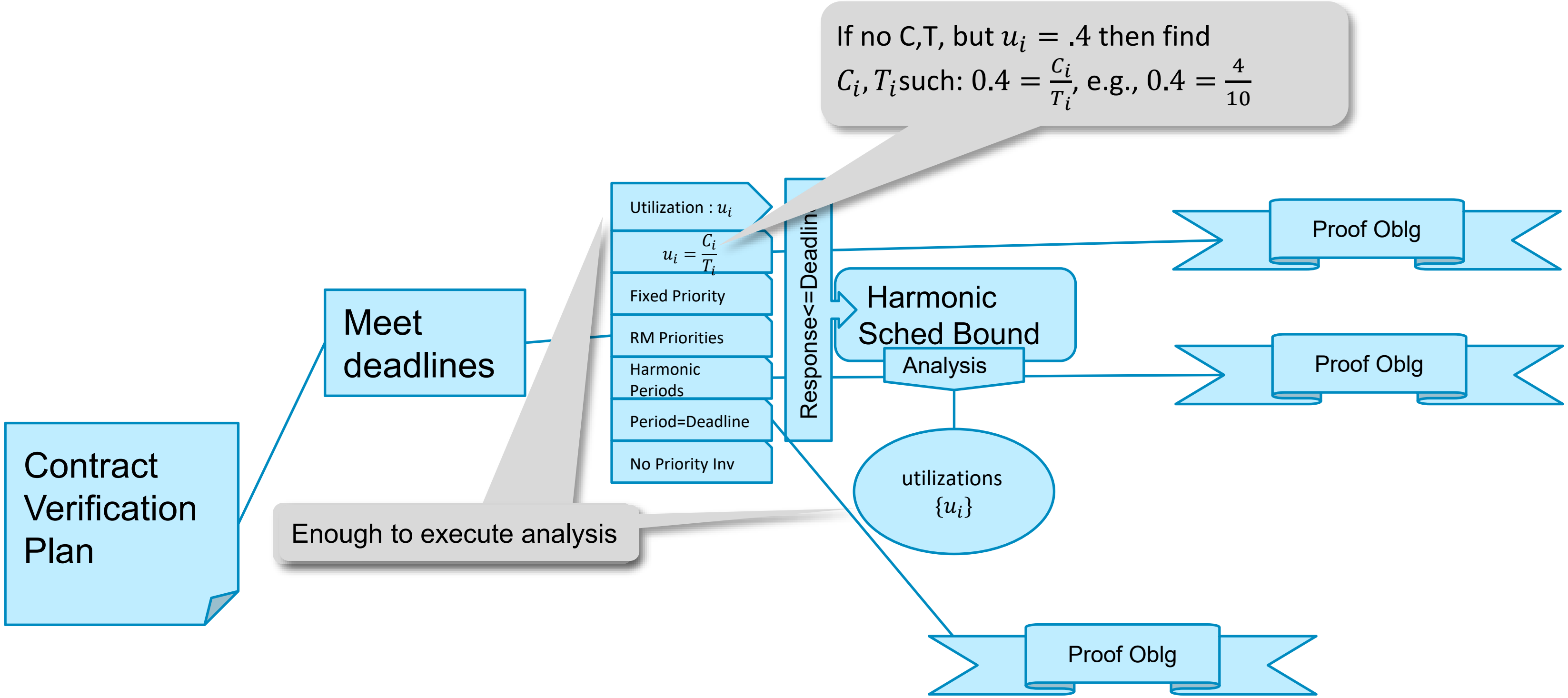
Integrity of Analysis: Repairing Assumptions (2)



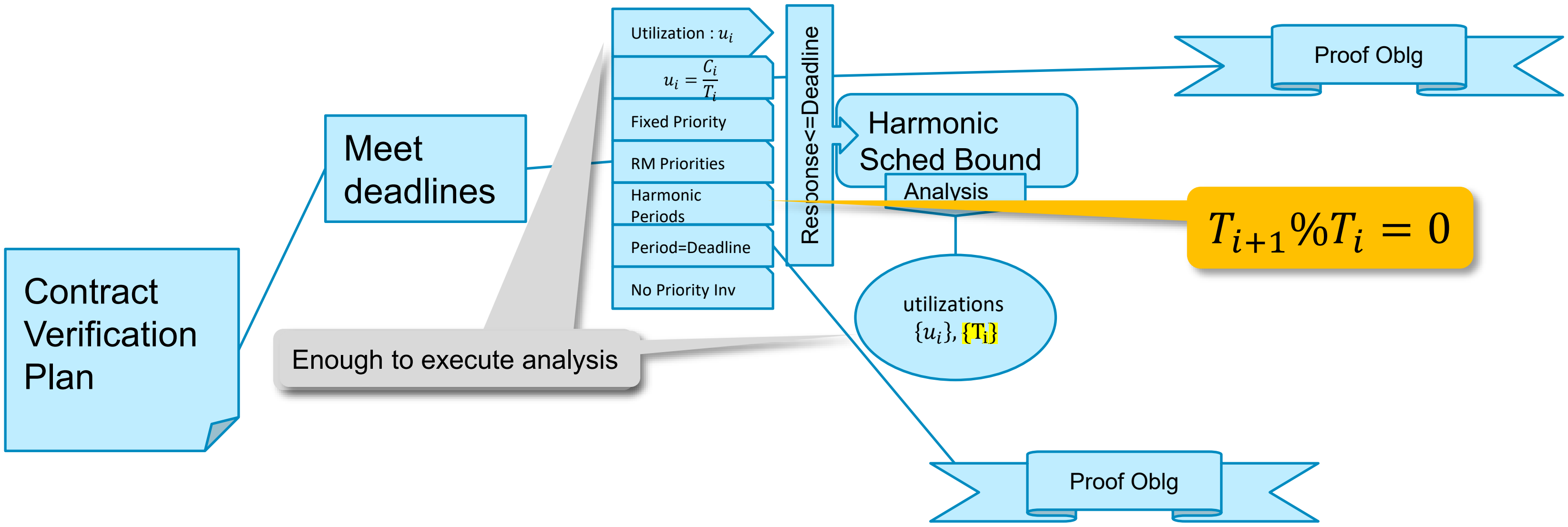
Integrity of Analysis: Repairing Assumptions (3)



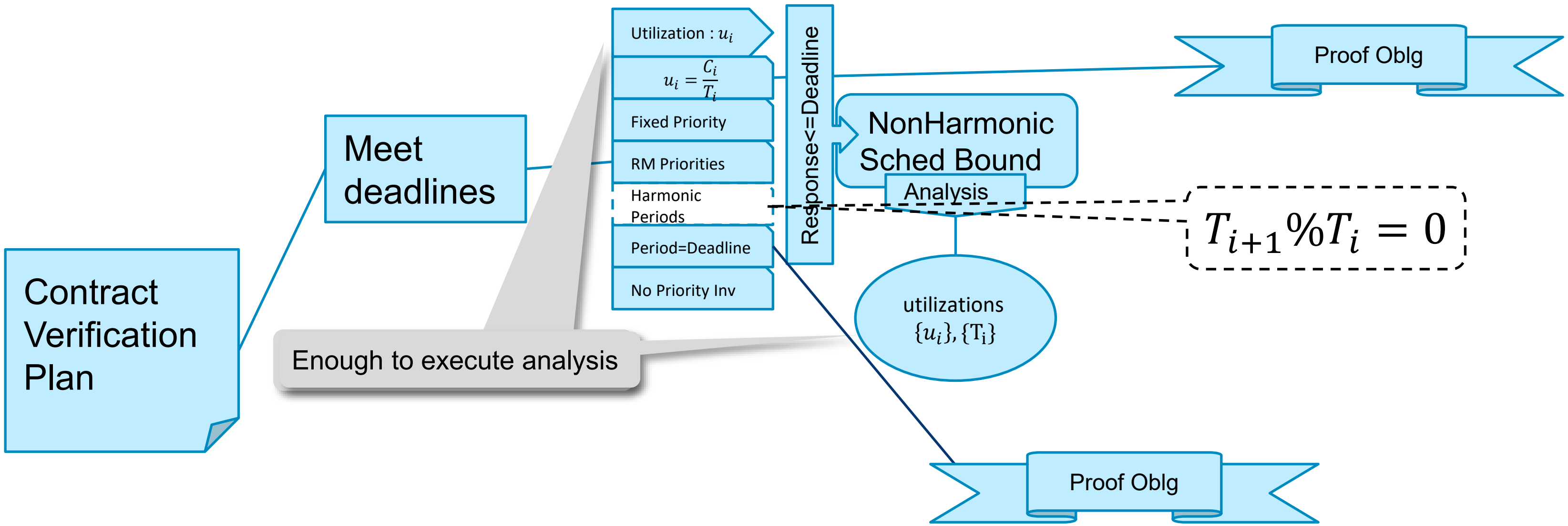
Refinement Throughout Development (1)



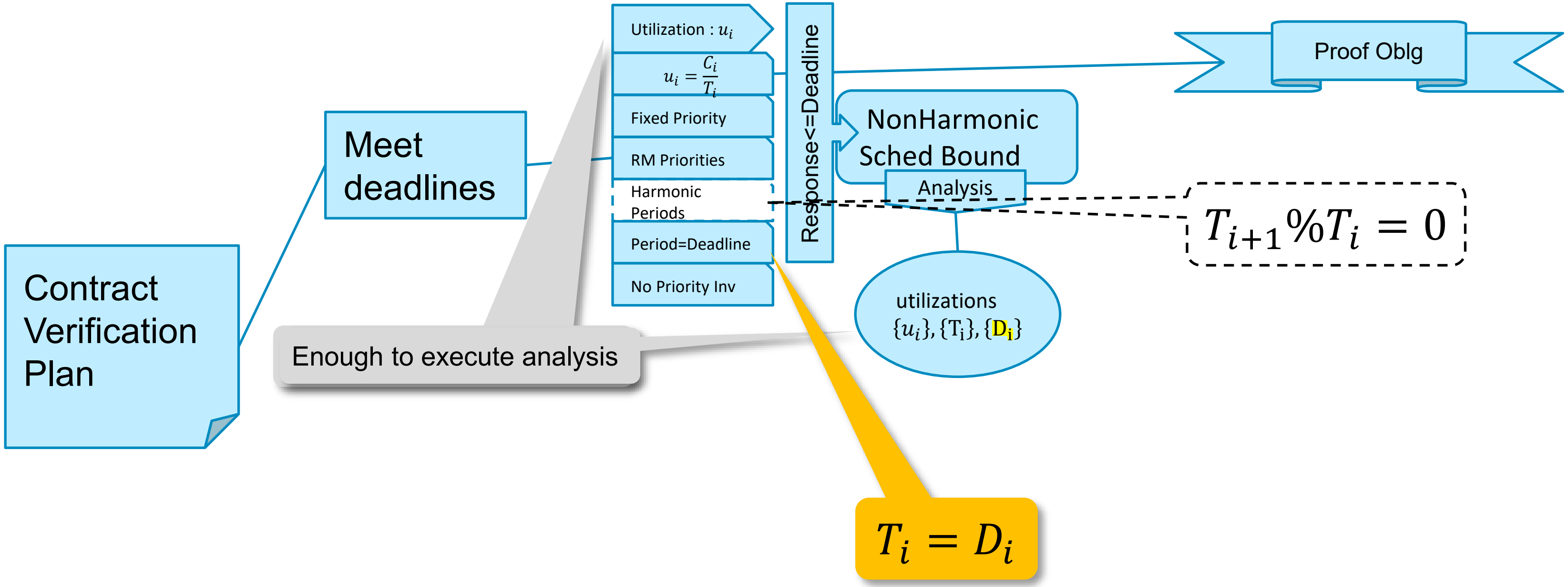
Refinement Throughout Development (2)



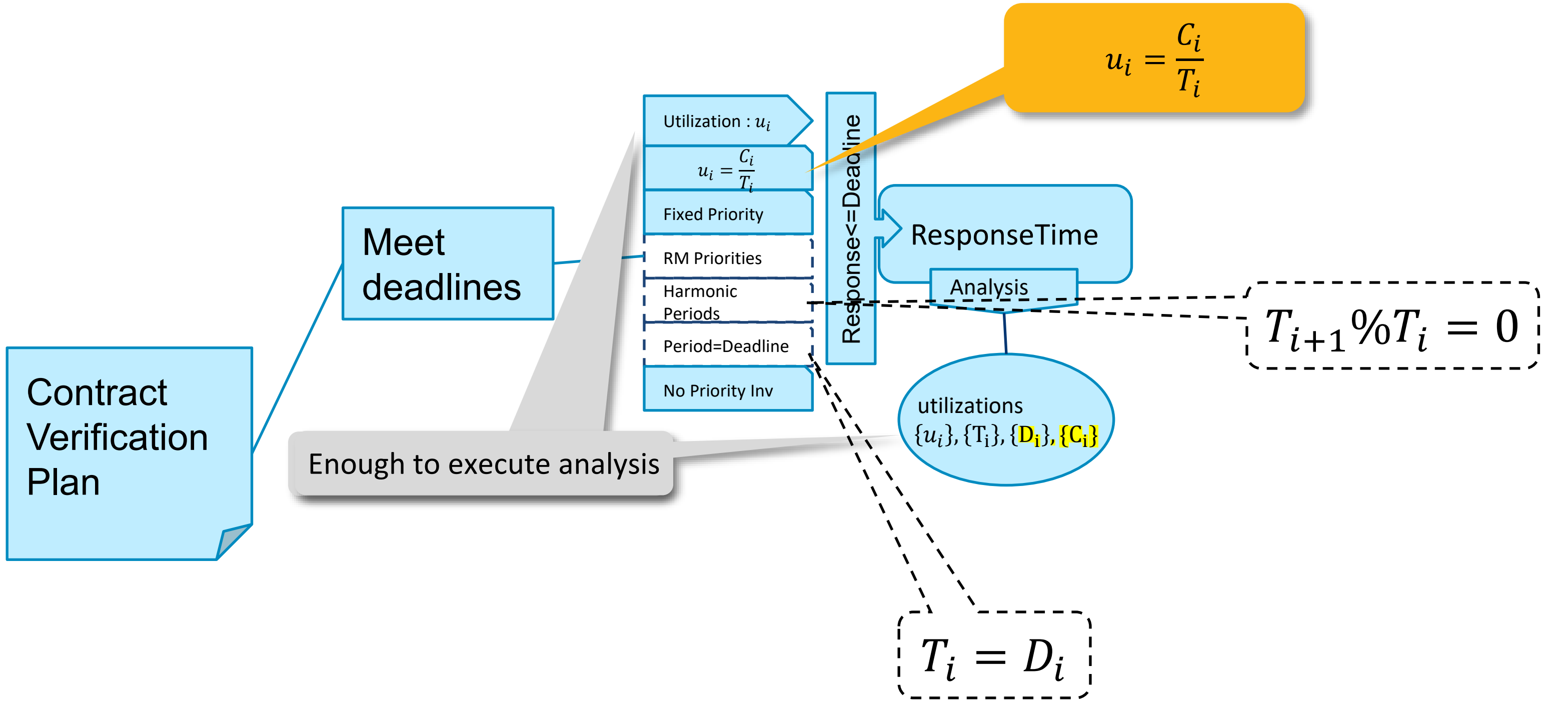
Refinement Throughout Development (3)



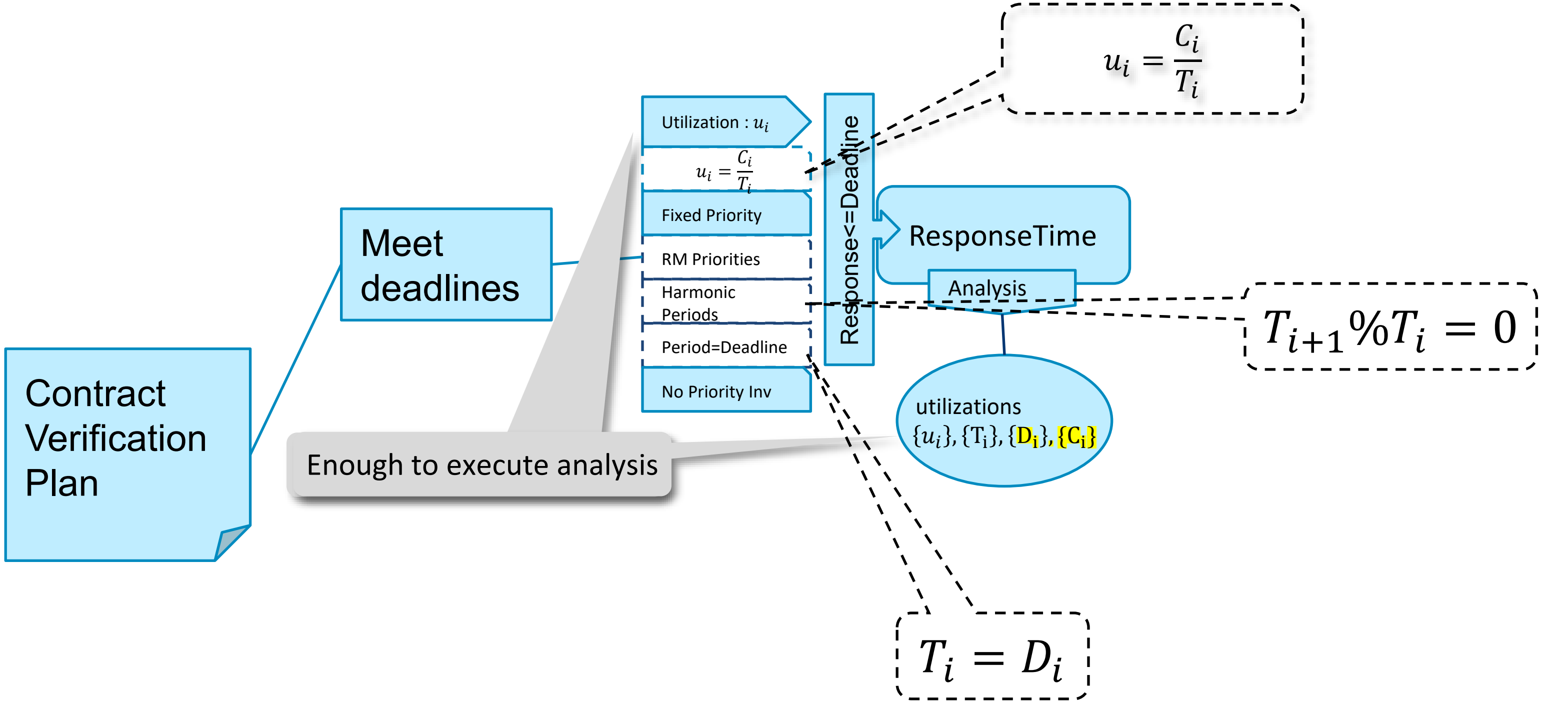
Refinement Throughout Development (4)



Refinement Throughout Development (5)



Refinement Throughout Development (6)



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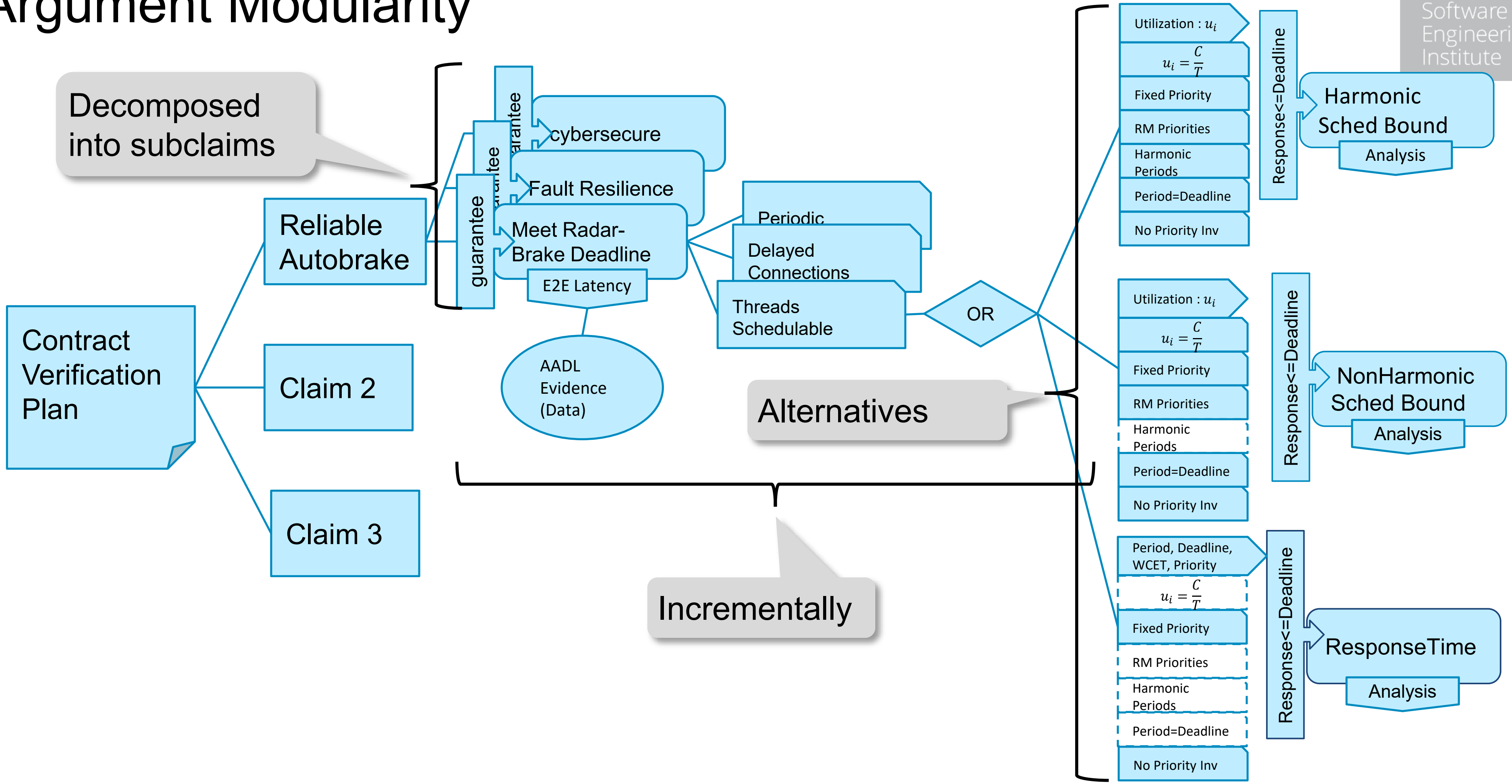
Argument Modularity



Implementation: Symbolic Contract Argumentation

Assumptions
- Constraints that must be satisfied for a valid analysis

Analysis
- Evaluate whether the guarantee can be discharged

Guarantee
- Assertion presented as a true fact on model

Implementation
- Constraint Satisfaction Solver (Satisfiability Modulo Theories – Z3)
- Implements contract argumentation
  - Evaluate whether constrains can be satisfied with facts from analysis guarantees
- Validate assumptions
  - Proof obligations: lack of constraints allow any value that satisfy assumption (e.g., RM priorities)

Artifacts
- Annex language hosted in AADL/OSATE
  - Model Query Language adaptable for multiple modeling language (e.g., SysML V2)
- Automatic Execution of Contract Verification Plan
  - Assumption repair & analyses alternatives

Contract Argumentation Scalability

Exploit Knowledge from Scientific Domain

- Efficient algorithms from specialized domains
  - E.g., greedy worst-case response time in real-time theory
  - Implemented in imperative languages

Assume correctness of analysis

- When validating the contract argumentation
- Enables connection with other lower-level verification results
  - E.g., PROSA: coq (theorem prover) verification of real-time theory

Correctness of implementation

- Exploit proven properties of runtime mechanisms: e.g., schedulers, hypervisors
- Exploit code generation
- Deferred code verification to conform to assumptions

Impact

Certification

- Automated and sound verification of assurance claims through models

Fielding Speed

- Automated assurance watchdog
  - Validate incremental refinement through design
- Concurrent formal assurance argument construction and system development

Digital Engineering and AADL Ecosystem

- Incremental sound analysis infrastructure to DoD modeling efforts
- Architecture-Centric Virtual Integration Practice (ACVIP) within FVL
- DARPA programs using AADL

Concluding Remarks

Certification in Digital Engineering Era

- Follow model-analyze-build
  - Automated argumentation supported by model-based analysis contracts

Shift Left

- Start verifying early design decisions
- As design is refined
  - Ensure properties of pervious design decisions are preserved
  - New refinements can provide additional evidence / properties to support assurance

Down To The Implementation

- Drive properties & assumptions down to the implementation

Scalable

- Exploit efficient analysis from different domains

Sound

- Exploit advances in formal verification
  - Combination of analysis, verification of assumptions, implementation compliance, analysis correctness

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To learn how the results of our project can help improve the effectiveness of your systems' assurance.

Document Markings

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