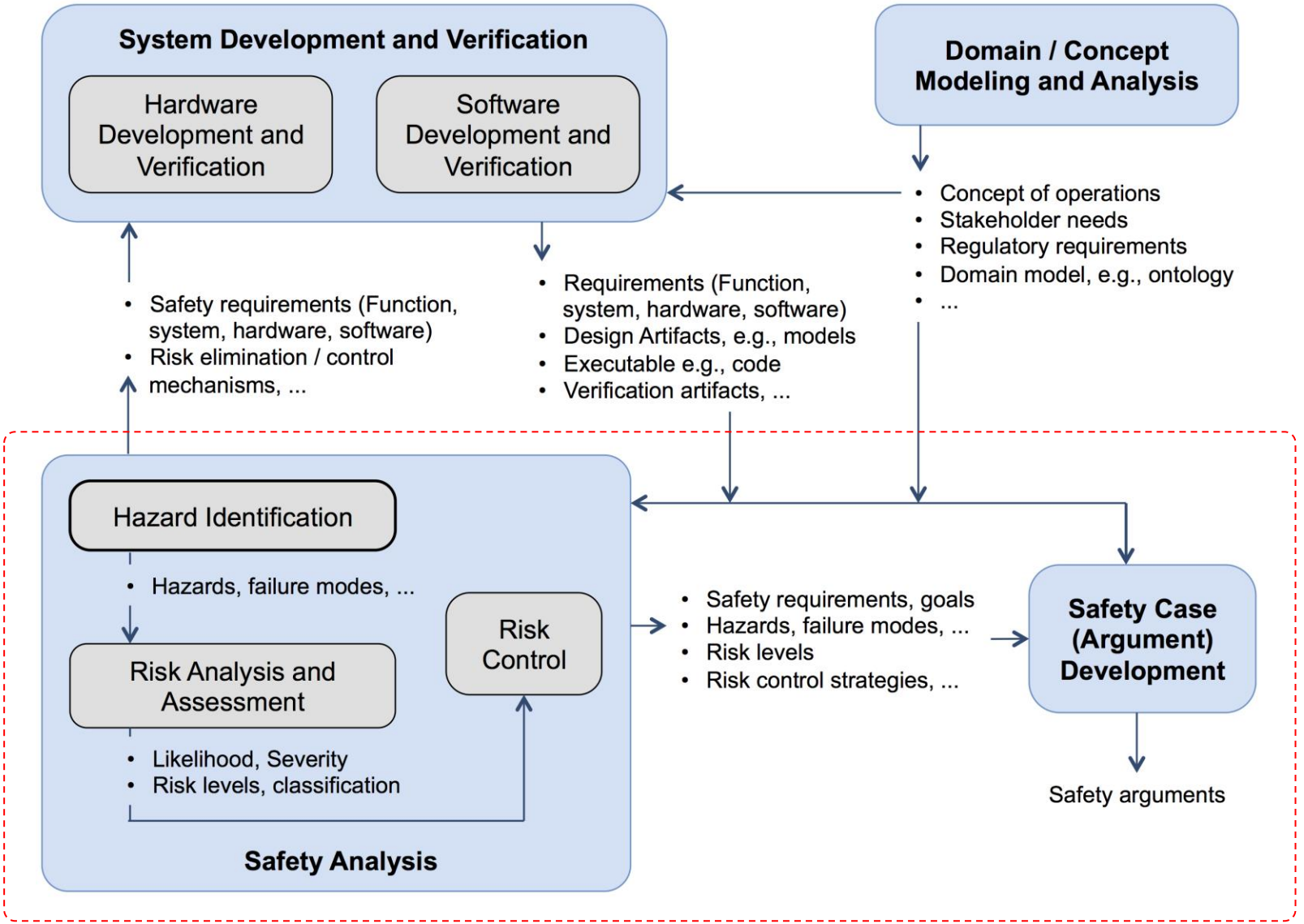
The Role of Formalization and Argumentation in Assurance Cases

Ewen Denney and Ganesh Pai

SGT / NASA Ames Research Center

{ewen.denney, ganesh.pai}@nasa.gov

Safety Risk Management & Assurance (SRM&A)



Notions of Assurance Case in Aviation

- UK MoD Defence Standard 00-56, Issue 4, June 2007
  - "... Safety case shall consist of a structured argument, supported by a body of evidence, that provides a compelling, comprehensible and valid case that a system is safe for a given application in a given environment".

- Civil Aviation / UAS operations in civil airspace
  - Preference for using normative regulations
  - Performance-based standards
  - "Safety cases" for one-off systems,
    - i.e., Concepts that are built once and fielded
    - e.g., RVSM implementation over some airspace sector
  - Notion of safety case is compatible but seems to be different

Notions of Assurance Case in Aviation

- Eurocontrol Safety Case Development Manual, 2.2 Ed., Nov. 2006
  - "Safety case is the document assurance (i.e., argument and supporting evidence) of the achievement and maintenance of safety"

- ICAO Guidance Material for Building a Safety Case for ADS-B separation service, May 2011
  - "A safety case is a document which provides substantial evidence that the system to which it pertains meets its safety objectives"
  - "... An explicit documentation of a safety-critical system, its corresponding safety objectives, and the associated safety risk assessment and risk management of the system, at appropriate milestones in the life of the system".

Notions of Assurance Case in Aviation

- FAA
  - Order 8900.1 Flight Standards Information Management System, Vol. 16, UAS, Ch. 7, SRM, Safety Case Template
    - "Core" content
      - Environment (airspace system) description
      - System description and system change description
      - Airworthiness description of affected items
      - Aircraft capabilities and flight data
      - Accident / incident data
      - Hazard analysis and details of risk analysis, risk assessment, and risk control
      - Emergency and contingency procedures
      - Pilot / crew roles and responsibilities
  - Safety Risk Management Plan
    - Hazard tracking
- No expectation of an explicit, or structured, argument containing claims, argument, evidence, etc.

Notions of Assurance Case in Aviation

- CAA – Congested Areas Operating Safety Case (CAOSC) IN-2014/184
  - "For SUAS (small UAS) and SUAS applications, it is not expected that complex hazard identification and risk assessment techniques will be used (e.g., Goal Structured Notation) ..."

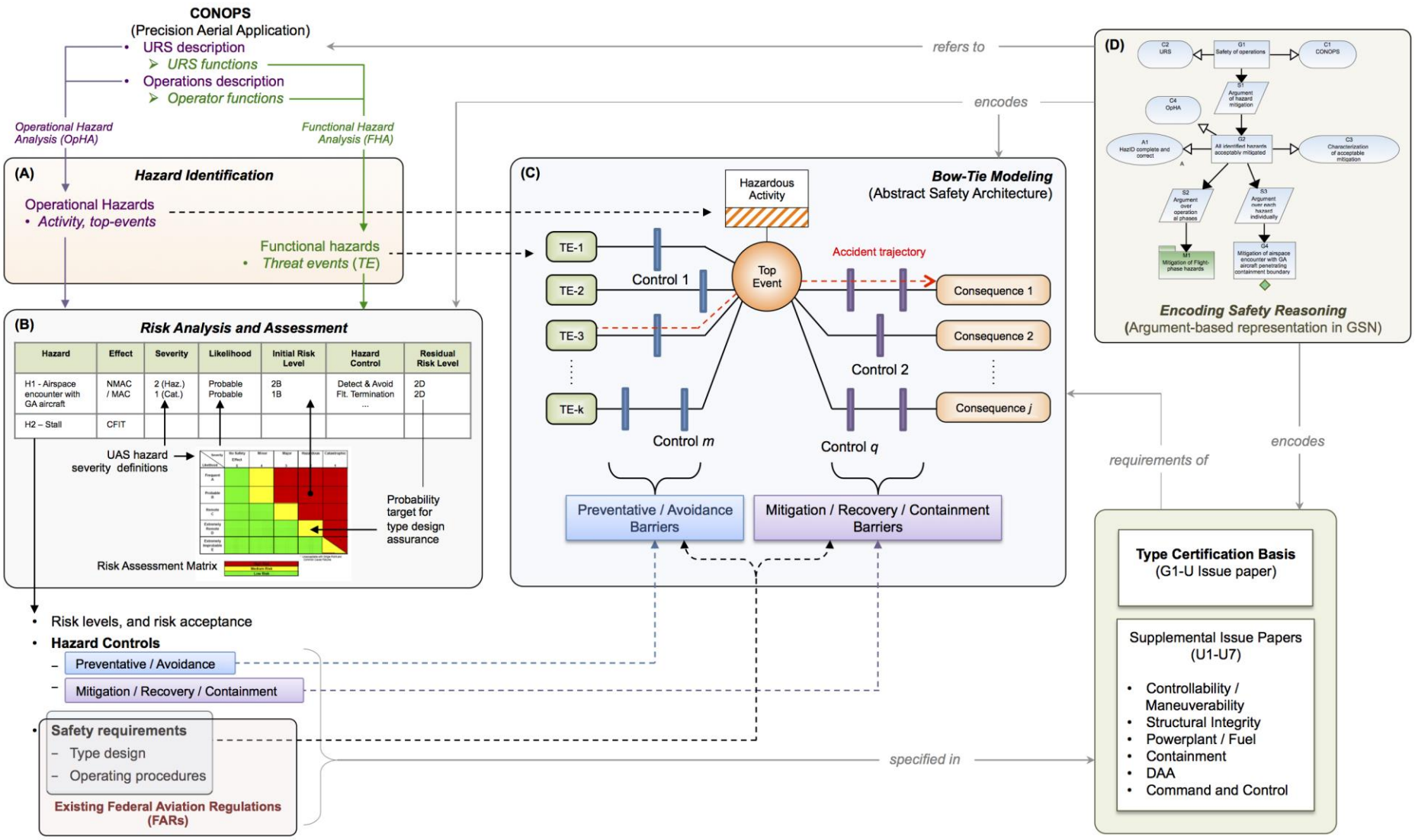
- Safety Case Template
  - Core content: System, Operations, and Hazard and Risk Assessment
  - Additionally, a "Self assessment"
    - Textual Claims, Arguments and Evidence
    - "There is no mandatory requirement to use complex techniques (e.g. Goal Structured Notation)."

Our Position

- Arguments are useful
  - To organize safety information, also to organize airworthiness claims and evidence
    - “Internal” complexity management and “confidence” on having done due diligence
  - Need not always be shown to / seen by regulator
    - Queries, views
  - Hide arguments à la hiding formalism in requirements using structured natural language
    - Report generation

- For UAS
  - Operations may continue to require safety cases
    - Only if they represent unique concepts needing one-off safety assessments
  - Airworthiness will follow traditional process as regulations get formulated
    - Likely to be a combination of performance based and normative
  - Not all assurance will require assurance cases
    - Structures, Physical modeling, ...

Instantiated Methodology for SRM&A



The Role of Formalization

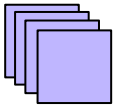
Two distinct notions of formalization

- Formal languages
  - Natural language
  - Controlled natural language
  - Formal assurance language
- Formal structures
  - Formalize the “scaffolding” to support automation
  - Support range of languages
  - Support range of reasoning structures

The Role of Automation

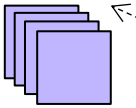
- Maintaining consistency and supporting evolution
  - Systems and safety cases evolve
  - Keep consistent during development / in operation
- Structuring large arguments
  - Modularization
  - Hierarchisation
- Aiding stakeholder comprehension
  - Diverse stakeholders care about different things
- Supporting analysis and review
  - Assess progress, coverage, confidence
- Supporting reuse
  - Extract reusable safety artifacts

Argument Structures and Safety Cases



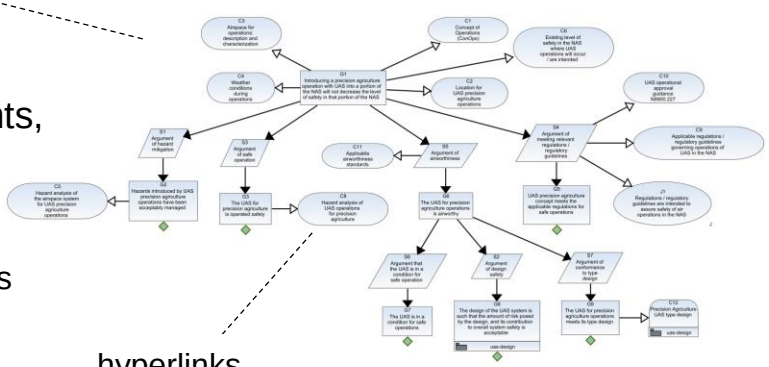
hyperlinks

External Documents
e.g., hazard logs, requirements, etc.



hyperlinks

Argument Structures
e.g., in GSN
with well-formedness constraints



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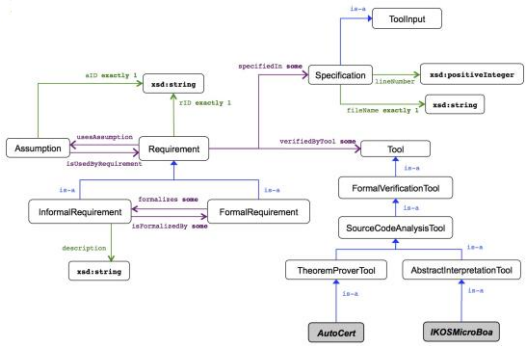
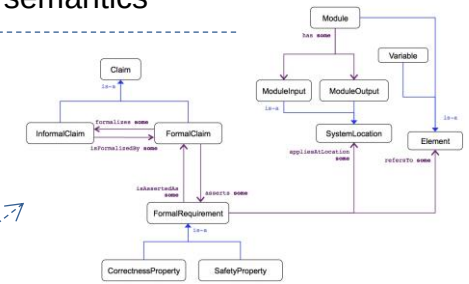


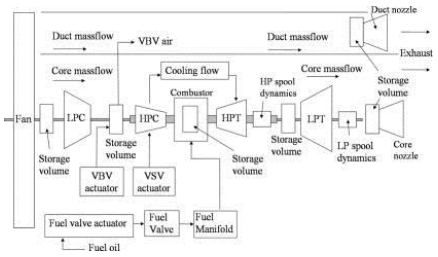
semantics

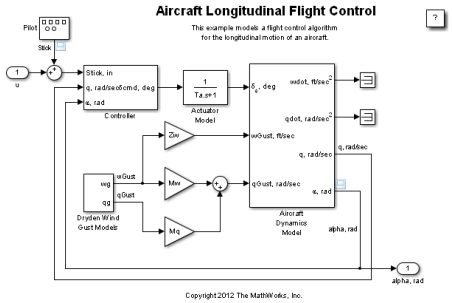


Domain model

Ontologies
e.g., in OWL
- System organization
- Regulations
- Environment / Domain, etc.

Models / Artifacts of the System
e.g., in MATLAB / Simulink, etc.





All of this constitutes the safety case

Lightweight Semantics

- Modeling domain knowledge
  - Ontologies provide additional semantics to argument structures
  - Capture as metadata associated with argument structure nodes
  - Attribute syntax

    attribute ::= attributeName param*
    param ::= String | Int | Nat | nodeID | sameNodeTypeID | goalNodeId | strategyNodeId | evidenceNodeId | assumptionNodeId | contextNodeId | justificationNodeId | contextNodeId | userDefinedEnum

    - userDefinedEnum

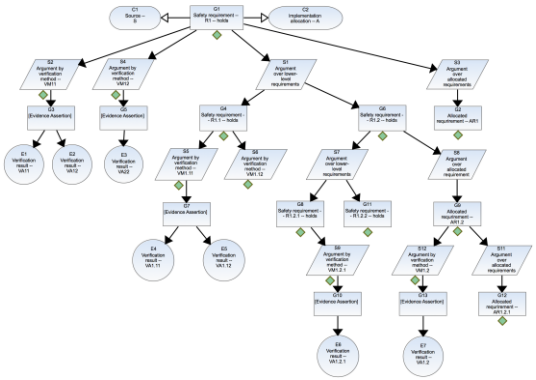
      severity ::= catastrophic | hazardous | major | minor | noSafetyEffect
      likelihood ::= frequent | probable | remote | extremelyRemote | extremelyImprobable

    - Examples
      - Attribute: risk(severity, likelihood), formalizes(sameNodeTypeID)
      - Attribute instance: risk(severity(catastrophic), likelihood(remote))
      - Parameter type synonyms: requirement == string

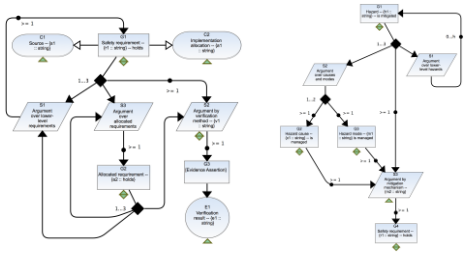
Example

requirement(id, hierarchyLevel, assuranceConcern)
formalClaim(id), informalClaim(id), hazard(id)
    id ::= int | string
    hierarchyLevel ::= highLevel | lowLevel
    assuranceConcern ::= functional | safety | reliability | availability | maintenance
requirementAppliesTo(elementLevel, elementType, element)
    elementLevel ::= system | subsystem | component | module | function | model | signal
    elementType ::= hardware | software
    element ::= aileron | elevator | flaps | propulsionBattery | avionicsBattery | actuatorBattery |
        avionics | autopilot | FMS | AP | aileronPIDController | elevatorPIDController |
        propulsion | engine | propeller | engineMotorController | actuator |
        flightComputer | wing | actuatorMotorController pilotReceiver | IMU |
references(variable)
    variable ::= aileronValue | pitchAttitude | flareAltitude | vRef | vNE | thrust | vS1
regulation(part)
    part ::= 14CFR23.73 | 14CFR23.75
risk(severity, likelihood)
    severity ::= catastrophic | hazardous | major | minor | noSafetyEffect
    likelihood ::= frequent | probable | remote | extremelyRemote | extremelyImprobable
isFormalizedBy(sameNodeTypeID)

Consistency and Evolution

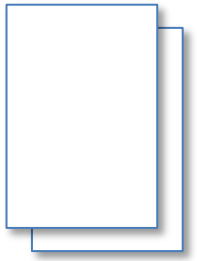


Pattern Library

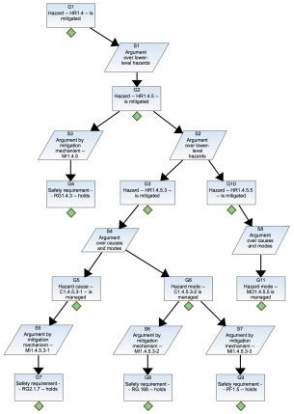


Artifacts

Requirements, Hazard Logs,
Design documents,
Test / verification records, ...

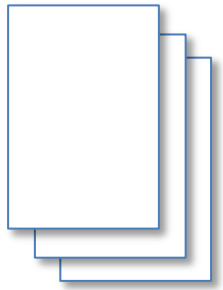


Bidirectional Mapping



Argument Fragments

- Automation in
  - Argument generation
  - Change update & impact analysis
  - Task generation
  - Confidence
  - ...



Tabular Requirements Specifications

Hazards Table

ID	Hazard	Cause / Mode	Mitigation	Safety Requirement
HR.1.3	Propulsion system hazards			
HR.1.3.1	Motor overheating	Insufficient airflow	Monitoring	RF.1.1.4.1.2
		Failure during operation		
HR.1.3.7	Incorrect programming of KD motor controller	Improper procedures to check programming before flight	Checklist	RF.1.1.4.1.9

System Requirements Table

ID	Requirement	Source	Allocation	Verification Method	Verification Allocation
RS.1.4.3	Critical systems must be redundant	AFSRB	RF.1.1.1.1.3		
RS.1.4.3.1	The system shall provide independent and redundant channels to the pilot	AFSRB			

Functional Requirements Table

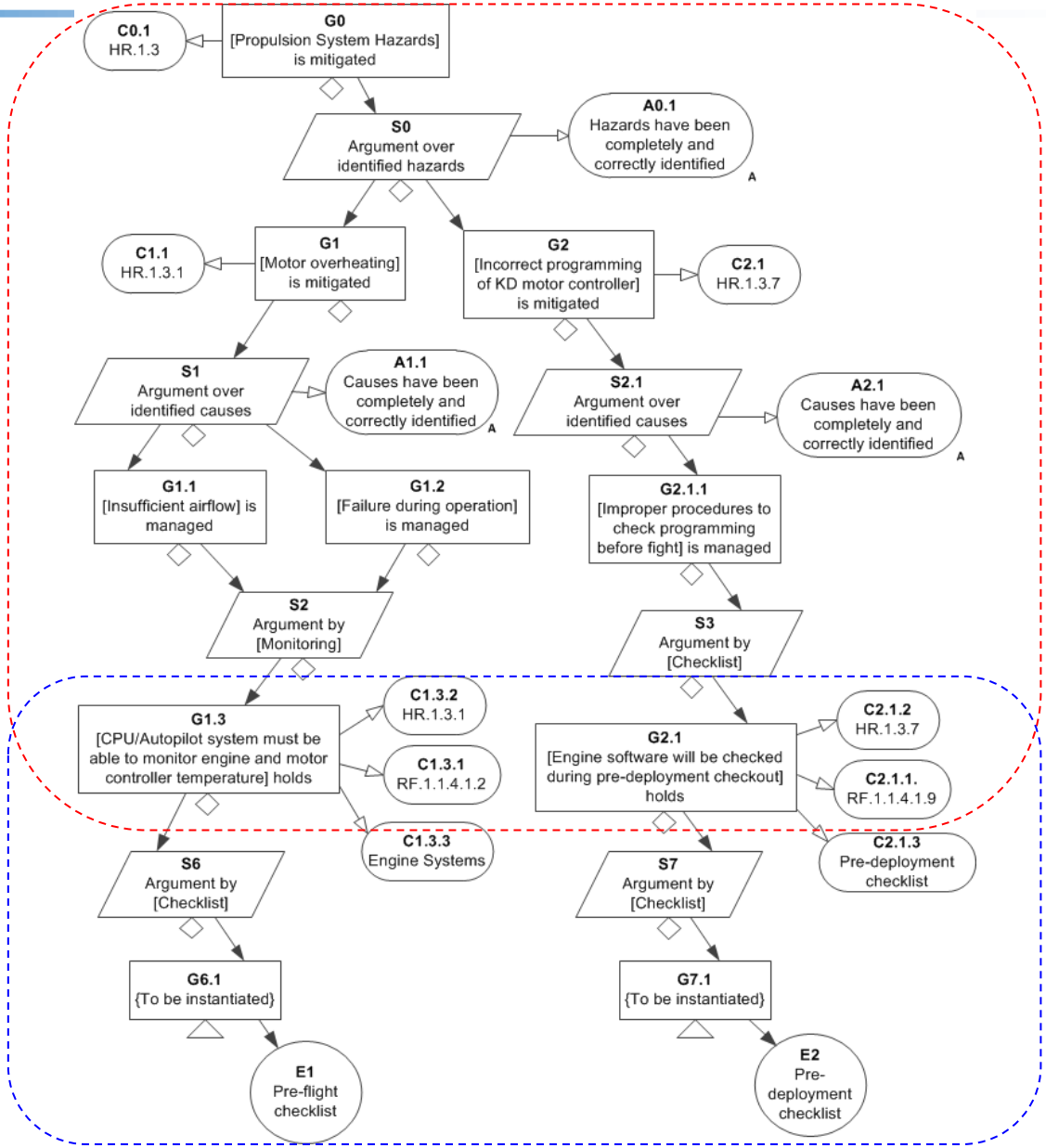
ID	Requirement	Source	Allocation	Verification Method	Verification Allocation
RF.1.1.1.1.3	FCS must be dually redundant	RS.1.4.3	FCS	Visual Inspection	FCS-CDR-20110701, TR20110826
RF.1.1.4.1.2	CPU/autopilot system must be able to monitor engine and motor controller temperature.	HR.1.3.1	Engine systems	Checklist	Pre-flight checklist
RF.1.1.4.1.9	Engine software will be checked during pre-deployment checkout	HR.1.3.7	Pre-deployment checklist	Checklist	Pre-deployment checklist

Mapping Multiple Tables

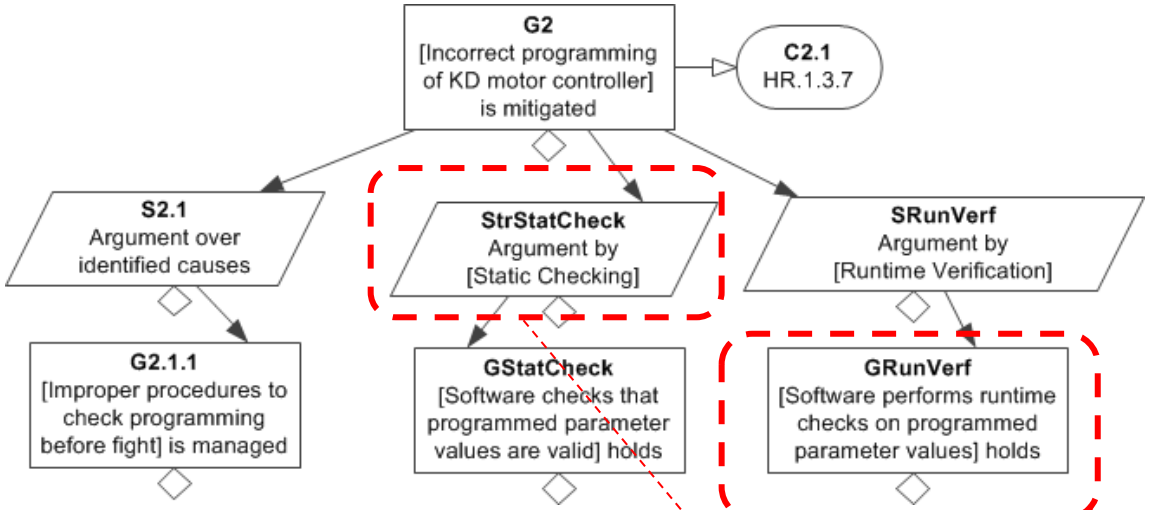
From hazards table

Linking tables using common content

From functional requirements table



Mapping Modifications



Evidence linking
(Strategy definition)

Claims definition

Hazards Table

ID	Hazard	Cause / Mode	Mitigation	Safety Requirement
HR.1.3	Propulsion system hazards			
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		Failure during operation		
HR.1.3.7	Incorrect programming of KD motor controller	Improper procedures to check programming before flight	Checklist	RF.1.1.4.1.9
		-	*Static checking*	*GStatCheck*
		-	*Runtime Verification*	*GRunVerf*

Comprehension: Motivating Queries and Views

- Real argument structures / safety cases are large
  - EUROCONTROL Airport surface surveillance with ADS-B preliminary safety case is 200 pages!
- Safety cases contain diverse information and heterogeneous reasoning
  - Results of various analyses, inspections, audits, reviews, simulations, other verification activities, etc.
  - Evidence of safe prior operations, if available / applicable
- Safety cases evolve
  - Assumptions validated / invalidated
  - Counterevidence, additional corroborative evidence, new evidence
- Need to improve comprehension, change management, assessment
  - Present role-specific information to stakeholder(s)
    - e.g., show traceability of different kinds to regulator
  - Updates safety case to be consistent with reality
  - Change safety case during as it evolves
  - Need to locate specific information for all of the above

Arguments, Queries, and Views

- Query
  - A pre-query Q, of *arity* 1, according to well-formedness rules

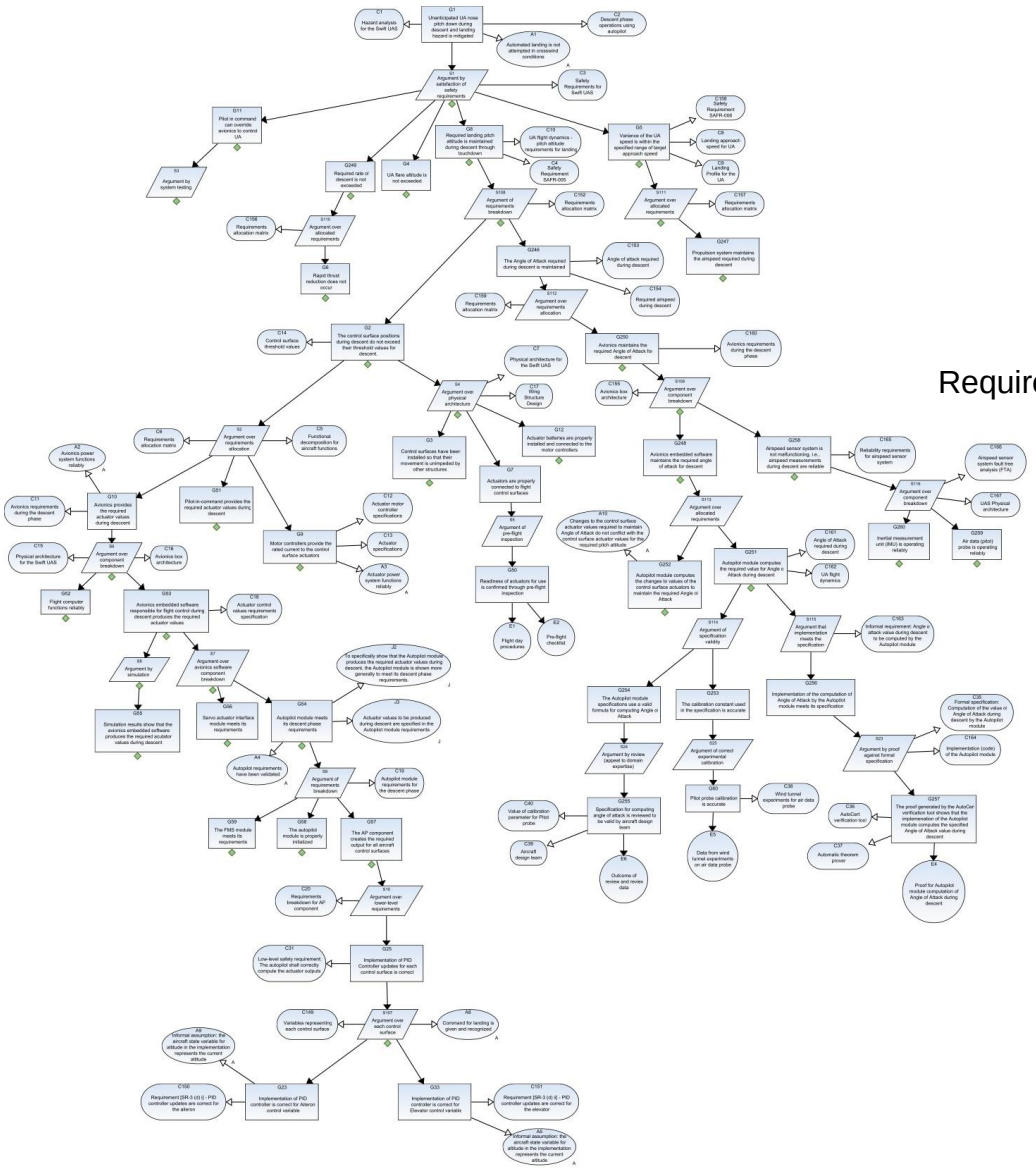
applied to

- Argument structure / diagram
  - Diagram in GSN showing the structure and elements of an argument

produces

- View: Sub-argument derived from query
  - Represented as a *View diagram*
    - Shows argument structure that satisfies the query
    - Hides all nodes that do not satisfy the query
    - Abstracted into *concealment* nodes (*C*-nodes)

Example Argument for Querying



Unanticipated UA nose pitch down during descent and landing hazard mitigation

Metadata
Regulatory requirements
System Organization
Requirement types, and relations

Arguments over safety requirements
Arguments over functional breakdown
Arguments over physical architecture
…

Diverse evidence

- Reviews
- Inspections
- System Testing
- …

AQL Queries and Views: Example

- Natural language query
  - Which parts of the argument structure address the FARs 14 CFR Parts 23.73 and 23.75?

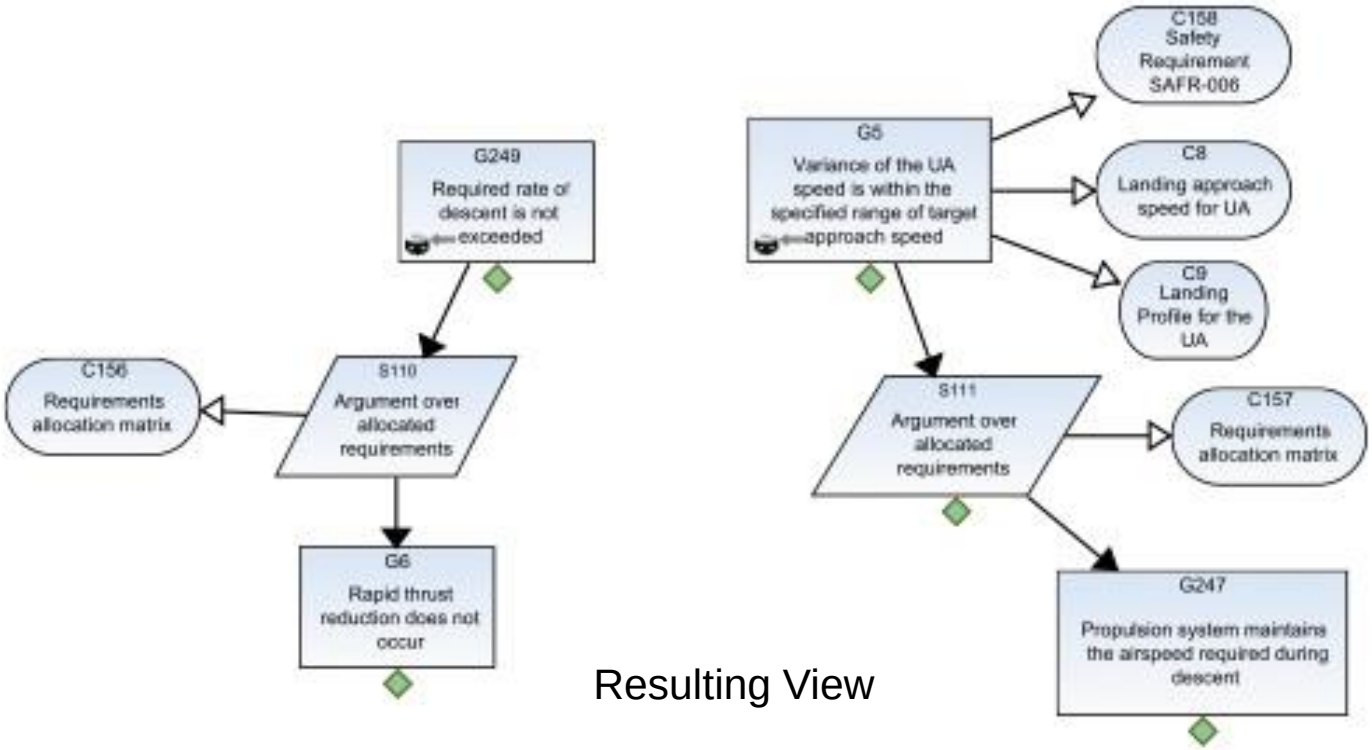
- Interpretation
  - Those fragments of the argument structure whose root goals contain claims related to the regulatory requirements 14 CFR 23.73, 23.75.

- Formulating an AQL query
  - Goal(s) where attributes (or description) have references to the regulations, or
  - Complete sub-trees with the goals above as root(s)

AQL Queries and Views: Example

AQL

(type **has** goal) and (attributes **has** (regulation (14CFR23.73) or
attributes **has** regulation(14CFR23.75)) or
E (isSolvedBy+)((attributes **has** (regulation (14CFR23.73) or
attributes **has** regulation(14CFR23.75))



Resulting View

Structuring: Motivating Hierarchy

- Safety cases aggregate heterogeneous reasoning and evidence
  - Safety / System / Subsystem / Component / Software Analysis
  - Requirements, Design information, Models, Code
  - Verification, Inspections, Reviews, Simulations
  - Data and records from prior/ongoing operations, maintenance, ...
- Aggregation of large amounts of information
  - Preliminary safety case ~ 200 pages
  - Slice of safety argument ~ 500+ nodes
- Structures that are inherently hierarchical
  - Requirements decomposition
  - Formal property decomposition
  - Physical / structural breakdown
- Represent argument at multiple levels of abstraction
  - Refine abstract to concrete, retaining trace between levels
- Modules vs hierarchy
  - Horizontal vs vertical decomposition

Abstraction Types

- Hierarchical node types
  - Hierarchical Goal: abstract well-developed argument fragments, hiding intermediate decomposition steps
    - e.g., Refinement and formalization of a requirement
  - Hierarchical Strategy: aggregate meaningful chain of strategies (plus supplemental reasoning)
    - e.g., Decomposition over system breakdown, followed by decomposition over operating phases
  - Hierarchical Evidence: fully developed argument chain (hierarchical strategy with no outgoing goals)
    - e.g., Formal decomposition of a requirement ending in proof

Example

MIZOPEX Ground-based Sense and Avoid (GBSAA)

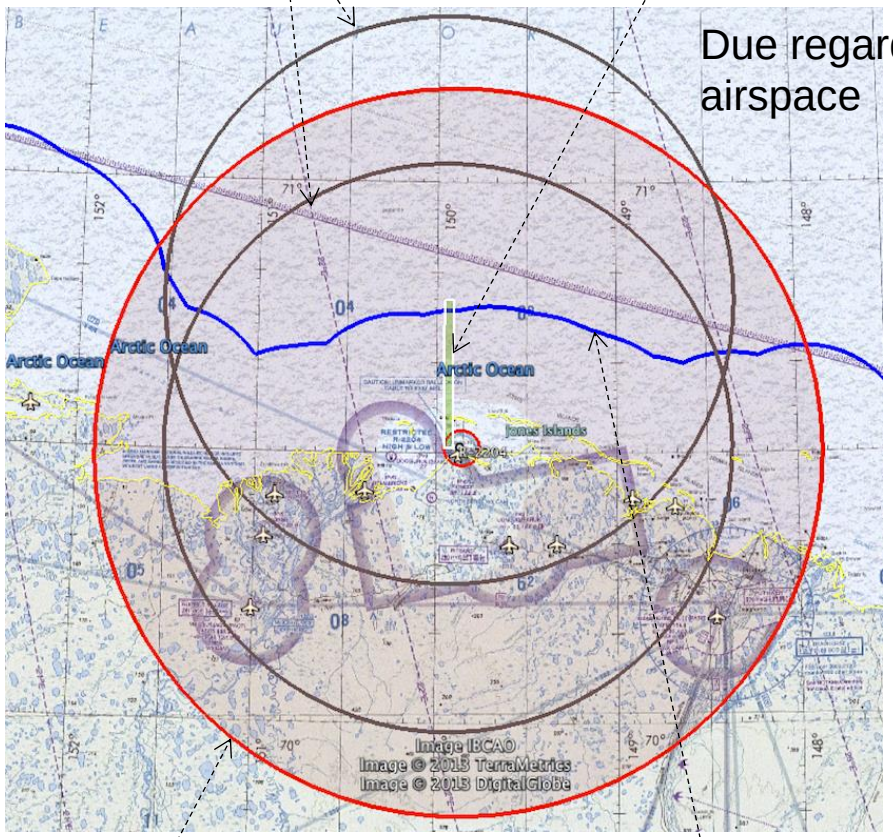
- Performing Earth Science measurements in the Arctic Ice
  - Off the coast of Alaska (Oliktok Point)
  - Satellite-based solution was too expensive
  - Use airborne instruments on UAS
    - Two classes of small UAS
    - NASA SIERRA; University of Alaska's Boeing Insitu ScanEagle
  - Too dangerous for visual observers
    - So use ground-based air defense RADAR for "sense-and-avoid"

- Considered an alternative means of compliance (AMOC) by the FAA
  - Hard requirement to submit a safety case for approval of operations by means of a Certificate of Authorization (COA)
  - Use N 8900.207, FAA National Policy Document on UAS operational approval guidance (now replaced by N 8900.227)
  - Our role
    - Create an operational safety case for this AMOC

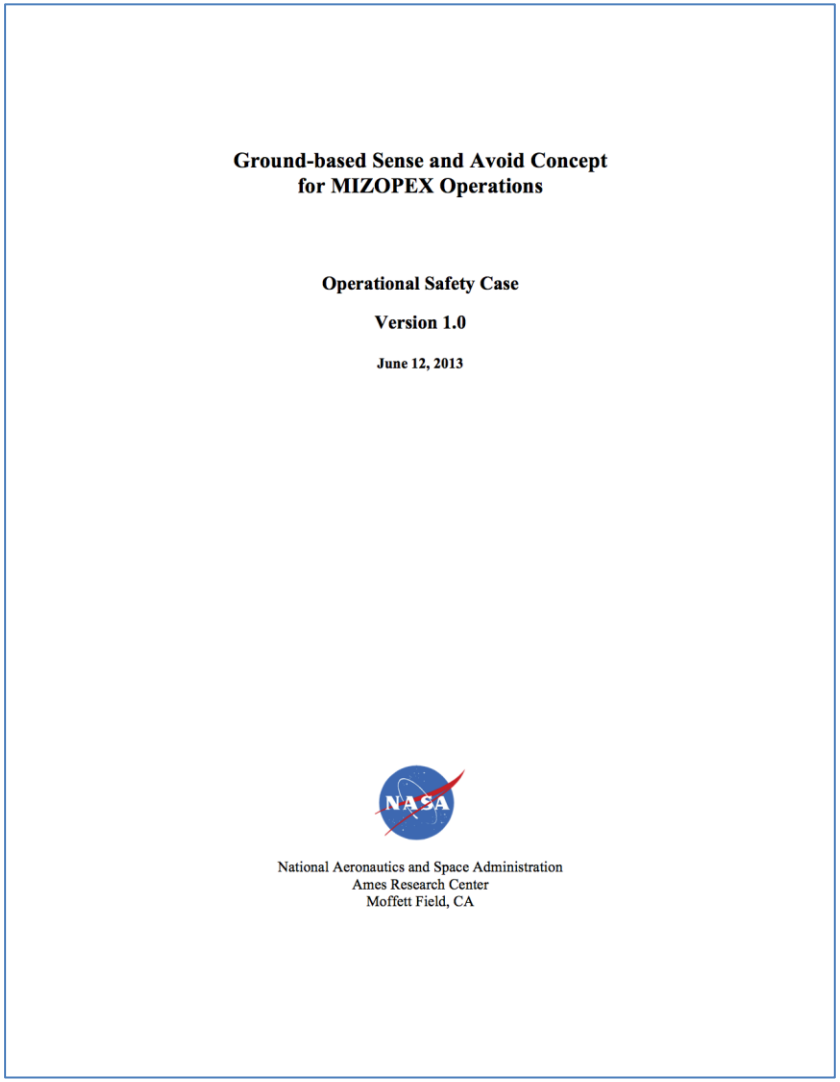
MIZOPEX GBSAA Concept

SIERRA UAV

Air Defense RADAR for monitoring and airspace deconfliction



MIZOPEX GBSAA Operational Safety Case



Ground-based Sense and Avoid Concept for MIZOPEX Operations

Operational Safety Case

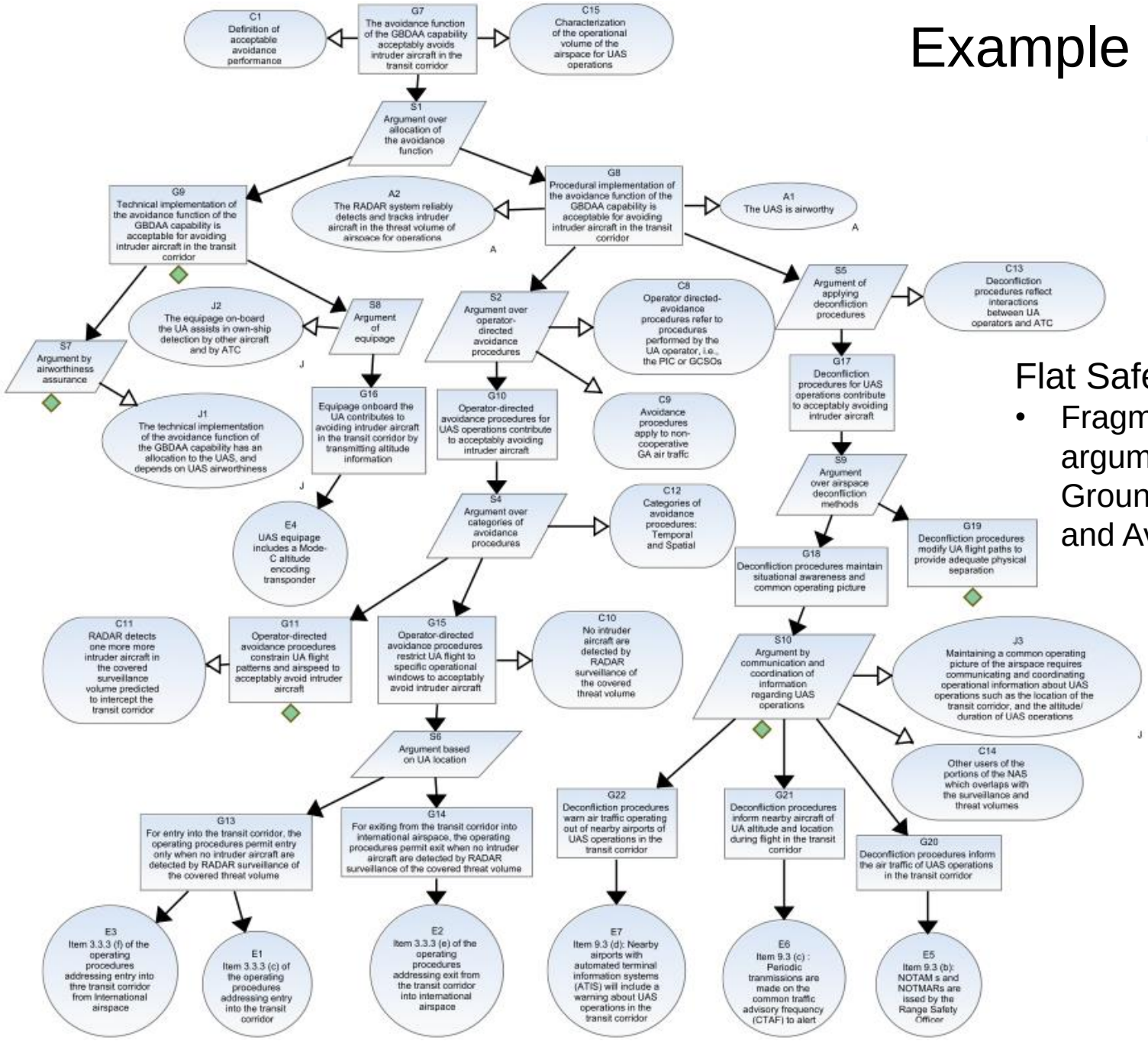
Version 1.0

June 12, 2013

National Aeronautics and Space Administration
Ames Research Center
Moffett Field, CA

- Accepted by the FAA, COAs granted
  - Primarily a report
  - Explicit argumentation not required to be communicated by the regulator
  - However, we are preparing safety arguments
  - First known example of GBSAA use for civilian UAS operations in the NAS
  - First known accepted safety case for civilian UAS operations in the NAS
  - Explicitly required hazard tracking and monitoring to validate assumptions and safety case

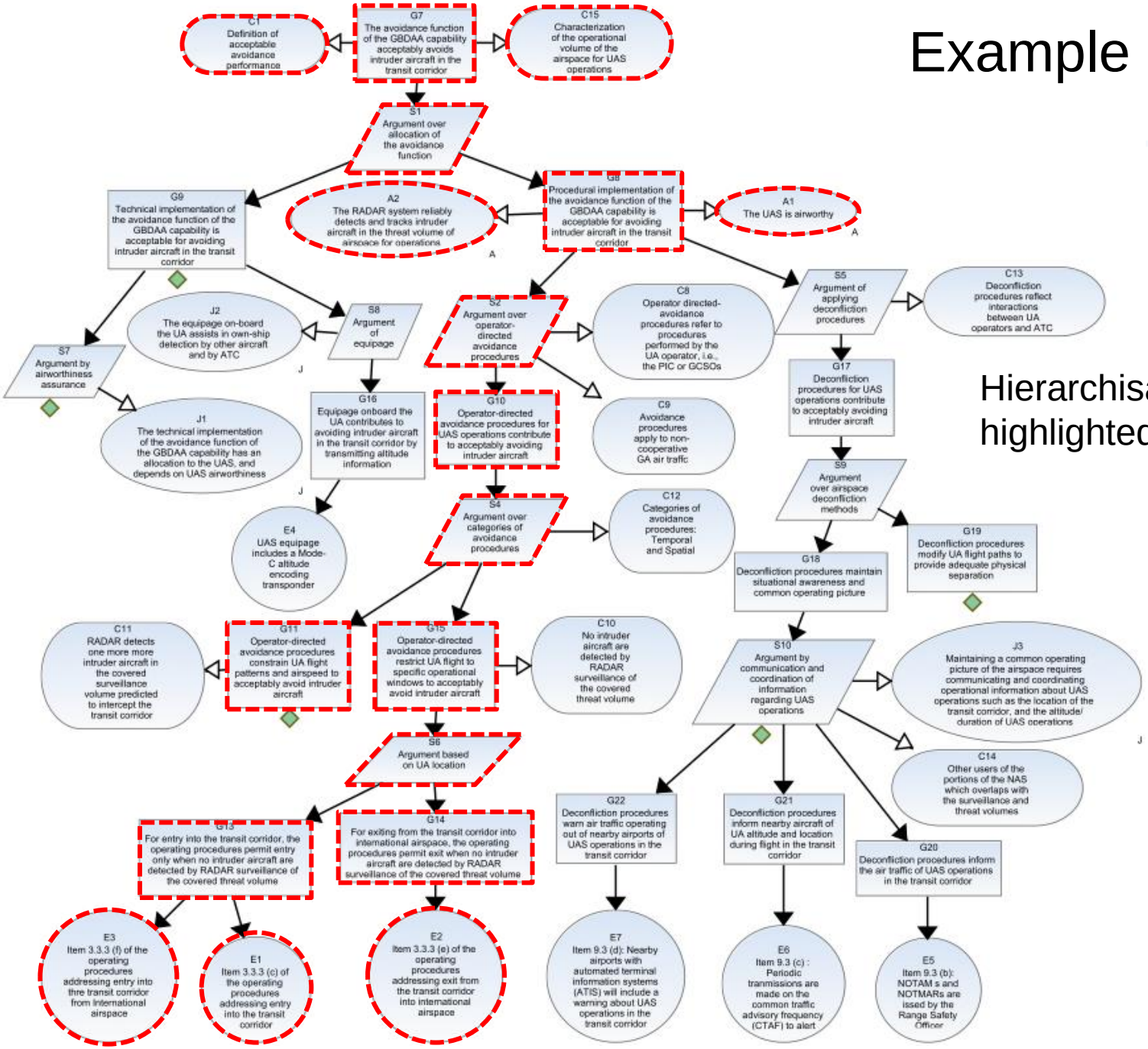
Example



Flat Safety Argument

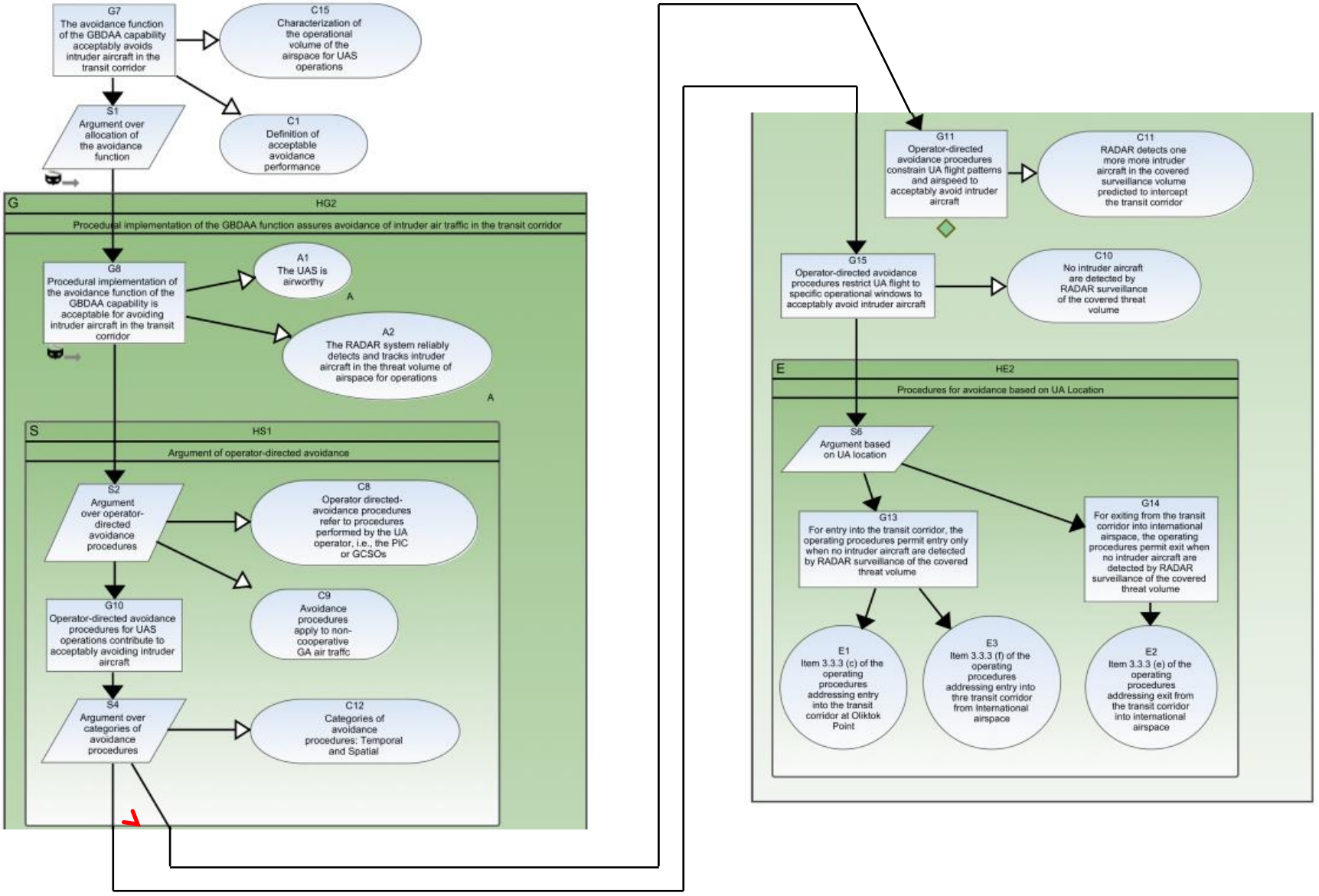
- Fragment of larger argument for Ground-based Detect and Avoid (GBDAA)

Example



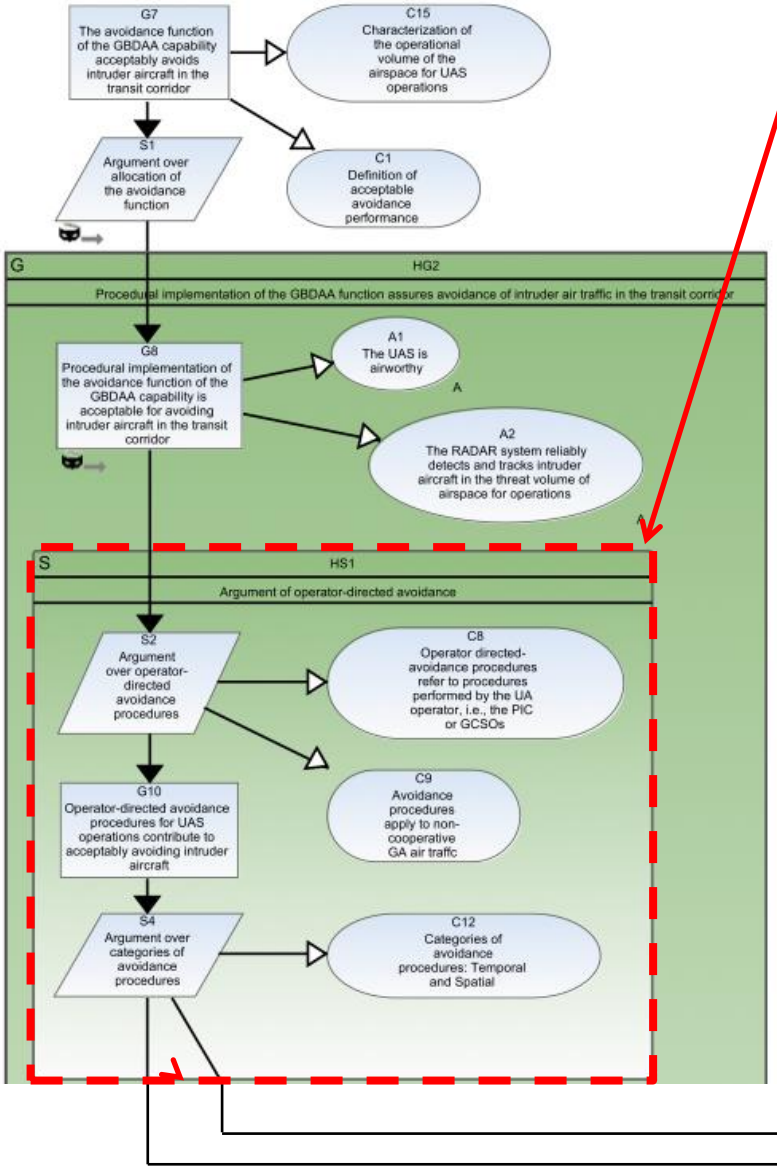
Hierarchisation of highlighted slice

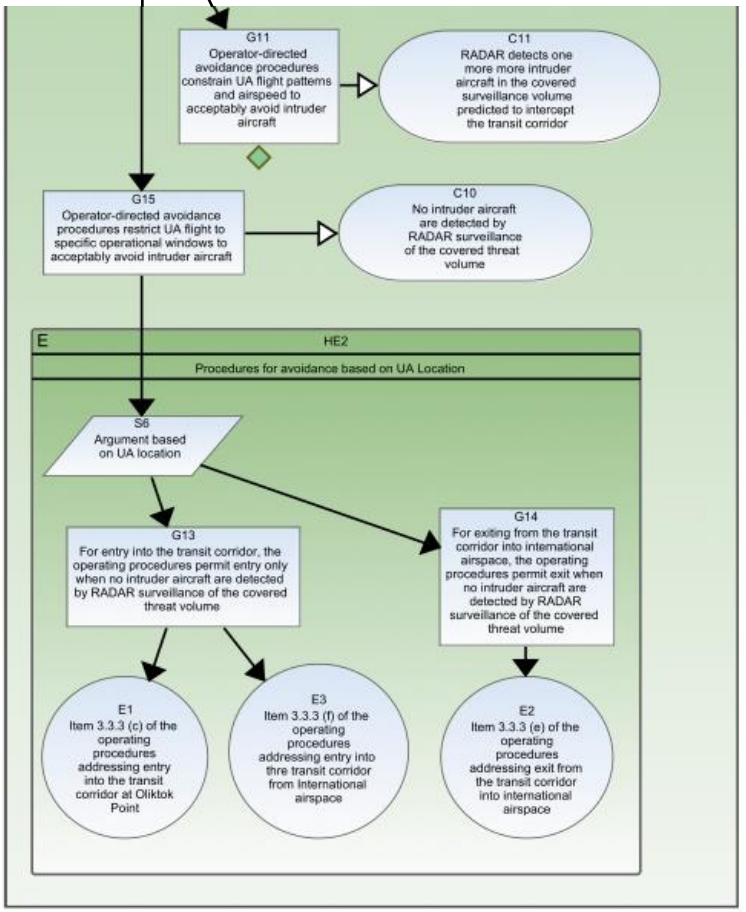
Hierarchised Fragment



A. Hierarchical Strategy (Open)

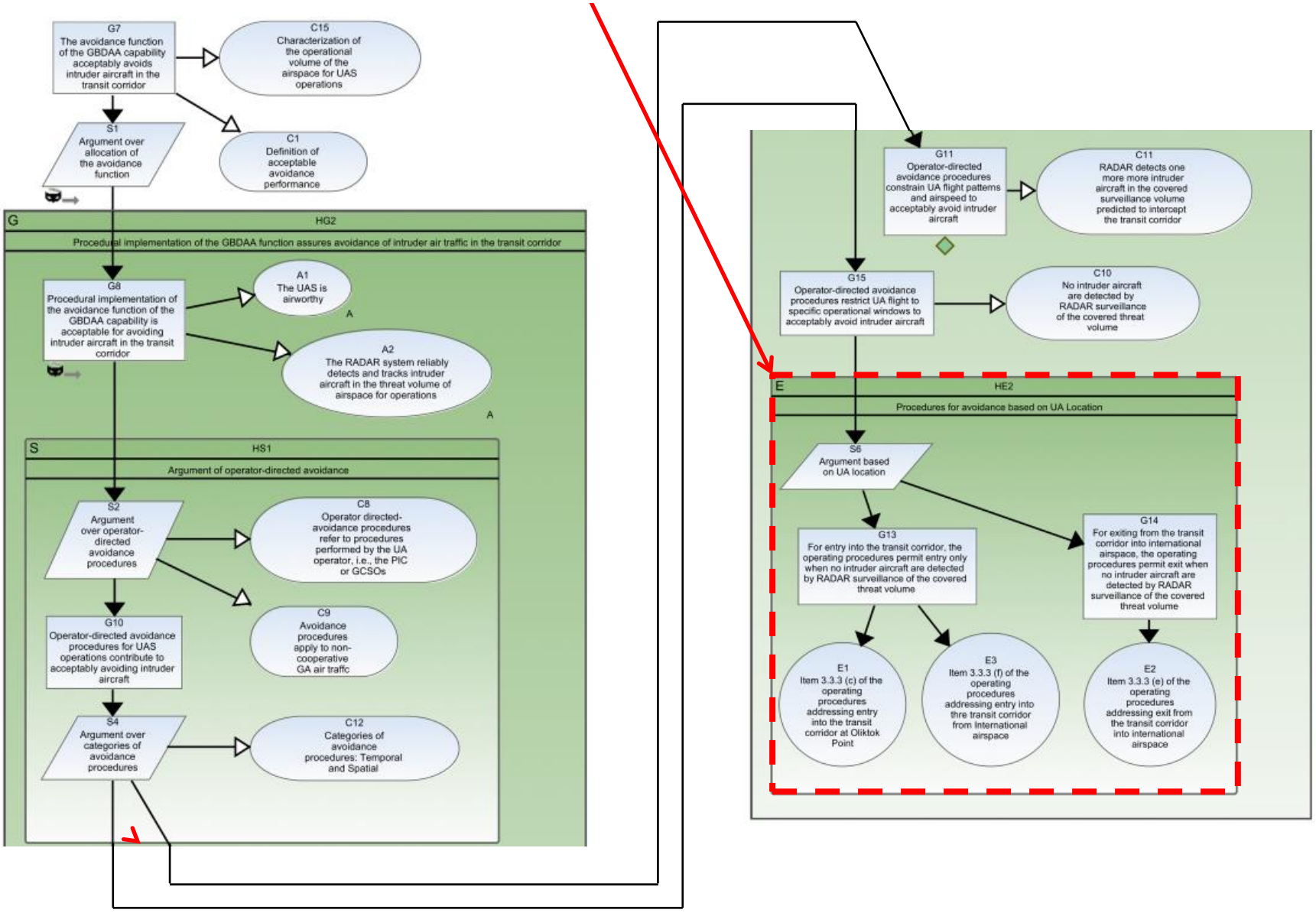
- Representing a chain of strategies
- "Operator directed avoidance" followed by "Categories of avoidance procedures"





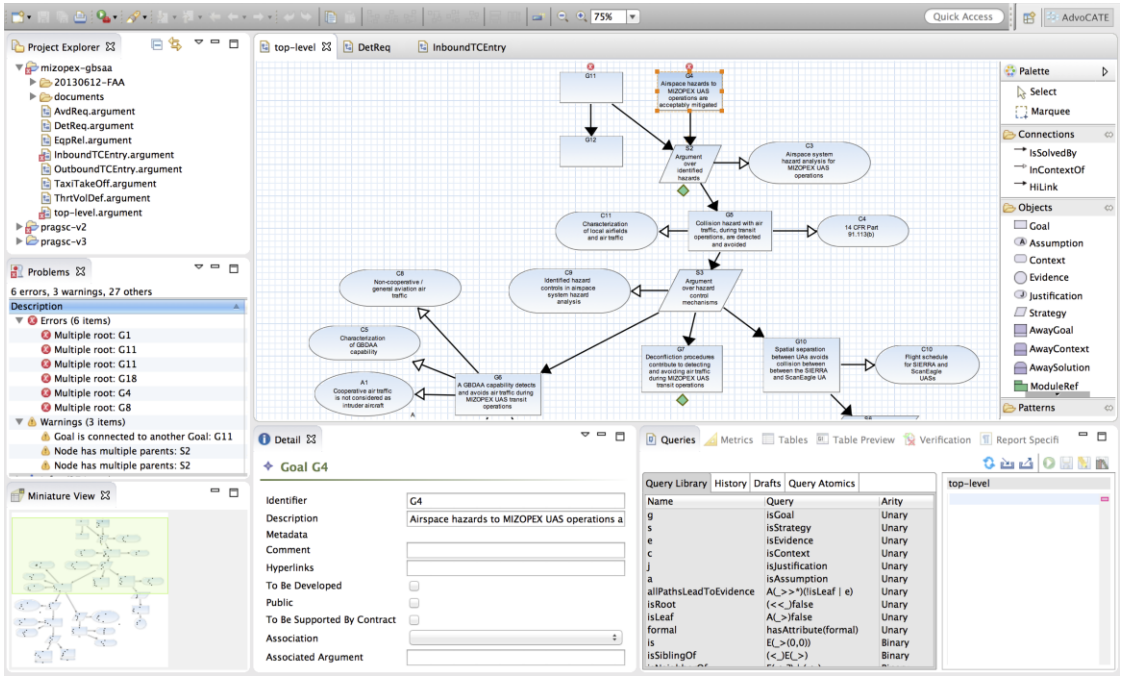
B. Hierarchical Evidence (Open)

- Representing procedures for avoidance based on aircraft location



Tool Support

AdvoCATE: Assurance Case Automation Toolset



- Creation of safety / assurance argument
  - Hyperlinks in nodes to documents, data for evidence, context, etc.
  - Metadata on nodes: hazards, high/low requirements, risk (severity, likelihood), provenance

Vision

Safety infor**m**ation, **a**ssurance and **r**isk managemen**t**

(SMART) Dashboard

- Functionality
  - Report generation
  - Generation of to-do lists
  - Generation of traceability matrices
  - Computation of metrics
  - Queries, views
  - Verification
- Structuring
  - Patterns
  - Modules
  - Hierarchy
- Integration/generation
  - Requirements tables
  - Formal methods

Concepts

Concepts: Syntax and Semantics

Syntax	Semantics
Proof	Inference Tree

Concepts: Syntax and Semantics

Syntax

Argument Structure

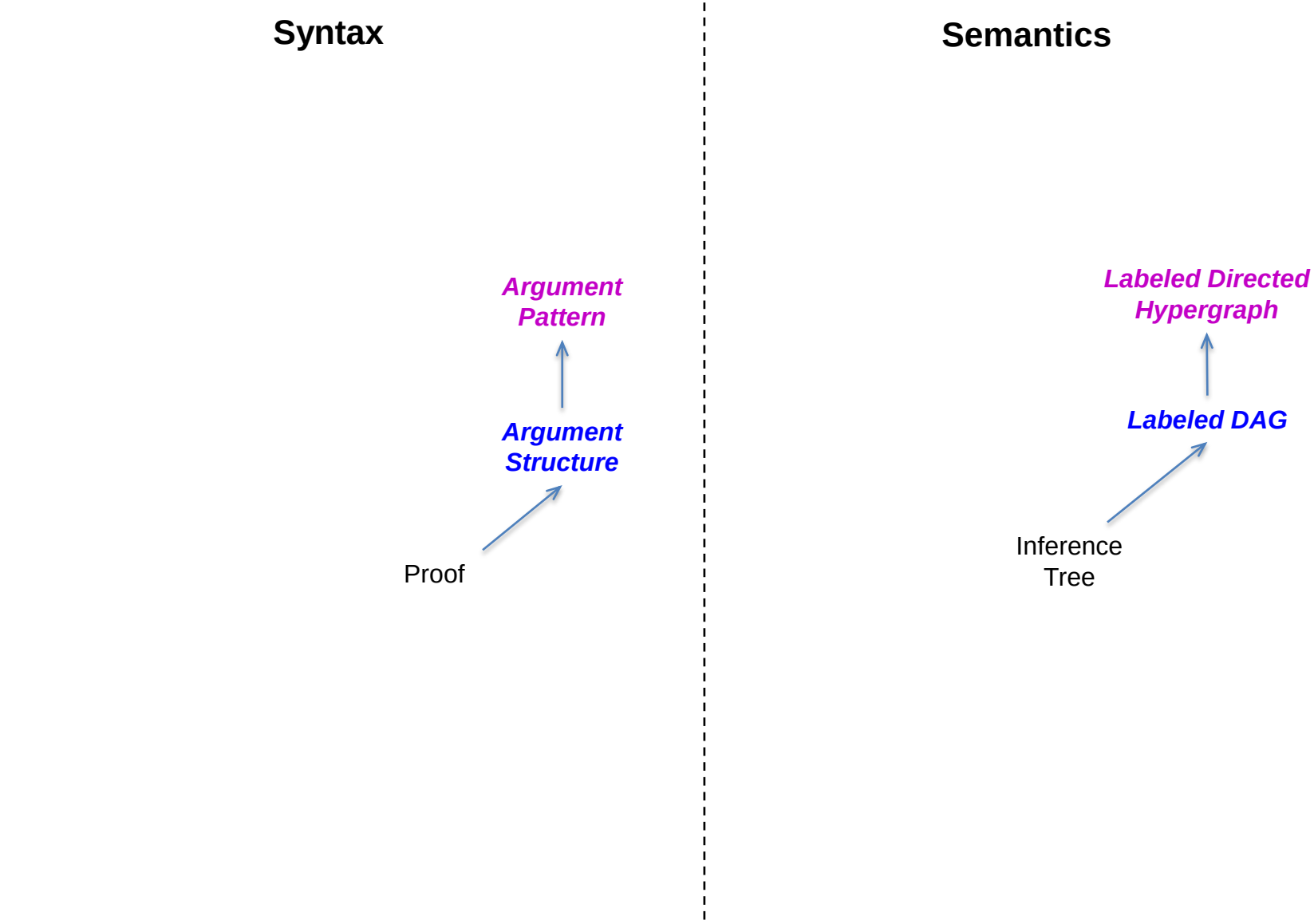
Proof

Semantics

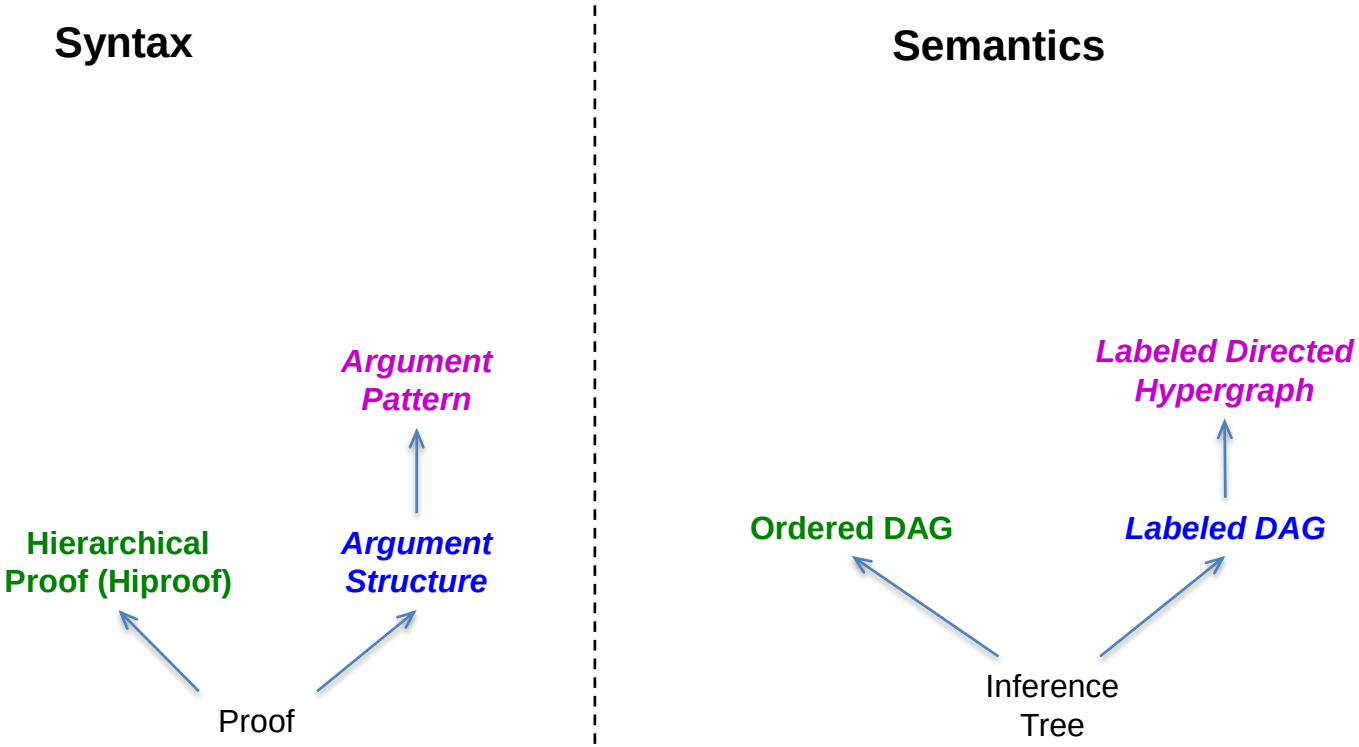
Labeled DAG

Inference Tree

Concepts: Syntax and Semantics

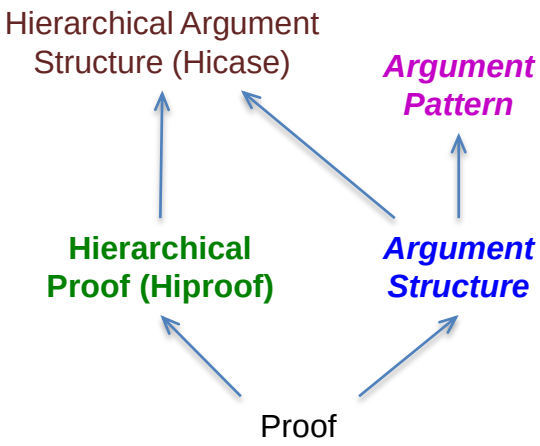


Concepts: Syntax and Semantics

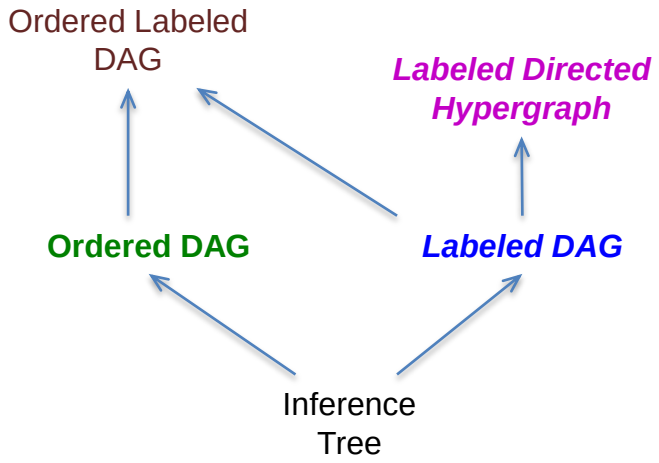


Concepts: Syntax and Semantics

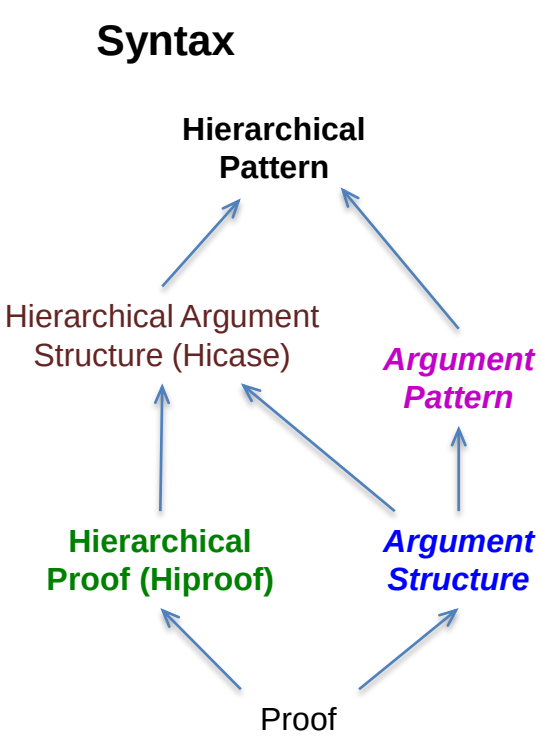
Syntax

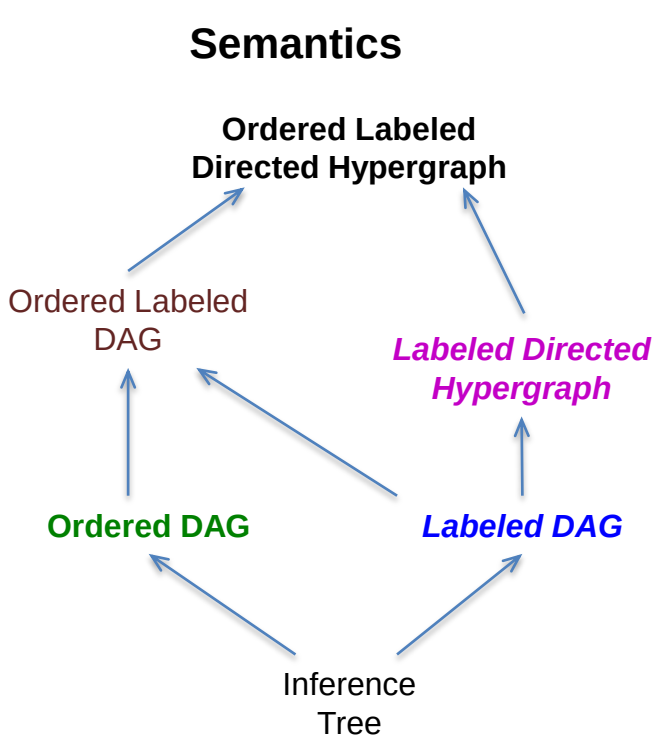


Semantics

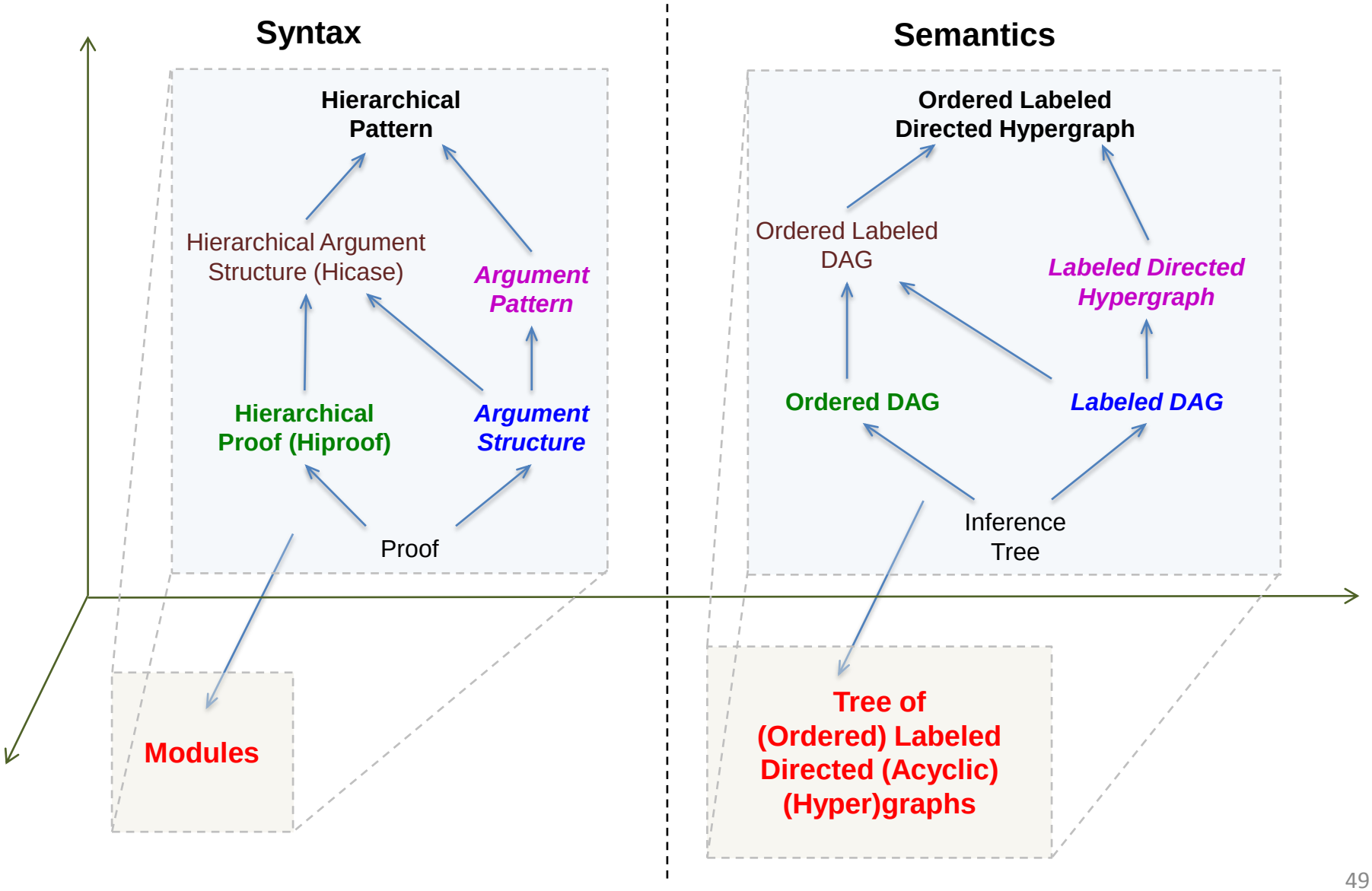


Concepts: Syntax and Semantics





Concepts: Syntax and Semantics



Conclusions

- An argument is a means to an end
- Automation: Why?
  - Consistency and evolution
  - Comprehension, analysis, and review
  - Reuse
- Automation: How?
  - Pattern instantiation and transformation
  - Querying, views, metrics, verification
  - Confidence
- Rigorous basis
  - Family of reasoning structures: arguments + metadata
  - Spectrum of language formality: natural → lightweight → formal
  - Ongoing work on integrating confidence quantification
  - Formal basis for dynamic safety cases
- Raising the level of abstraction of arguments
  - cf. Model-based development
  - Implemented in AdvoCATE
  - Need to *qualify* argument generation tool

Questions

- When are arguments appropriate, and when performance standards?
- When is formalism appropriate?
- What is appropriate level of abstraction? Can we assign automatically?
- What is basis for round-trip engineering?
- What is relation between language structure and reasoning structure?
- What is high-level domain-specific query language?
- How to combine hierarchy and patterns?
- What are views for modules, hierarchy?

Please consider attending

3rd International Workshop on Assurance Cases for Software-intensive Systems (ASSURE 2015)

September 22, 2015. Delft, The Netherlands.

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