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On the Interpretation Of Assurance Case Arguments

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Introduction

- I'm focused on the assurance and certification of software for commercial airplanes
- Currently assured by DO-178C
  - Enumerates 71 "objectives" that must be satisfied for the most critical software
  - e.g., "Ensure that each High Level Requirement (HLR) is accurate, unambiguous, and sufficiently detailed, and that the requirements do not conflict with each other" [Section 6.3.1.b]
- It seems to work: no incidents due to flaws in software implementation
  - DO-178C is about correctness of implementation wrt HLR
  - ARP 4754 and others are concerned with safety of HLR

Introduction (ctd.)

- But the world is changing
  - NextGen integrates once separate air and ground systems
  - Unmanned vehicles in same airspace
  - More autonomous systems
  - New methods of software development and assurance
- We don't really know why DO-178C works
  - So difficult to predict impact of changed environment
  - And difficult to update (10 years to go from B to C)
- So look at Assurance Cases as a possible way forward
  - Retrospective reformulation of DO-178C as an assurance case (Michael Holloway)
  - Then look for a scientific basis to assurance cases

Assurance Cases

- The idea is that we "make the case" to justify deployment of some system by
  - Stating the claim that it must satisfy
    - ⋆ Generally safety- or correctness-related
  - Developing evidence about its assumptions, design, implementation, performance etc.
  - Constructing a structured argument that justifies the claim, based on the evidence
- How should we interpret these arguments?
- And what are the expectations on them?
  - "compelling, comprehensible and valid" [00-56]
  - Are these all the same?

Complications: Inductive and Deductive Arguments

- The world is an uncertain place (random faults and events)
- Our knowledge of the world is incomplete, may be flawed
- Our reasoning may be flawed also
- So an assurance case cannot expect to prove its claim
- Hence, the overall argument is inductive
  - Evidence & subclaims strongly suggest truth of top claim
- Rather than deductive
  - Evidence & subclaims imply or entail the top claim

Complications: Confidence Items

- If the overall argument is inductive
- Does that mean all its steps may be inductive too?
- Traditionally, yes!
  - Considered unrealistic to be completely certain
  - cf. ceteris paribus hedges in science
- Can add ancillary confidence items to bolster confidence in inductive steps
  - Evidence or subclaims that do not directly contribute to the argument
  - i.e., their falsity would not invalidate the argument
  - But their truth increase our confidence in it
- Eh?

Complications: Graduated Assurance

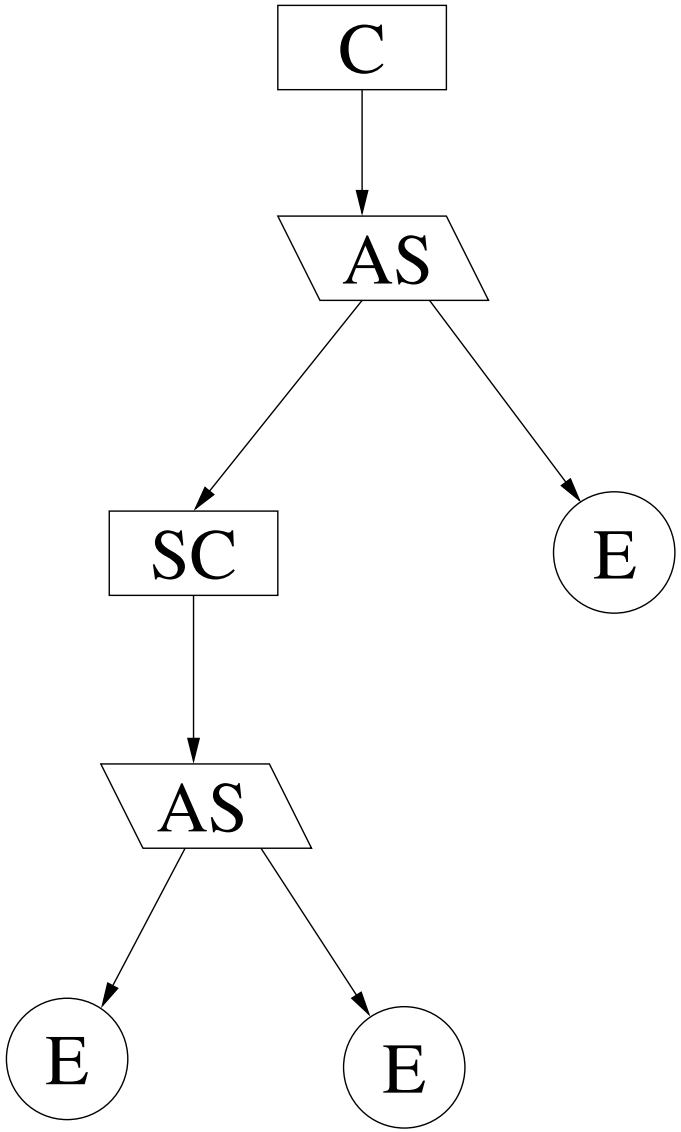
- Assurance is expensive, so most standards and guidelines allow less assurance effort for elements that pose lesser risks
- E.g. DO-178C
  - 71 objectives for Level A, 33 with independence
  - 69 objectives for Level B, 21 with independence
  - 62 objectives for Level C, 8 with independence
  - 26 objectives for Level D, 5 with independence
- So if Level A is "compelling, comprehensible and valid"
- The lower levels must be less so, or not so
- We need some idea what is lost, and a measure of how much

Proposed Interpretation

- Clearly need a semantics to account for all this
- I'm going to propose a simple, even obvious, semantics for a sound assurance case
- I further propose that only sound assurance cases should be accepted
- However, sound assurance cases can have different strengths

Structured Argument

In a generic notation (GSN shapes, CAE arrows)



C: Claim

AS: Argument Step

SC: Subclaim

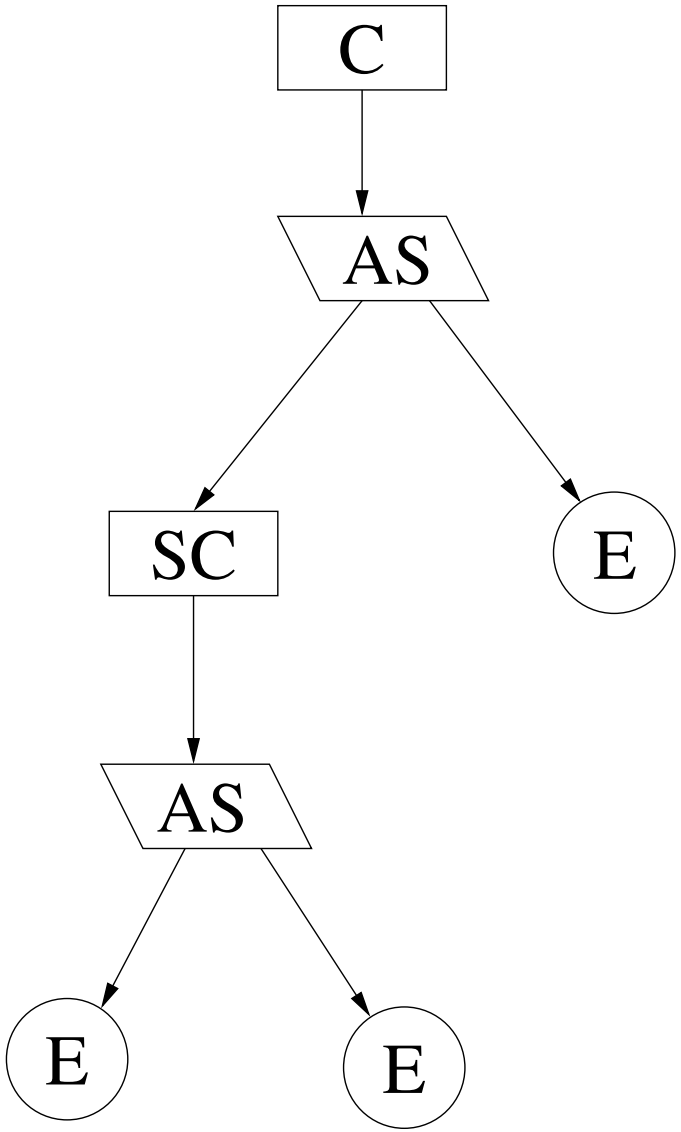
E: Evidence

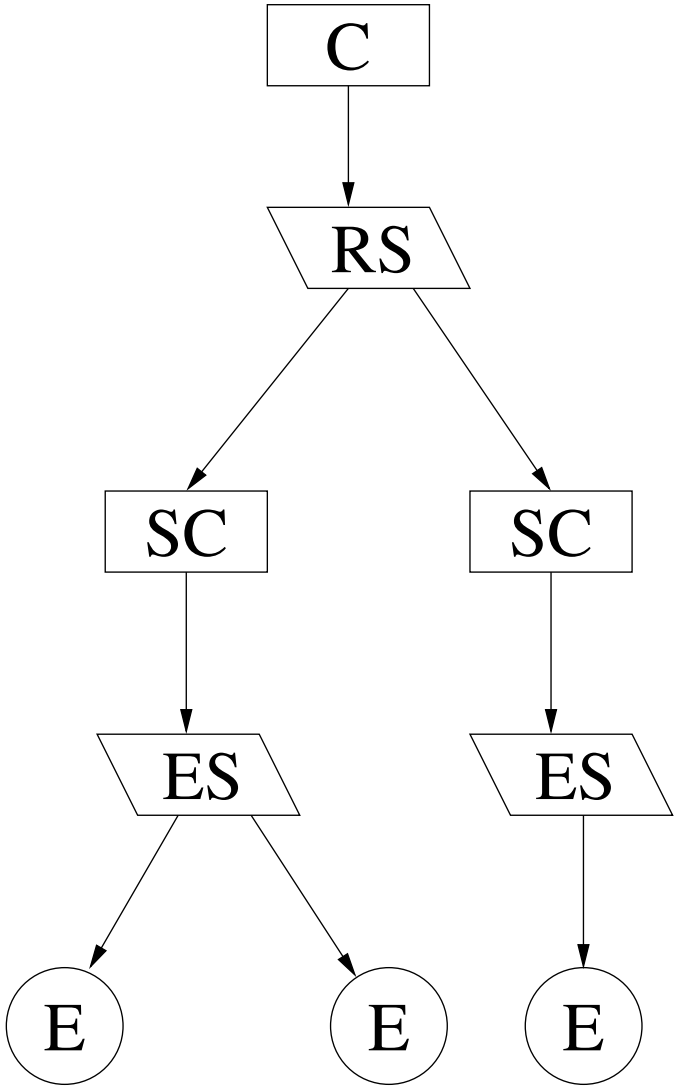
A hierarchical arrangement of argument steps, each of which justifies a claim or subclaim on the basis of further subclaims or evidence

Argument Steps and Layered Arguments

- We decompose top-level claim into conjunction of subclaims
- And iterate
- Until we get down to subclaims supported by evidence
- Provide a narrative justification for each step
- Easier to understand when just two kinds of argument steps
  - Reasoning steps: subclaim supported by further subclaims
  - Evidential steps: subclaim supported by evidence
- Call this a simple form argument
  - Can normalize to this form by adding subclaims
  - In the paper I explain how to give a direct interpretation

Normalizing an Argument to Simple Form





RS: reasoning step; **ES**: evidential step

Why Focus on Simple Form?

- The two kinds of argument step are interpreted differently
- Evidential steps
  - These are about epistemology: knowledge of the world
  - Bridge from the real world to the world of our concepts
  - Have to be considered inductive
  - Multiple items of evidence are "weighed" not conjoined
- Reasoning Steps
  - These are about logic/reasoning
  - Conjunction of subclaims leads us to conclude the claim
    - ⋆ Deductively: subclaims imply claim (my preference)
    - ⋆ Inductively: subclaims suggest claim
- Combine these to yield complete arguments
  - Those evidential steps whose weight crosses some threshold of credibility are treated as premises in a classical deductive interpretation of the reasoning steps

Weighing Evidential Steps

- We measure and observe what we can
  - e.g., test results
- To infer a subclaim that is not directly observable
  - e.g., correctness
- Different observations provide different views
  - Some more significant than others
  - And not all independent
- "Confidence" items can be observations that vouch for others
  - Or provide independent backup
- Need to "weigh" all these in some way
- Probabilities provide a convenient metric
- And Bayesian methods and BBNs provide tools

The Weight of Evidence?

- Plausible to suppose that we should accept claim C given evidence E when $P(C \mid E)$ exceeds some threshold
- These are subjective probabilities expressing human judgement
- Experts find $P(C \mid E)$ hard to assess
- And it is influenced by prior $P(C)$, which can express ignorance. . . or prejudice
- Instead, factor problem into alternative quantities that are easier to assess and of separate significance
- So look instead at $P(E \mid C)$
  - Related to $P(C \mid E)$ by Bayes' Rule
  - But easier to assess likelihood of observations given claim about the world than vice versa

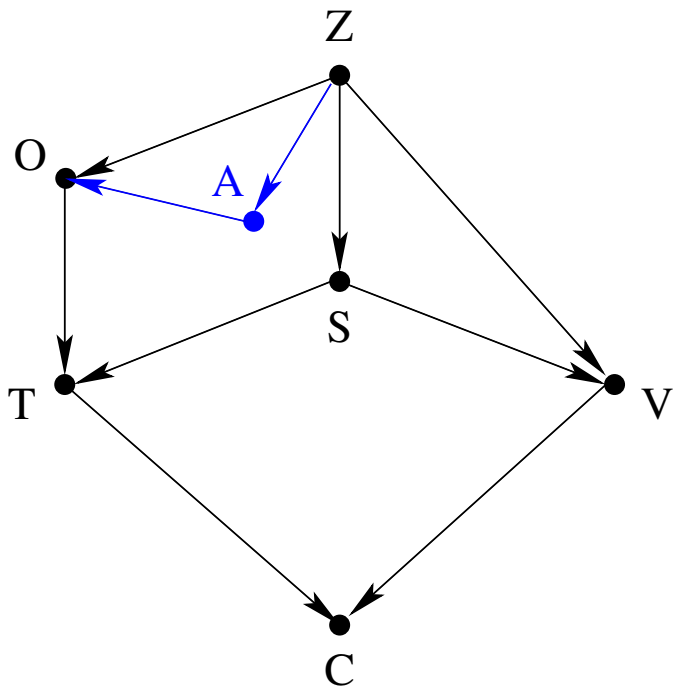
Confirmation Measures

- We really are interested in the extent to which E supports C . . . rather than its negation $\neg C$
- So focus on the ratio or difference of $P(E \mid C)$ and $P(E \mid \neg C)$, . . . or logarithms of these
- These are called confirmation measures
- They weigh C and $\neg\, C$ "in the balance" provided by E
- Suggested that these are what criminal juries should be instructed to assess (Gardner-Medwin)
- Good's measure: $\log \dfrac{P(E \mid C)}{P(E \mid \neg\, C)}$
- Kemeny and Oppenheim's measure: $\dfrac{P(E \mid C) - P(E \mid \neg\, C)}{P(E \mid C) + P(E \mid \neg\, C)}$
- Much discussion on merits of these and other measures

Application of Confirmation Measures

- I do not think the specific measures are important
- Nor do I advocate applying these methods to the evaluation of individual arguments
- Rather, use BBNs and confirmation measures for what-if investigations
  - Can help in selection of evidence for evidential steps
  - e.g., refine what objectives DO-178C should require
- Example (next slides) use of "artifact quality" objectives as confidence items in DO-178C

Weighing Evidential Steps With BBNs



Z: System Specification

O: Test Oracle

S: System's true quality

T: Test results

V: Verification outcome

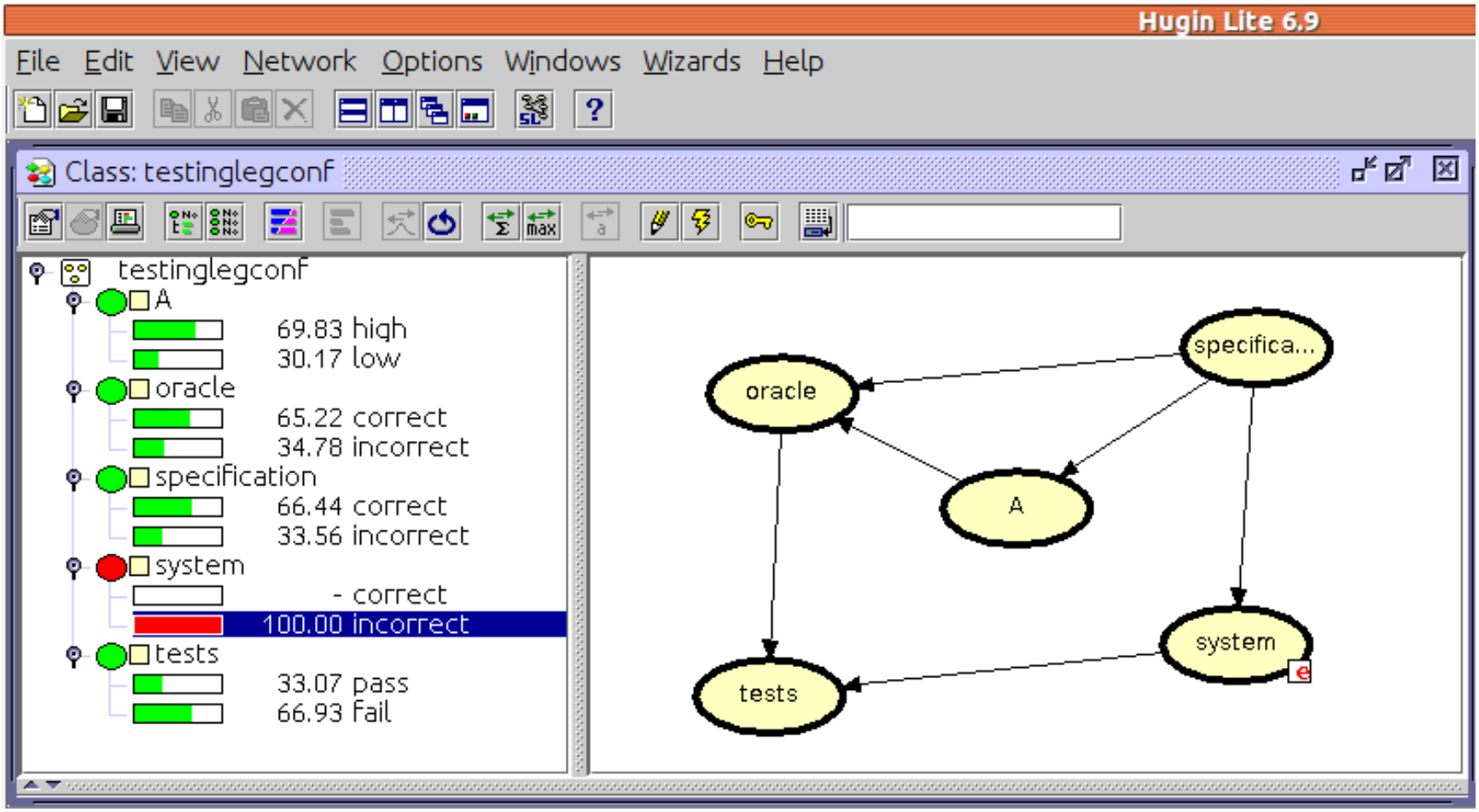
A: Specification "quality"

C: Conclusion

Example joint probability table: successful test outcome

Correct System		Incorrect System	
Correct Oracle	Bad Oracle	Correct Oracle	Bad Oracle
100%	50%	5%	30%

Example Represented in Hugin BBN Tool



Evaluating Reasoning Steps

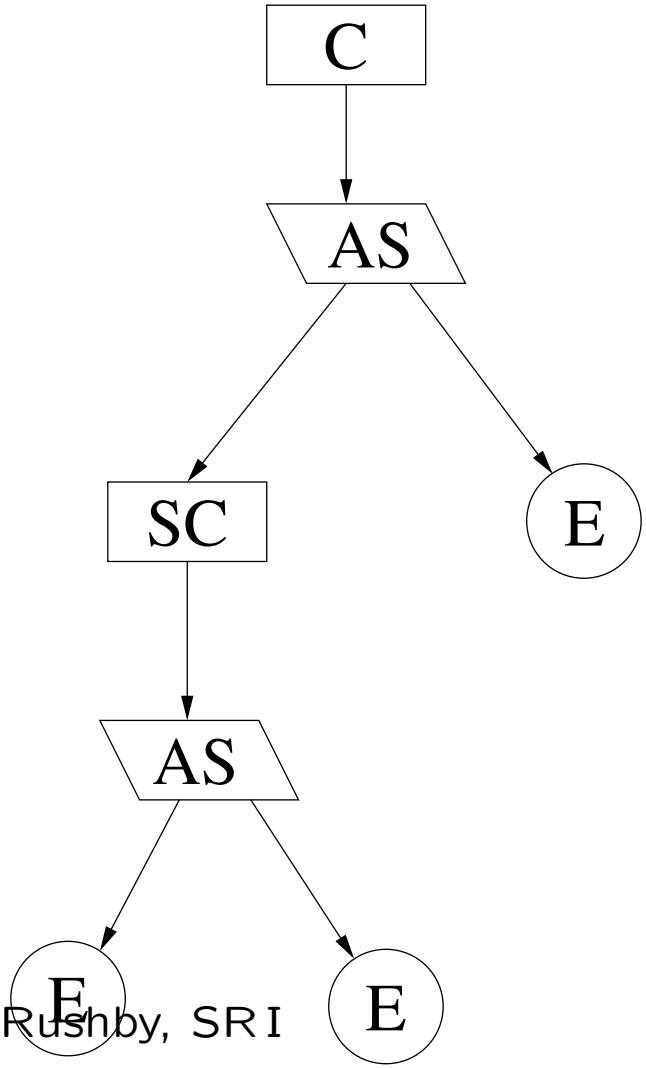
- When all evidential steps cross our threshold for credibility, we use them as premises in a classical interpretation of the reasoning steps
  - Deductive: p_1 AND p_2 AND $\cdots$ AND p_n IMPLIES c
  - Inductive: p_1 AND p_2 AND $\cdots$ AND p_n SUGGESTS c
- I advocate the deductive interpretation, for three reasons
  - There is no classical interpretation for inductive reasoning
    - ⋆ Many proposals: Dempster-Shafer, fuzzy logic, probability logic
    - ⋆ But none universally accepted
    - ⋆ And they flatten the argument (forthcoming slide)
  - Inductive reasoning is not modular: must believe either the gap is insignificant (so deductive), or taken care of elsewhere (so not modular)
  - There is no way to evaluate the size of the gap in inductive steps (next slide)

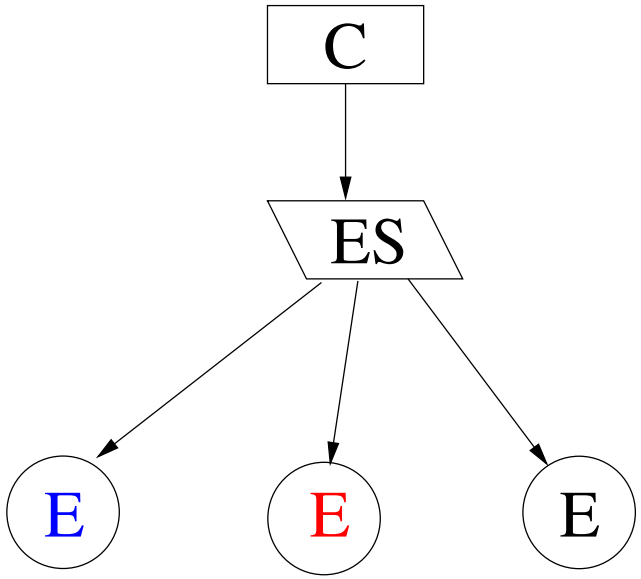
The Inductive Gap

- Must surely believe inductive step is nearly deductive and would become so if some missing subclaim or assumption a were added
  - p_1 AND p_2 AND $\cdots$ AND p_n SUGGESTS c
  - a AND p'_1 AND p'_2 AND $\cdots$ AND p'_n IMPLIES c
- If we knew anything at all about a it would be irresponsible not to add it to the argument
- Since we did not do so, we must be ignorant of a
- Follows that we cannot estimate the doubt in inductive argument steps

Probabilistic, Fuzzy and D-S Interpretations

- Insensitive to logical content of reasoning steps
- Effectively replace each subclaim by its supporting evidence
- Thereby flattening the argument





Flattened Arguments

- There's a reason we don't do this
  - An assurance case is not just a pile of evidence
    - ⋆ That's DO-178C, for example
  - It is an argument
  - With a structure based on our reasoning about the system

- So the reasoning steps should be interpreted in logic

Graduated Assurance

- I'll say an assurance case is valid if its reasoning steps are judged to be deductively valid
  - Expect to see justification in some form
- A valid case is sound if in addition its evidential steps cross the threshold for credibility
  - All inductive doubts located here
- For graduated assurance, need some additional notion of argument strength
- One approach to weakening an argument for lower levels is to reduce the threshold on evidential steps
- But others actually change the argument
  - E.g., Level D of DO-178C removes the Low Level Requirements (LLR) and all attendant steps

Evaluating Argument Strength Under Reduced Thresholds

- Although I don't advocate flattening then BBNs
  - As a way to evaluate soundness of an argument
- It could be a way to quantify strength of a sound argument
- More simply
  - Just sum (Adams' Uncertainty Accumulation)
  - Or multiply (independence assumption)

  The probabilities calculated (by BBNs) for evidential steps
- Beware of gaming:
  - Combining subclaims to maximize strength measure
- Could do this on an ordinal scale (low, medium, high, etc.)
- Note that it's a weakest link calculation
- Graduated assurance retains soundness, reduces strength

Evaluating Argument Strength Under Changes

- Recall Level D of DO-1788C changes the argument
  - Removes everything to do with LLR
- Reason for LLR is not just more evidence, but the credibility of the overall argument strategy
  - More credible to go from HLR to EOC via LLR (Levels A, B, C)
  - Than in a single leap (Level D)
- So there's more to it than just evidential strength
  - Topic for future work: related to ability to withstand defeaters

Conclusion

- Interpretation is a combination of probability and logic
- (Possibly informal) probabilities for evidential steps
- Logic for reasoning steps
- Case is sound **if** evidential steps cross some threshold **and** reasoning steps are deductively valid
  - All inductive doubt is located in the evidential steps
  - Inductive reasoning steps are too low a bar
- Graduated Assurance may weaken evidential support
  - Overall strength of a sound case is then determined by weakest evidential step
  - Can formalize this in probability logic, but I think the real appeal has to be to intuition and consensus. . .
- Deeper notion of strength needed for other forms of graduated assurance: defeaters and argumentation frameworks may be the way to go here

Links

- Lengthy report: http://www.csl.sri.com/~rushby/abstracts/assurance-cases15

- What do you think?