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Scientific Certification

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Does The Current Approach Work?

- Fuel emergency on Airbus A340-642, G-VATL, on 8 February 2005 (AAIB SPECIAL Bulletin S1/2005)
- Toward the end of a flight from Hong Kong to London: two engines shut down, crew discovered they were critically low on fuel, declared an emergency, landed at Amsterdam
- Two Fuel Control Monitoring Computers (FCMCs) on this type of airplane; they cross-compare and the “healthiest” one drives the outputs to the data bus
- Both FCMCs had fault indications, and one of them was unable to drive the data bus
- Unfortunately, this one was judged the healthiest and was given control of the bus even though it could not exercise it
- Further backup systems were not invoked because the FCMCs indicated they were not both failed
Safety Culture

- See also incident report for Boeing 777, 9M-MRG (Malaysian Airlines, near Perth Australia)

- It seems that current development and certification practices may be insufficient in the absence of safety culture

- Current business models are leading to a loss of safety culture
  - Outsourcing, COTS

- Safety culture is implicit knowledge

- Surely, a certification regime should be effective on the basis of its explicit requirements
Approaches to Software Certification

- The implicit (or indirect) standards-based approach
  - Airborne s/w (DO-178B), security (Common Criteria)
  - Follow a prescribed method (or prescribed processes)
  - Deliver prescribed outputs
    - e.g., documented requirements, designs, analyses, tests and outcomes, traceability among these
  - Internal (DERs) and/or external (NIAP) review

- Works well in fields that are stable or change slowly
  - Can institutionalize lessons learned, best practice
    - e.g. evolution of DO-178 from A to B to C

- But less suitable with novel problems, solutions, methods

- Implicit that the prescribed processes achieve the safety goals
  - No causal or evidential link from processes to goals

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Approaches to Software Certification (ctd.)

- The **explicit goal-based** approach
  - e.g., air traffic management (CAP670 SW01), UK aircraft

- **Applicant develops an assurance case**
  - Whose outline form may be specified by standards or regulation (e.g., MOD DefStan 00-56)
  - Makes an **explicit** set of **goals** or **claims**
  - Provides supporting **evidence** for the claims
  - And **arguments** that link the evidence to the claims
    - Make clear the underlying **assumptions** and **judgments**
    - Should allow different viewpoints and levels of detail

- The case is evaluated by **independent assessors**
  - **Goals**, **evidence**, **claims**
Critique of Standards-Based Approaches

- Usually define only the evidence to be produced
- The goals and arguments are implicit
- Hence, hard to tell whether given evidence meets the intent
- E.g., use a “safe programming language (subset)”
  - Misra C: no demonstration of effectiveness, some contrary experience (cf. Les Hatton)
  - Coverity, Prefix etc.: probabilistic absence of runtime exceptions
  - Astrée, Spark Ada (with the Examiner): guaranteed absence of runtime exceptions
- And the intent may not be obvious
- E.g., MC/DC testing
  - Is it evidence for good testing or good requirements
Multiple Forms of Evidence

- More evidence is required at higher Levels/EALs/SILs
- What’s the argument that these deliver increased assurance?
- Generally an implicit appeal to diversity
  - And belief that diverse methods fail independently
  - Not true in $n$-version software, should be viewed with suspicion here too
- Need to know the arguments supported by each item of evidence, and how they compose
Two Kinds of Uncertainty In Certification

- One kind is failure of a claim, usually stated probabilistically (frequentist interpretation)
  - E.g., $10^{-9}$ probability of failure per hour,
    or $10^{-3}$ probability of failure on demand

- The other kind is failure of the assurance process
  - Seldom made explicit
  - But can be stated in terms of subjective probability
    - E.g., 95% confident this system achieves $10^{-3}$ probability of failure on demand
    - Note: this does not concern sampling theory and is not a confidence interval

- Demands for multiple forms of evidence are generally aimed at the second of these
Bayesian Belief Nets

- **Bayes Theorem** is the principle tool for analyzing subjective probabilities
- Allows a prior assessment of probability to be updated by new evidence to yield a rational posterior probability
- Math gets difficult when the models are complex
  - i.e., when we have many conditional probabilities of the form $p(A \mid B \text{ and } C \text{ or } D)$
- **BBNs** provide a graphical means to represent these, and tools to automate the calculations
- Can allow principled construction of multi-legged arguments
Unconditional Claims in Multi-Legged Arguments

- Can get surprising results
  - Under some combinations of prior belief, increasing the number of failure-free tests may decrease our confidence in the test oracle rather than increase our confidence in the system reliability

- The anomalies disappear and calculations are simplified if one of the legs in a two-legged case is unconditional
  - E.g., 95% confident that this claim holds unconditionally
  - Formal methods deliver this kind of claim
  - E.g., Spark Ada (with the Examiner): guaranteed absence of run time exceptions

- Extends to multiple unconditional claims
Rational Safety Cases

- Currently, we apply safety analysis methods (HA, FTA, FMEA etc.) to an informal system description
  - Little automation, but in principle
  - These are abstracted ways to examine all reachable states
- Then, to be sure the implementation does not introduce new hazards, require it exactly matches the analyzed description
  - Hence, DO-178B is about correctness, not safety
- Instead, use a formal system description
  - Then have automated forms of reachability analysis
  - Closer to the implementation, smaller gap to bridge
- Analyze the implementation for preservation of safety, not correctness
  - Favor methods that deliver unconditional claims
From Software To System Certification

- The things we care about are system properties
- So certification focuses on systems
  - E.g., the FAA certifies airplanes, engines and propellers
- But modern engineering and business practices use massive subcontracting and component-based development that provide little visibility into subsystem designs
- Strong case for “qualification” of components
  
  **Business case:** Component vendors want it (cf. IMA)
  
  **Certification case:** system integrators and certifiers do not have visibility into designs and processes

- But then system certification is based on the certification data delivered with the components
  - Must certify systems without looking inside subsystems
Compositional Analysis

- Computer scientists have ways to do compositional verification of programs—e.g., prove
  - Program A guarantees $P$ if environment ensures $Q$
  - Program B guarantees $Q$ if environment ensures $P$

Conclude that $A \parallel B$ guarantees $P$ and $Q$

- Assumes programs interact only through explicit computational mechanisms (e.g., shared variables)

- Software and systems can interact through other mechanisms
  - Computational context: shared resources
  - Noncomputational mechanisms: the controlled plant

- So compositional certification is harder than verification
Unintended Interaction Through Shared Resources

- This must not happen

- Need an integration framework (i.e., an architecture) that
guarantees composability and compositionality

  **Composability**: properties of a component are preserved
when it is used within a larger system

  **Compositionality**: properties of a system can be derived
from those of its components

- This is what partitioning is about

- Or separation in a MILS security context

- Will be discussed in Thursday’s MILS session
Unintended Interaction Through The Plant

- The notion of interface must be expanded to include assumptions about the noncomputational environment (i.e., the plant)
  - Cf. Ariane V failure (due to differences from Ariane IV)
- Compositional reasoning must take the plant into account (i.e., composition of hybrid systems)
- Must also consider response to failures
  - Avoid domino effect
  - Control number of cases (otherwise exponential)
Compositional Design and Development

- Compositional certification will be impossible unless there is a deliberate (and successful!) attempt to control subsystem interactions during design and development.

- It’s also what’s needed for safety: cf. Perrow’s tight coupling and high interactive complexity.
  - Would be manifested through excessively complex mutual assumptions and guarantees.

- The alternative is massive testing at every stage (cf. NASA), and you still have no guarantee of success.
A Science of Certification

- Certification is ultimately a judgment that a system is adequately safe/secure/whatever for a given application in a given environment.
- But the judgment should be based on as much explicit and credible evidence as possible.
- A Science of Certification would be about ways to develop that evidence.
Making Certification “More Scientific”

- Favor explicit over implicit approaches
  - i.e., goal-based over standards-based
  - At the very least, expose and examine the claims, arguments and assumptions implicit in standards-based approaches

- Be wary of demands for multiple forms of evidence, with implicit appeal to diversity and independence
  - Instead favor explicit multi-legged cases
  - Use BBNs to combine legs
  - Favor methods that deliver unconditional claims

- Use formal (“machinable”) design descriptions
  - Automate safety analysis methods
  - Analyze implementation for preservation of safety
Formal Methods (aside)

- Formal methods are not about priestly ways to complicate life
- They are about **automated analyses** that consider all possible executions
- To make them tractable, may need to approximate
  - **Crude**: downscaling
  - **Principled**: predicate abstraction, abstract interpretation, etc
- Most of the action is in improved automation, and automated abstraction
Formal Methods

- The move to model based development presents a (once in a lifetime) opportunity to move analytic methods into the early lifecycle, mostly based on formal methods
- Modern automated formal methods can deliver unconditional claims about small properties very economically
  - Static analysis, model checking, infinite bounded model checking and k-induction using SMT solvers, hybrid abstraction (which uses theorem proving over reals)
- Larger properties will require combined methods (cf. the Evidential Tool Bus)
- The applications of formal methods extend beyond verification and refutation (bug finding): test generation, fault tree analysis, human factors, . . .
- Tool diversity may be an alternative to tool qualification
Compositional Certification

- This is the big research challenge
- It demands clarification of the difference between verification and certification (because we know how to do the former compositionally, but not the latter)
- And explication of what constitutes an interface to a certified component
  - The certification data is in terms of the interface only
  - You cannot look inside
- Compositional certification should extend to incremental certification, reuse, and modification
- It’s also the big challenge for regulatory agencies
  - A completely different way of doing business
Just-In-Time Certification

- Rather than anticipate all circumstances at design time
- **Why not evaluate them at runtime?**
  - Maybe with a receding horizon
  - Fewer possibilities to examine, known current state
- Each component makes its model available to others, pursues its own goals while ensuring that possible moves by others cannot trap it into following a bad path, or cause violation of safety
  - Analyzed as a game: guarantee a winning strategy
- Instead of using model checking and other formal methods for analysis, we use them for synthesis
  - Ramage and Wonham: controller synthesis
- Certification would examine the models, trust the synthesis
A Research Agenda

- The Science of Certification
  - Or a science for certification
- Specification and verification of integration frameworks
  - Partitioning, separation, buses, kernels
- High-performance automated verification for strong properties of model-based designs
  - Mostly infinite state and hybrid systems
  And automation of related processes (test generation, FTA)
- Compositional certification
  - Composition of hybrid systems
- Tool qualification
  - Evidence management
- Just-in-time certification and runtime synthesis