Assurance Cases for Analysis of Complex System of Systems Software

Presented to the System of Systems Collaborators' Information Exchange
8 June 2010

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Problem: SoS are Common, but Difficult

Huge systems of systems (SoS) development efforts

• Have become quite commonplace as aerospace/defense solutions
  – The Global Earth Observation System of Systems (GEOSS)
  – The US Army’s Future Combat Systems
  – The US Coast Guard’s Deepwater
  – Etc.

• Exhibit extreme complexity – they're hard to understand in detail
• Are difficult, even impossible, to test adequately using traditional methods
• Use software as an enabler of SoS functionality

Often, SoS elements are dispersed geographically, adding complexity and making predictability of behavior difficult

How can project management, stakeholders, and decision makers achieve some reasonable level of confidence that software for a large-scale, dispersed SoS will meet operational needs, even before development of much of the software?
Recent Experience Led to Assurance Case Use

An SEI team was tasked with answering this question in the face of several challenges:

- the software design was actually many software designs documented in many places and with a tremendous volume of data
- the designs were in different stages of completeness, but none would be complete until after many production decisions had to be made
- conclusions had to be based as much as possible on actual data rather than on optimistic plans and confident assertions

Constraints

- short time frame: a project level review had a hard deadline
- limited availability of personnel, all with varying levels of domain knowledge
Had to Relate Operational Needs to Software

Context

- “Deep dive” analyses were already underway in key technical areas

The top-level SoS requirements were expressed in military terms.

- A requirements analysis would be repeating work already done
- Errors in requirements traceability could skew the entire analysis

We decided against re-casting the operational needs in terms of software and instead analyzed the software contributions to the definitive characterization of those needs—the Key Performance Parameters (KPPs).

The size of the analysis space, the complexity of the task, and the desire to leverage data suggested an assurance case approach

- The analysis was a structured decomposition of each KPP into more precise statements that could be more readily assessed in terms of evidence.
  - Challenge: be logical and consistent but avoid accumulating too much detail
  - Use engineering judgment to leap from higher-level concepts to lower-level ones
An Assurance Case is a Structured Argument

An assurance case
- is a generalization of a safety case
- presents an argument (similar to a legal case) that a system has or satisfies some property in a given context
- requires claims, evidence, and an argument linking evidence to claims
- should be sound and complete to justify belief in the main claim
- should be based on objective evidence

Goal Structuring Notation (GSN)
- graphically presents the argument by showing how claims are broken down into sub-claims until arriving at a sub-claim supported by evidence.

For our purposes, we used assurance cases to demonstrate that a SoS software design supported each of the SoS KPPs
- as in the claim, “The SoS will satisfy KPP k”
An Example

Assume we’re developing a SoS for a DoD project

• The SoS must exchange information with other systems
  – Our SoS is subject to the Net Ready Key Performance Parameter (NR KPP):
    • The system...must support Net-Centric military operations. The...system...must be able to enter and be managed in the network, and exchange data in a secure manner to enhance mission effectiveness. The...system...must continuously provide survivable, interoperable, secure, and operationally effective information exchanges to enable a Net-Centric military capability.

Chairman of the Joint Chiefs of Staff Instruction, “Interoperability and Supportability of Information Technology and National Security Systems,” CJCSI 6212.01E, 2008.
We Can Express the NR KPP Diagrammatically

Ctx1
Source Document: CJCSI 6212.01E

Clm1
The system of systems supports Net-Centric military operations

Clm2
The SoS is able to enter and be managed in the network

Clm6
The SoS is able to exchange data in a secure manner to enhance mission effectiveness

A1
It is assumed that hardware components of the network can be ignored in this analysis.

Clm13
The SoS continuously provides survivable, interoperable, secure, and operationally effective information exchanges

Nte1
This diagram focuses on threshold level KPP satisfaction.
Primary Sub-claim #2

Clm2
The SoS is able to enter and be managed in the network

Clm3
The SoS network conforms to the relevant standards

Clm4
The SoS communications software and protocol stack conform to the relevant standards

Ev1
Architecture documents

Ev2
Test plans/results related to standards compliance

Ev3
Architecture documents

Ev4
Architecture evaluation results

Ev5
Results of preliminary field tests and experiments

Examples of Evidence
Primary Sub-claim #6

Clm6
The SoS is able to exchange data in a secure manner to enhance mission effectiveness

Clm7
The security requirements (e.g., data security, information assurance, access control) for the SoS are met

Clm8
Security requirements are identified adequately across the SoS

Clm9
Security components within the design are consistent across the SoS

Clm10
Verification/validation of SoS security features is adequately planned and resourced

Clm11
The SoS supports information exchanges

Clm12
Information to be exchanged is defined

Ev11
Results of preliminary field tests and experiments

Ev12
Requirements database showing information transfers

Ev10
Formally tracked risks

Ev9
Test plans and descriptions

Ev8
Architecture evaluation results

Ev7
Architecture and design documents

Ev6
Requirements database showing security requirements
**Primary Sub-claim #13**

Clm13
The SoS continuously provides survivable, interoperable, secure, and operationally effective information exchanges

Clm11
The SoS supports information exchanges

Clm12
Information to be exchanged is defined

Ev12
Results of preliminary field tests and experiments

Clm15
Timelines are defined

Ev14
Results of preliminary field tests and experiments

Ev16
Formally tracked risks

Ev11
Requirements database showing information transfers

Ev13
Requirements database showing applicable timelines

Results of preliminary field tests and experiments

Modeling & simulation results
A Diagram Helps Visualize the Completed Case

Logic Should Hold…Even Without the Diagram
Scoring Can be Used to Express Risk

First, Develop Scoring Rules

<table>
<thead>
<tr>
<th>For Evidence</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Green</strong></td>
<td>Evidence is complete and adequate</td>
<td></td>
</tr>
<tr>
<td><strong>Yellow</strong></td>
<td>Evidence is incomplete or planned for the future</td>
<td></td>
</tr>
<tr>
<td><strong>Red</strong></td>
<td>Evidence is complete but inadequate, planned but now late, or non-existent</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>For Claims</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Green</strong></td>
<td>All lower-level claims and supporting evidence are green</td>
<td></td>
</tr>
<tr>
<td><strong>Yellow</strong></td>
<td>Some lower-level claims and supporting evidence are a combination of yellow and red</td>
<td></td>
</tr>
<tr>
<td><strong>Red</strong></td>
<td>All, or an overwhelming majority of, lower-level claims and supporting evidence are red</td>
<td></td>
</tr>
</tbody>
</table>

Then, Work Upward from Evidence...
Scored Diagram Provides a Roadmap

Quality of the Evidence Drives Assessment of Claims… and Relative Risk
It Wasn’t Really That Easy…

Up front planning is key
• Helps “socialize” the effort among affected areas of the project
• Minimizes need for repeated briefings
• Facilitates access to data & personnel

Software skills/domain knowledge are important
• Familiarity with technique and with operational concepts is needed, too

Starting with KPPs causes diagrams to grow quite busy very quickly
• Strong tendency to make very small steps in logic as one progresses down the analysis path in order to ensure the absolute soundness of the argument
• Engineering judgment needed to balance between precision in argument and comprehensibility
Assurance Cases are Helpful in the SoS Space

Assurance cases gave us a way of organizing a nebulous task and gave us a means of selecting among innumerable artifacts to study. They brought order to complexity.

- Due to time constraints we had to focus on big picture risks
- A more thorough analysis might have identified additional risks or strong points

The assurance case technique is a powerful tool for analyzing large and complex SoS software design.

- It provides a means of taking a crosscutting look at SoS
- It gives managers answers about design progress
  - rooted in facts and data instead of opinions based upon hope and best intentions
  - presented at a relevant level of detail to support decision making
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