SoSECIE Webinar

Welcome to the
2019 System of Systems Engineering Collaborators Information Exchange (SoSECIE)

We will start at 11AM Eastern Time

Skype Meeting +1 (703) 983-2020, 46013573#

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NDIA System of Systems SE Committee

- **Mission**
  - To provide a forum where government, industry, and academia can share lessons learned, promote best practices, address issues, and advocate systems engineering for Systems of Systems (SoS)
  - To identify successful strategies for applying systems engineering principles to systems engineering of SoS
- **Operating Practices**
  - Face to face and virtual SoS Committee meetings are held in conjunction with NDIA SE Division meetings that occur in February, April, June, and August
  - SoS Track at NDIA 22nd Annual Systems Engineering Conference, Grand Hilton Tampa Downtown, Tampa, FL, October 21-24, 2019
    - Conference Info: http://www.ndia.org/events/2019/10/21/22nd-annual-systems-and-mission-engineering-conference

NDIA SE Division SoS Committee Industry Chairs:
Mr. Rick Poel, Boeing
Ms. Jennie Horne, Raytheon
OSD Liaison:
Dr. Judith Dahmann, MITRE

Simple Rules of Engagement

- I have muted all participant lines for this introduction and the briefing.
- If you need to contact me during the briefing, send me an e-mail at sosecie@mitre.org.
- Download the presentation so you can follow along on your own
- We will hold all questions until the end:
  - I will start with questions submitted online via the CHAT window in Skype.
  - I will then take questions via telephone; State your name, organization, and question clearly.
- If a question requires more discussion, the speaker(s) contact info is in the brief.

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2019 System of Systems Engineering Collaborators Information Exchange Webinars

Sponsored by MITRE and NDIA SE Division

July 30, 2019
Graph Theoretic Architectural Analysis: Analysis of Complex Systems and Systems of Systems
Ms. Laura Antul

August 13, 2019
Systems of Systems, An Overreaching Paradigm
Mr. Reggie Cole

August 27, 2019
Understanding and Shaping the Future of Systems of Systems Engineering
Mr. Garry Roedler

September 10, 2019
An Analysis of Systems-of-Systems Opportunities and Challenges Related to Mobility
Mr. Jakob Axelsson

September 24, 2019
Modeling and Simulation for Internet of things as System of Systems
Dr. Paul C. Hershey

2019 System of Systems Engineering Collaborators Information Exchange Webinars

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October 22, 2019

Modeling Process for the Design of System of Systems Evolution

Dr. Jeremy Buisson, Dr. Isabelle Borne and Mr. Franck Petitdemange

November 5, 2019

Irrational System Behavior in a System of Systems

Mr. Douglas L. Van Bossuyt, Mr. Bryan M. O'Halloran and Mr. Ryan M. Arlitt

November 19, 2019

Multi-Dimensional Classification of System-of-Systems

Dr. Bedir Tekinerdogen

December 3, 2019

Digital Twin Strategies for System of Systems

Mr. Michael Borth

Graph Theoretic Architectural Analysis

Analysis of Complex Systems and Systems of Systems

Jeff Vodov
Laura Antul
Dr. Judith Dahmann

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Overview of SoS

- **Definition of SoS and SoSE**
  - “System of Systems is a “set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities””.
  - “Systems of Systems Engineering is “the process of planning, analyzing, organizing, and integrating the capabilities of a mix of existing and new systems into a system-of-systems capability that is greater than the sum of the capabilities of the constituent parts”.

*Department of Defense, "US Defense Acquisition Guidebook", Defense Acquisition University, 2008.

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Problem

Challenge: SME-driven/program-specific/qualitative architecture analysis

Example: Software Engineering Institute's (SEI's) Architecture Tradeoff Analysis Method® (ATAM®)

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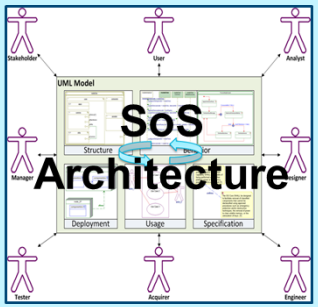
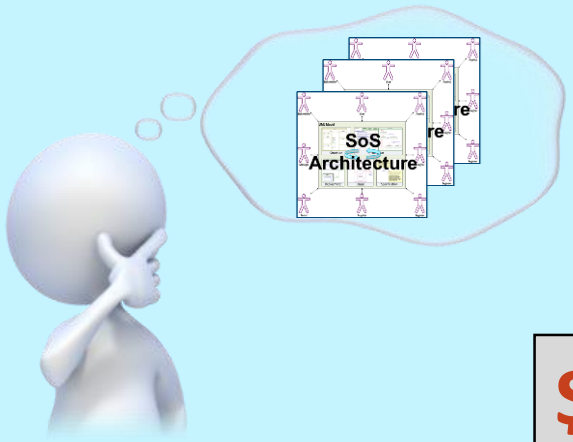
SoS Analysis of Alternatives

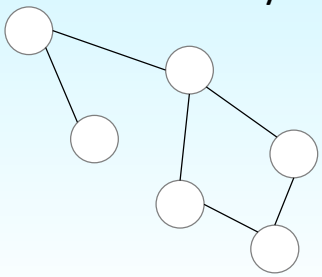




Establish baseline SoS architecture

Generate SoS architecture alternatives

SoS graph abstraction and network analysis



MIP contribution: inform prioritization of alternatives using lightweight analytics

Detailed evaluation with M&S environment

Inexpensive

Informed architecture selection

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Robustness as a proxy for Resilience

- **Robustness -** degree to which a system is able to withstand an unexpected internal or external event or change without degradation in system's performance
- **Resilience** - system's ability to recover or regenerate its performance after an unexpected impact produces a degradation of its performance

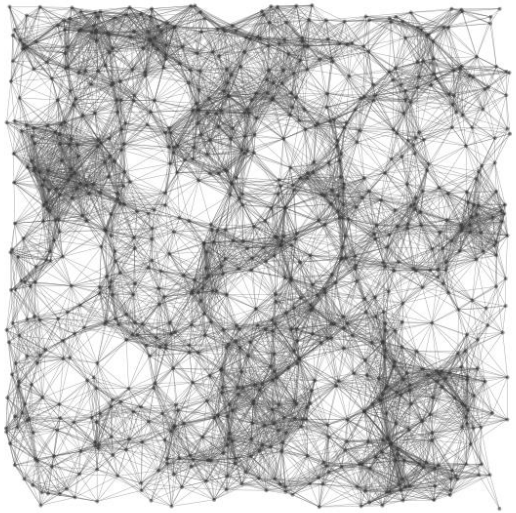

Image Source: http://graphstream-project.org/doc/Generators/Random-Euclidean-generator/

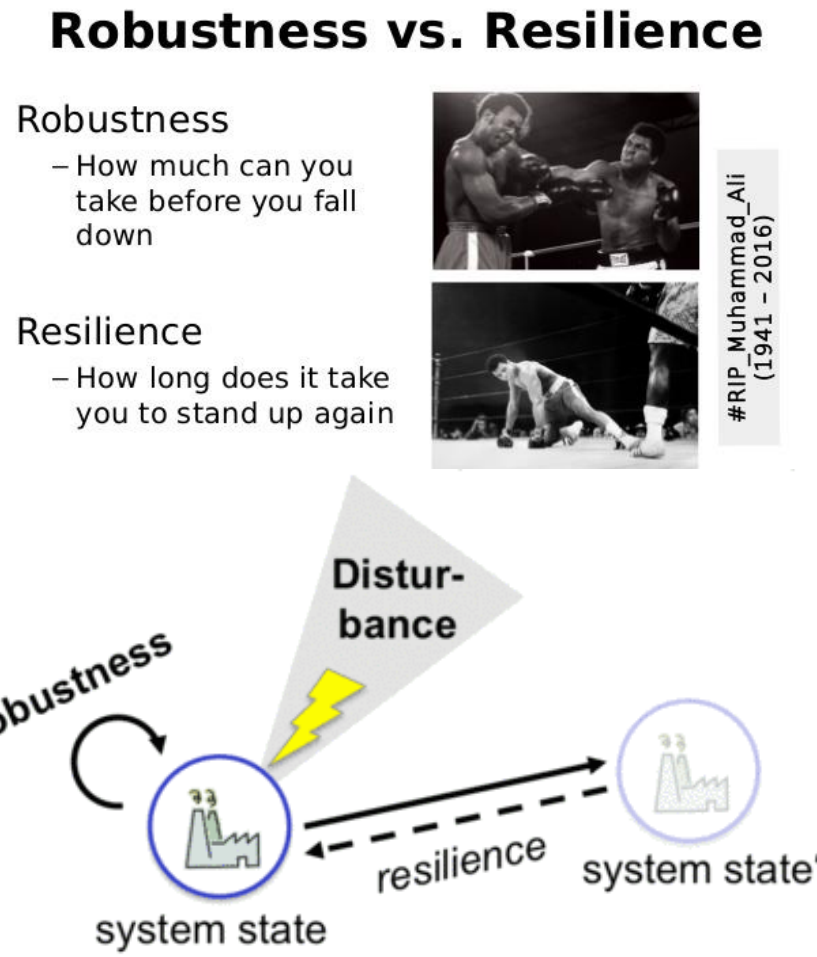

Image Source: http://www.psls.uni-bremen.de/robustness.html?&L=1

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Robustness Metric (Algebraic Connectivity Value)

- **Represents average difficulty of isolating a node**
  - Second smallest eigenvalue of a Laplacian Matrix
- **Inputs:**
  - Degree Matrix
    - Diagonal matrix that contains the number of nodes adjacent to a given node

$$D_{ij} = \begin{cases} d_i & \text{degree of component } i \text{ when } i = j \\ 0 & \text{otherwise} \end{cases}$$

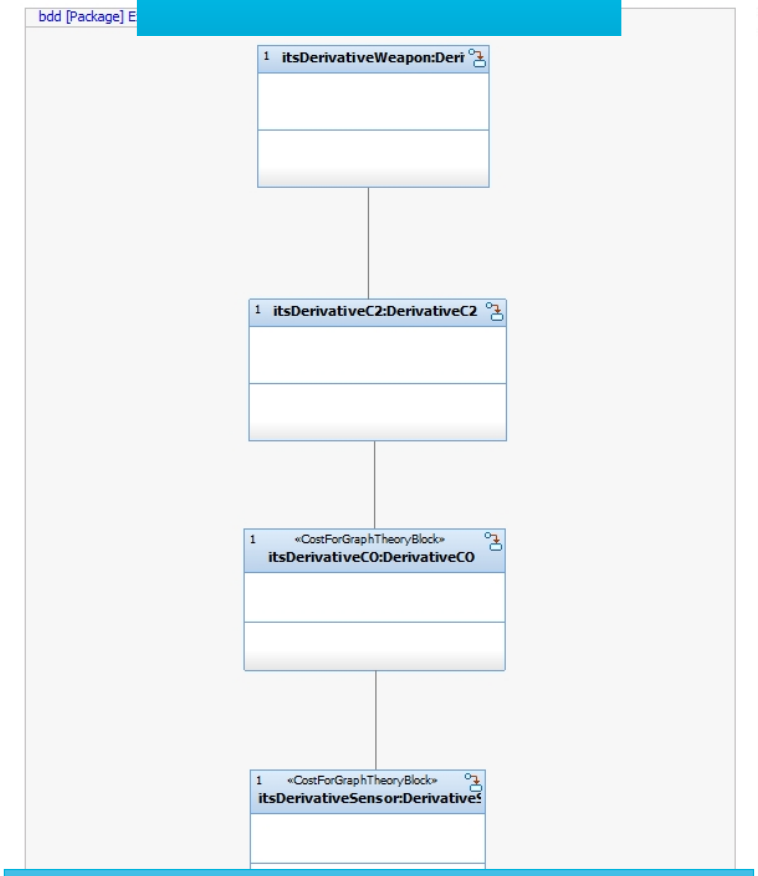
  - Adjacency Matrix
    - Symmetric matrix that contains a 1 if two given nodes are adjacent and 0 otherwise

$$A_{ij} = \begin{cases} 1 & \forall[(i,j)|(i \neq j) \quad \text{and} \quad (i,j) \in \Delta] \\ 0 & \text{otherwise} \end{cases}$$

Reference: H. Mehrpouyan, B. Haley, A. Dong, I. Y. Tumer, and C. Hoyle, "Resiliency analysis for complex engineered system design," *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, vol. 29, no. 01, pp. 93–108, Jan. 2015.

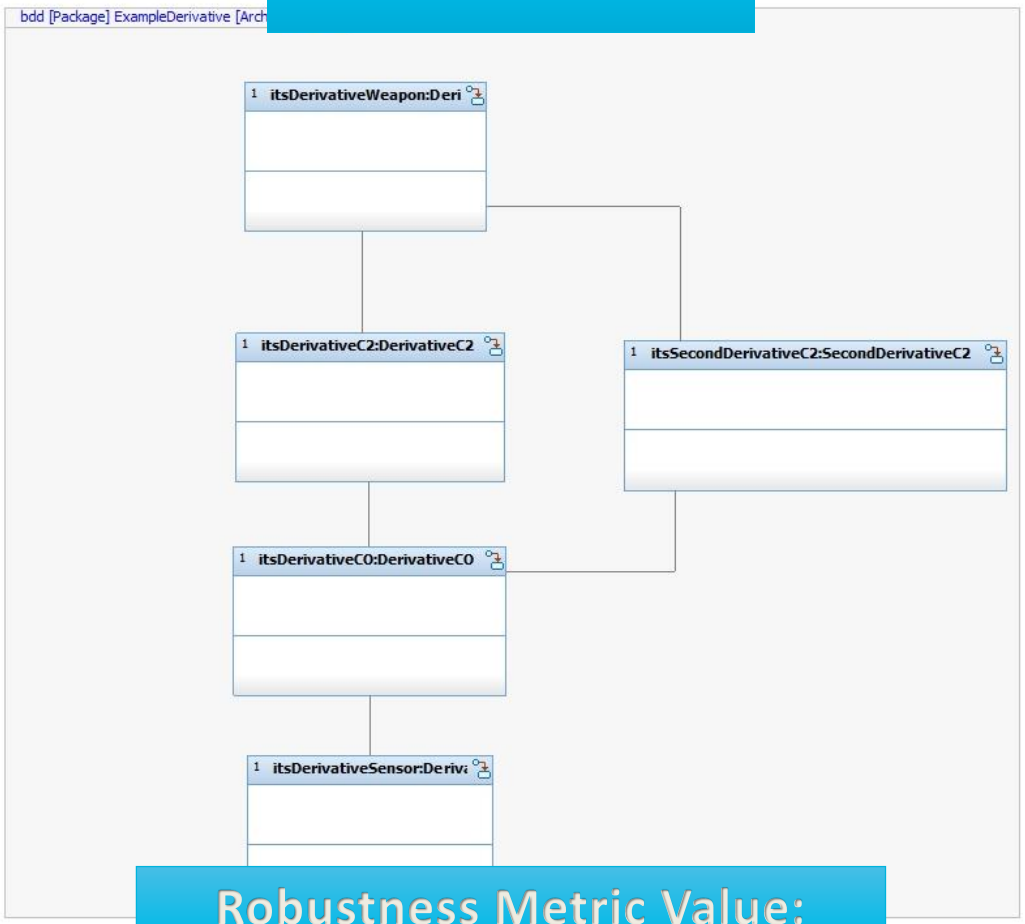
Identifying Robust SoS Architectures

Architecture 1



Robustness Metric Value: 0.5858

Architecture 2



Robustness Metric Value: 0.8299

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Graph Theoretic Architecture Analysis Plugin

Current Capability

- Allows for the comparison of two different architectures
  - Determines communication survivability against component or linkage failures
  - Analyzes relative importance of nodes within an architecture
  - Rapid analysis of topological robustness of an architecture
  - Calculates integration risk for each subsystem
  - Produces optimal set of subsystems for efficient worm propagation

- Proof of concept completed on an Army project
- Currently being adapted on an Air Force C2 Project

Return On Investment

- Providing decision makers with data-driven technical products that facilitate objective decision making between architecture alternatives. Objective identification of architecture components that:
  - Broker a significant amount of information
  - Store a significant amount of information
  - Most rapidly disseminate information anywhere in the network
  - Possess immediate neighbors who store a significant amount of information

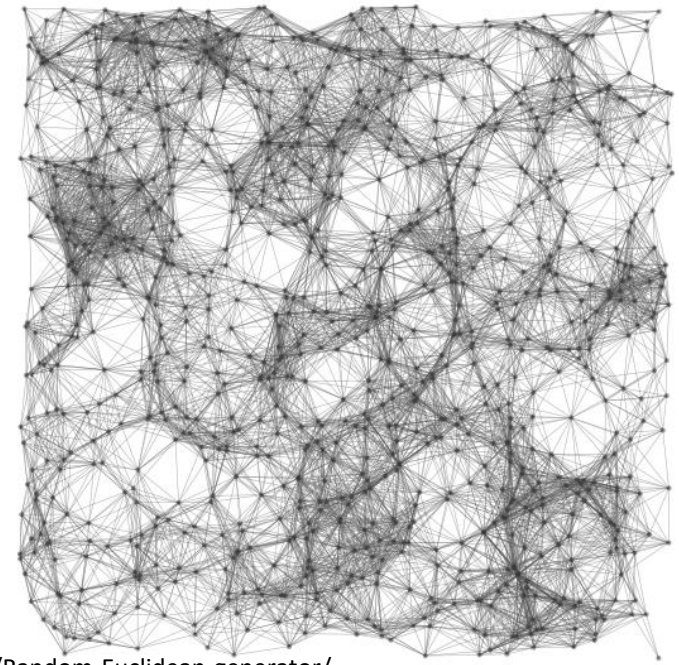

Image Source: http://graphstream-project.org/doc/Generators/Random-Euclidean-generator/

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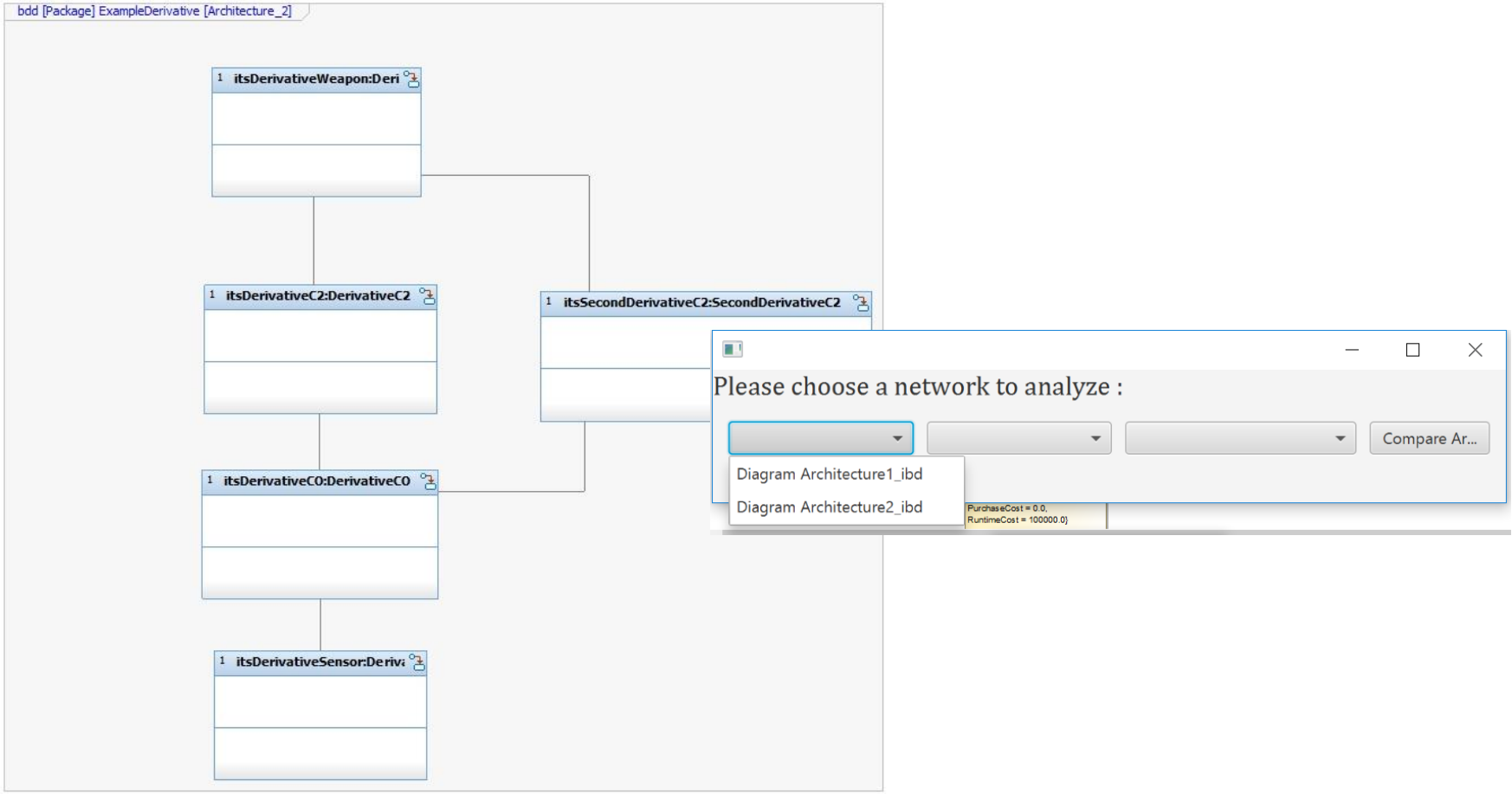
Graph Theory MBE GUI

Network Analysis GUI (1 of 9)



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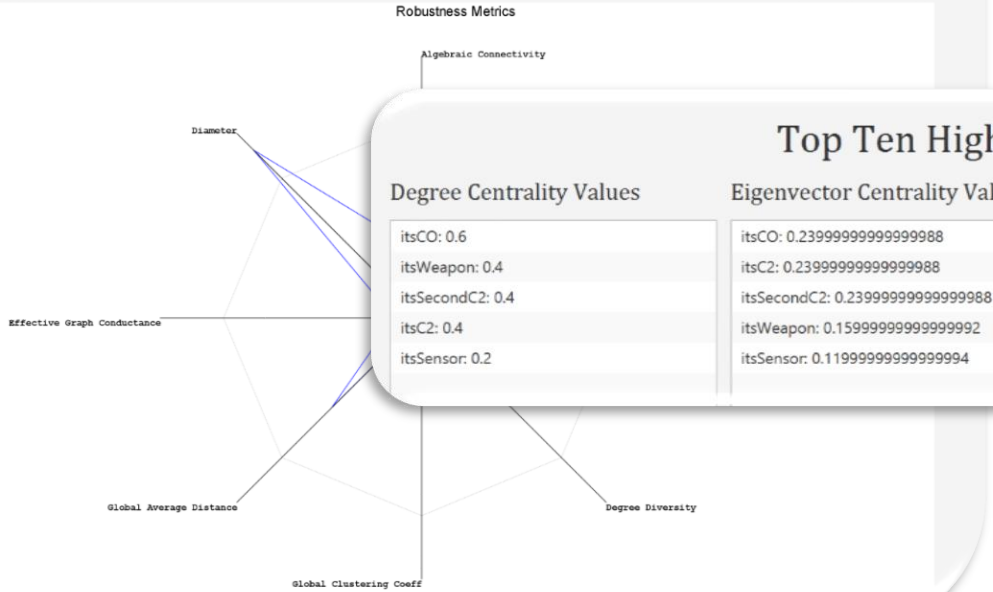
Network Analysis GUI (2 of 9)

Network Analysis Results

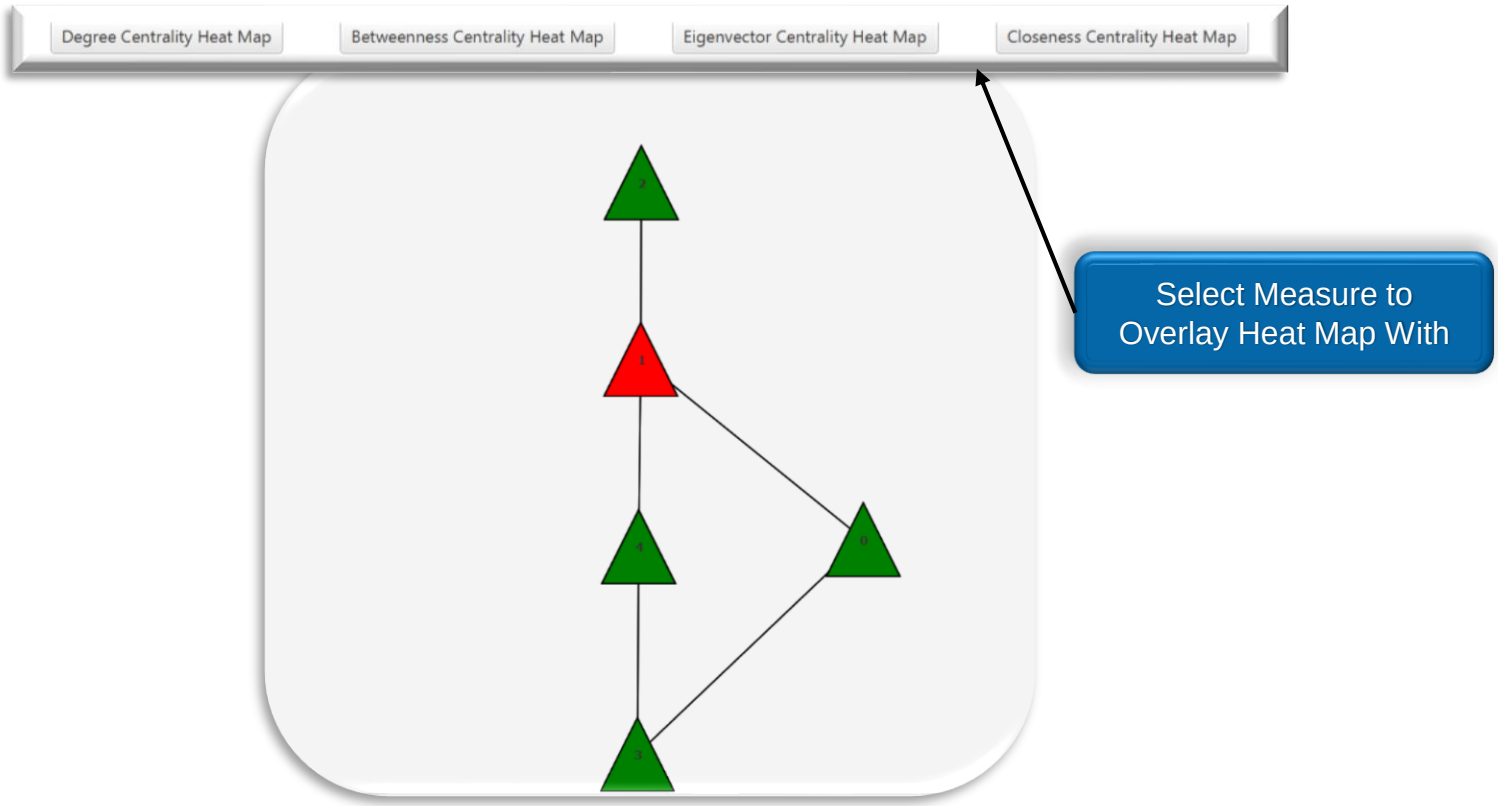
Diagram Architecture2_ibd Analysis



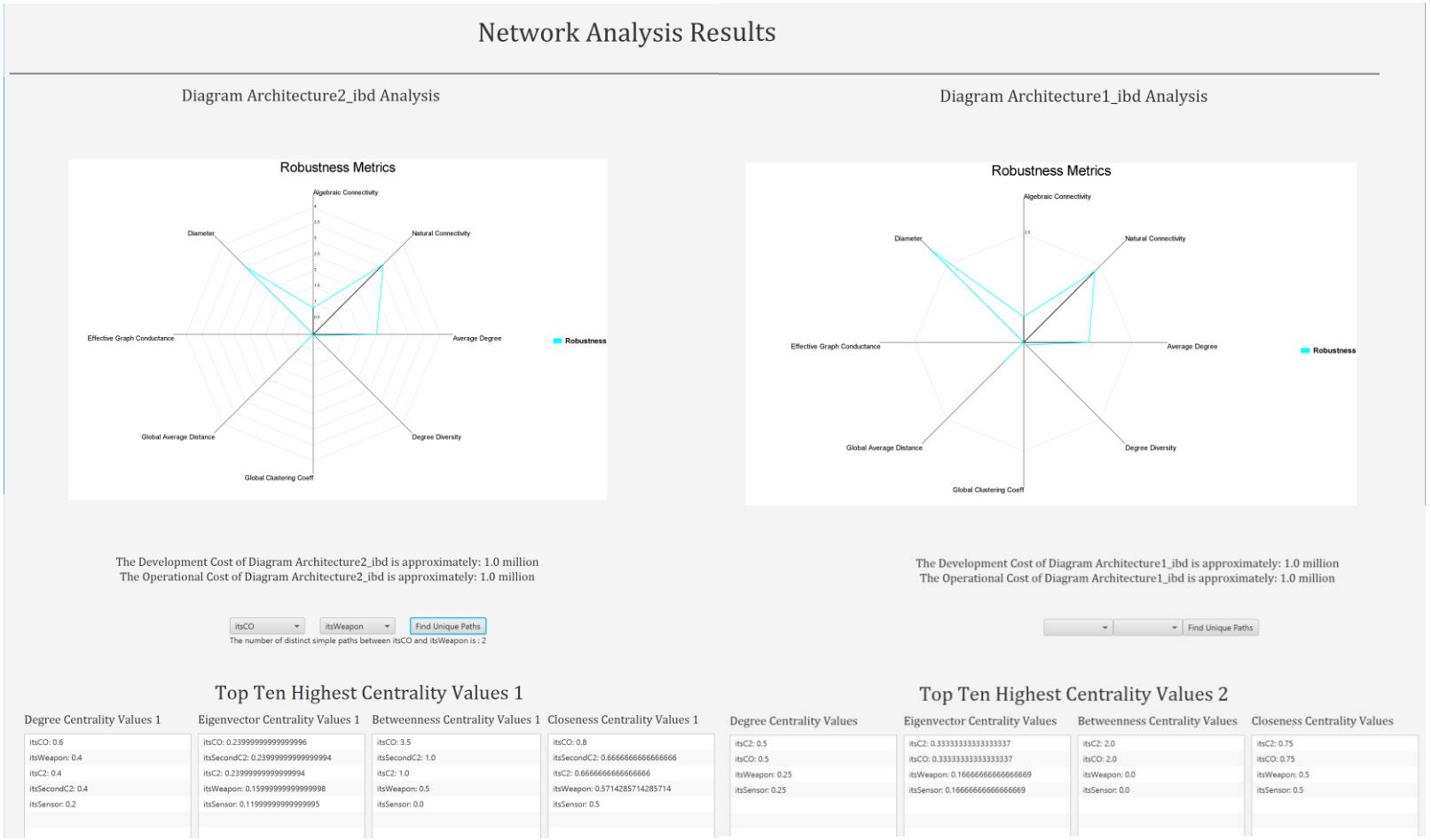
Top Ten Highest Centrality Values

Degree Centrality Values	Eigenvector Centrality Values	Betweenness Centrality Values	Closeness Centrality Values
itsCO: 0.6	itsCO: 0.23999999999999988	itsCO: 3.5	itsCO: 0.8
itsWeapon: 0.4	itsC2: 0.23999999999999988	itsC2: 1.0	itsC2: 0.6666666666666666
itsSecondC2: 0.4	itsSecondC2: 0.23999999999999988	itsSecondC2: 1.0	itsSecondC2: 0.6666666666666666
itsC2: 0.4	itsWeapon: 0.15999999999999992	itsWeapon: 0.5	itsWeapon: 0.5714285714285714
itsSensor: 0.2	itsSensor: 0.11999999999999994	itsSensor: 0.0	itsSensor: 0.5

Network Analysis GUI (3 of 9)



Network Analysis GUI (4 of 9)



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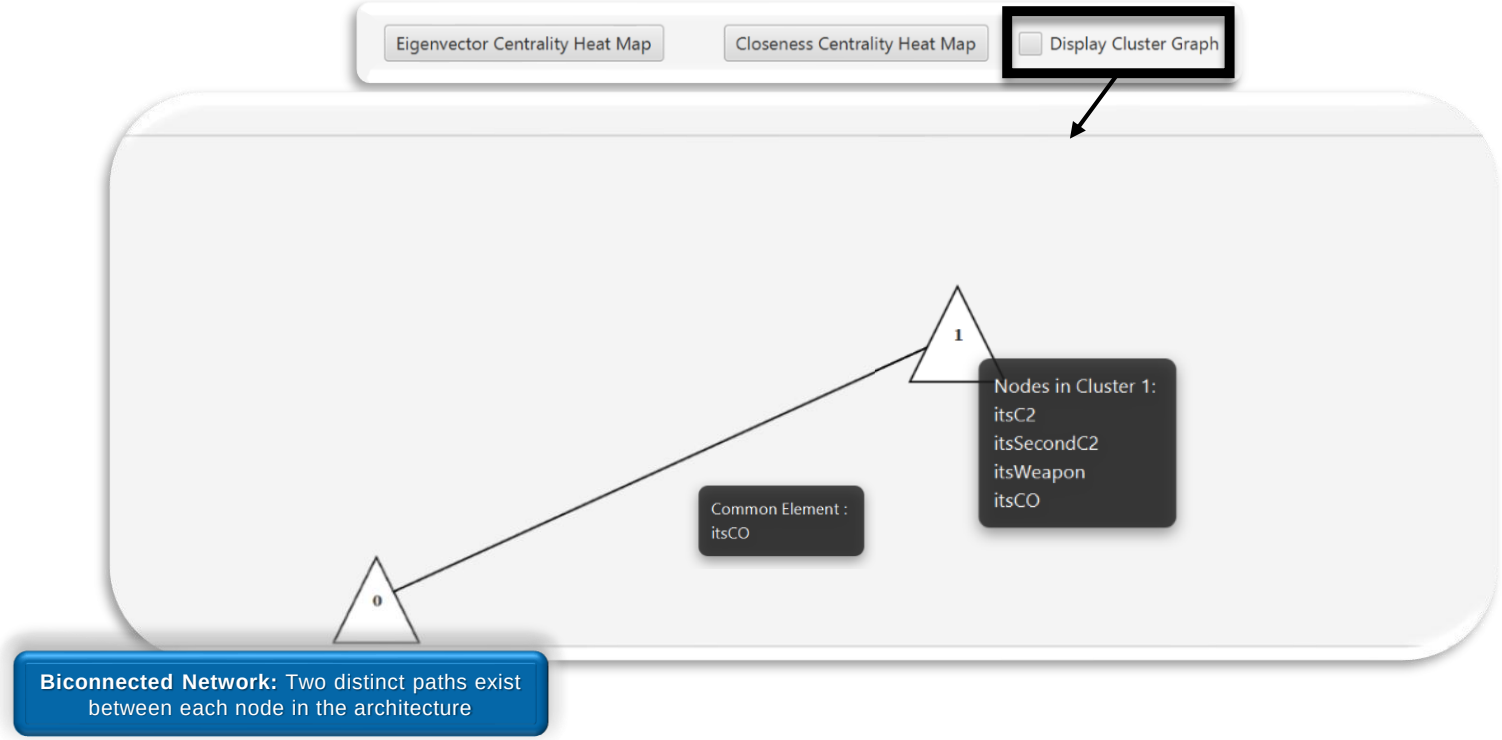
Network Analysis GUI (5 of 9)



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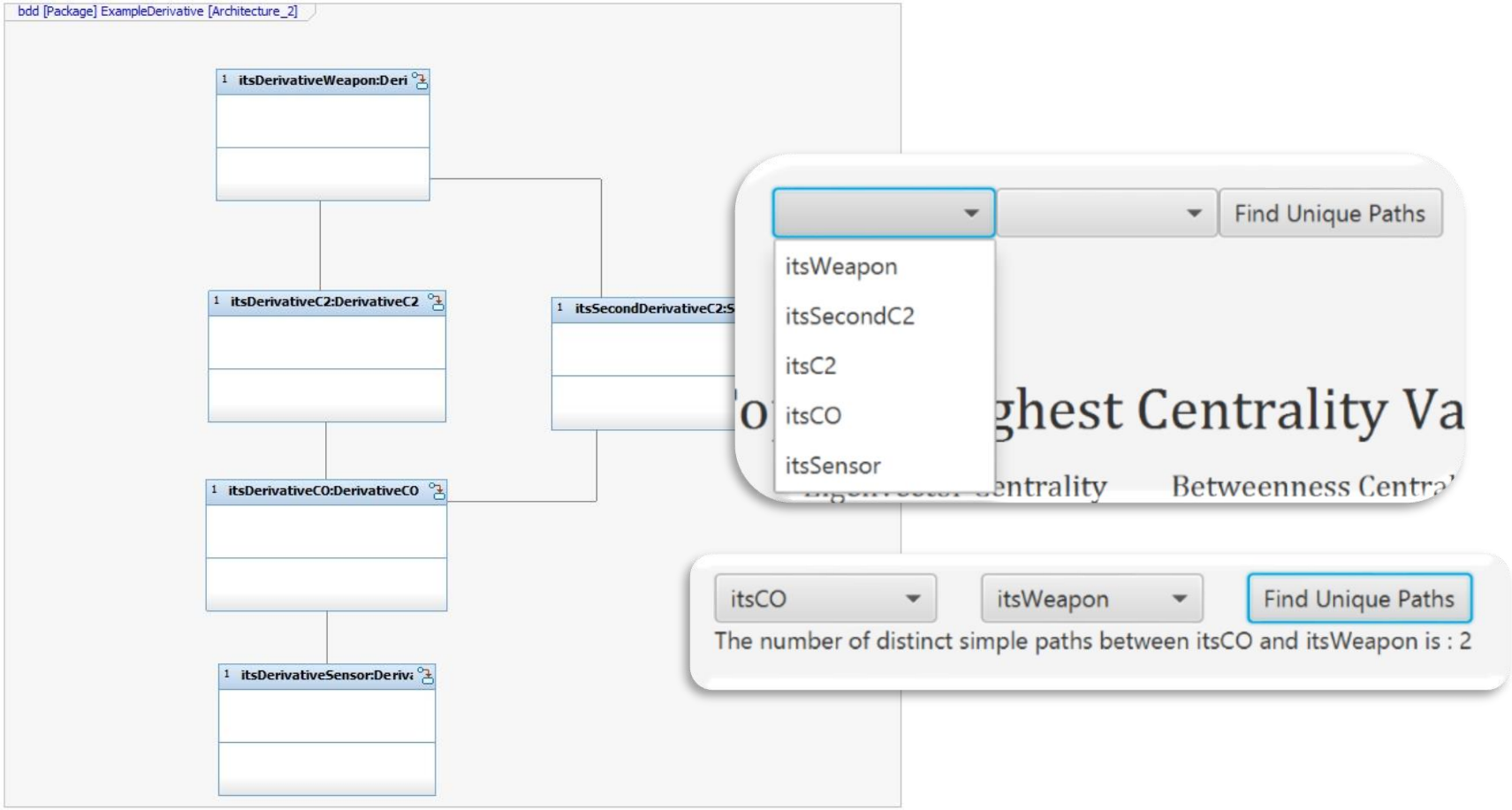
Network Analysis GUI (6 of 9)



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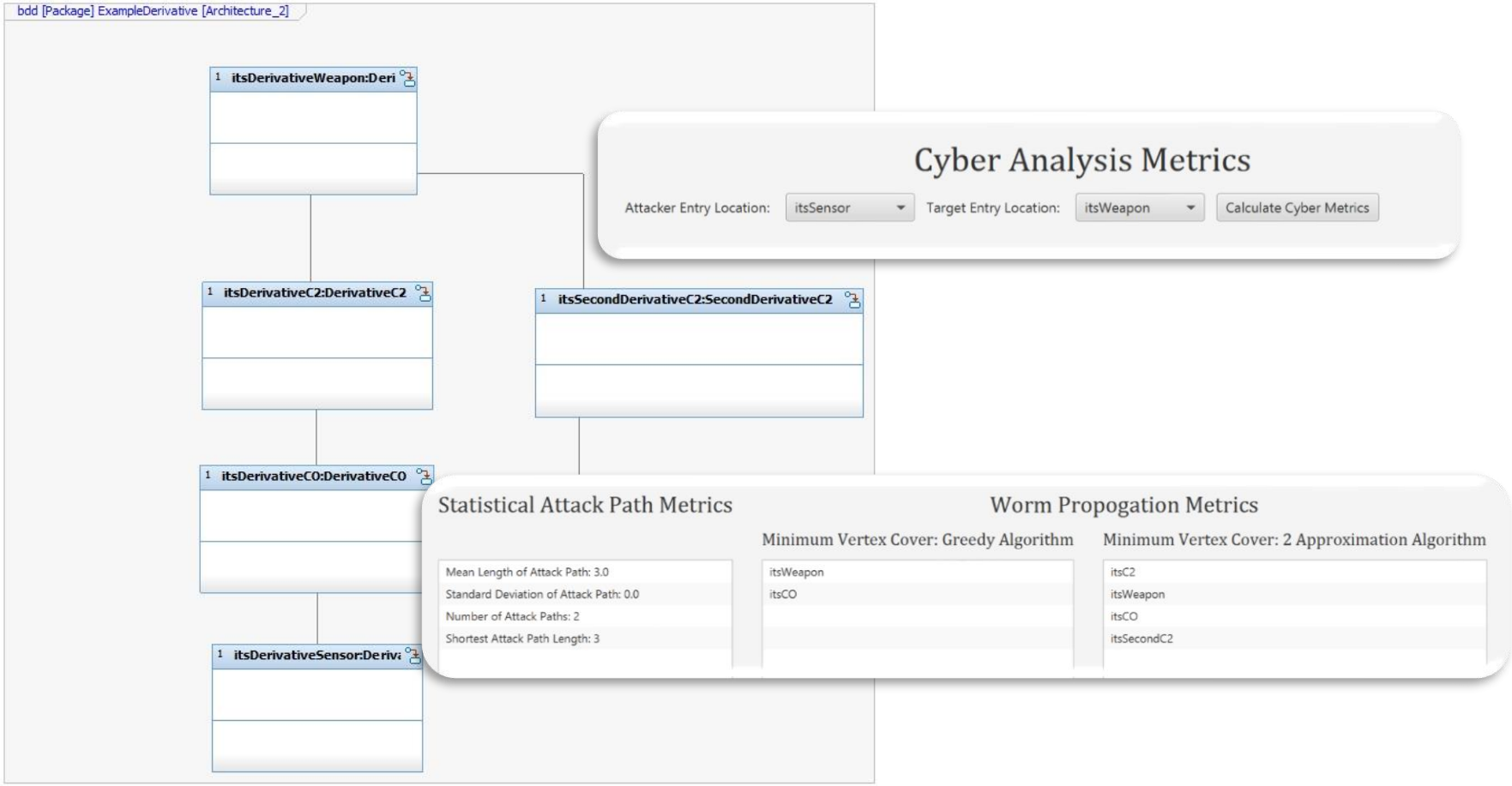
Network Analysis GUI (7 of 9)



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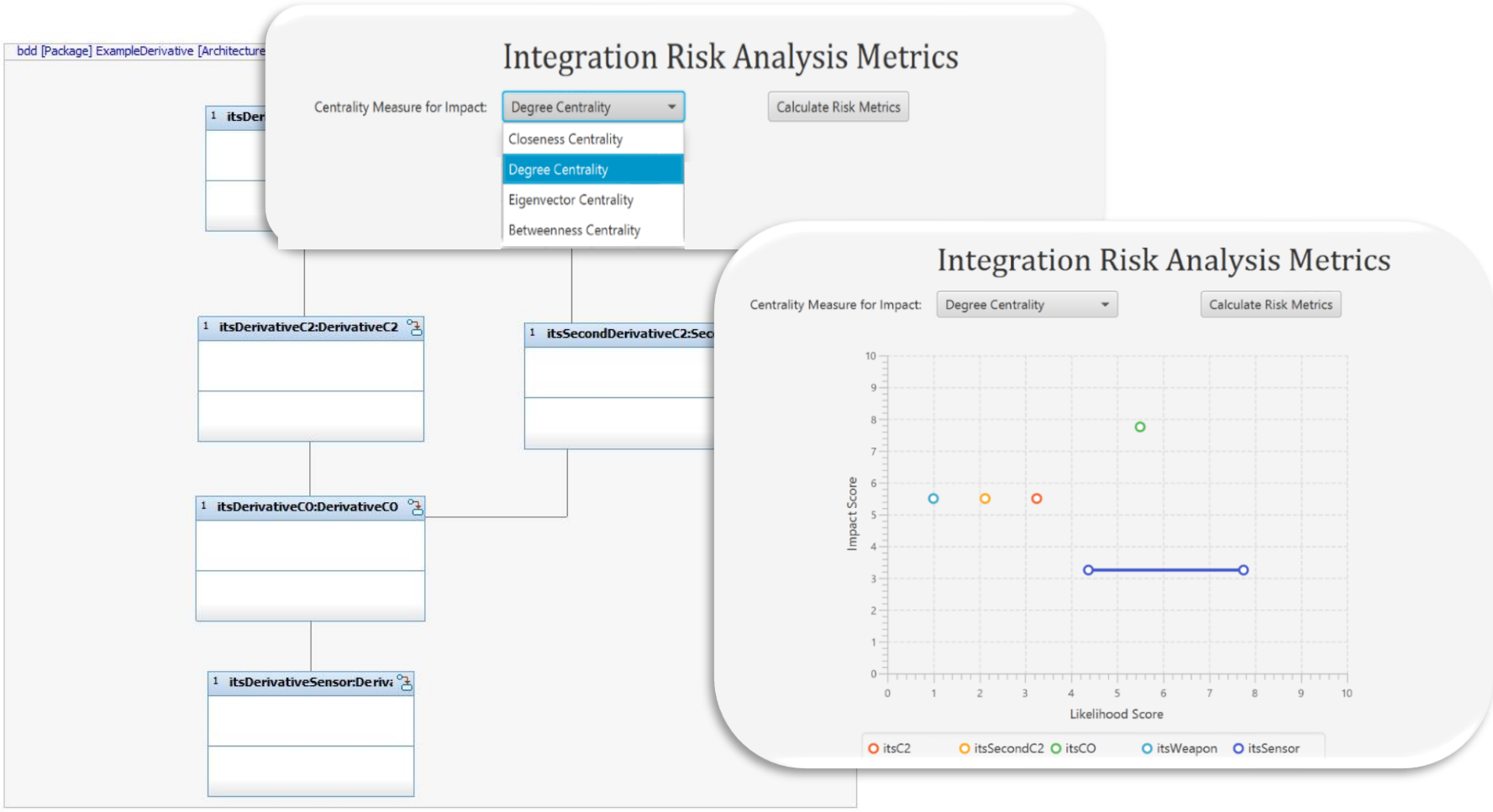
Network Analysis GUI (8 of 9)



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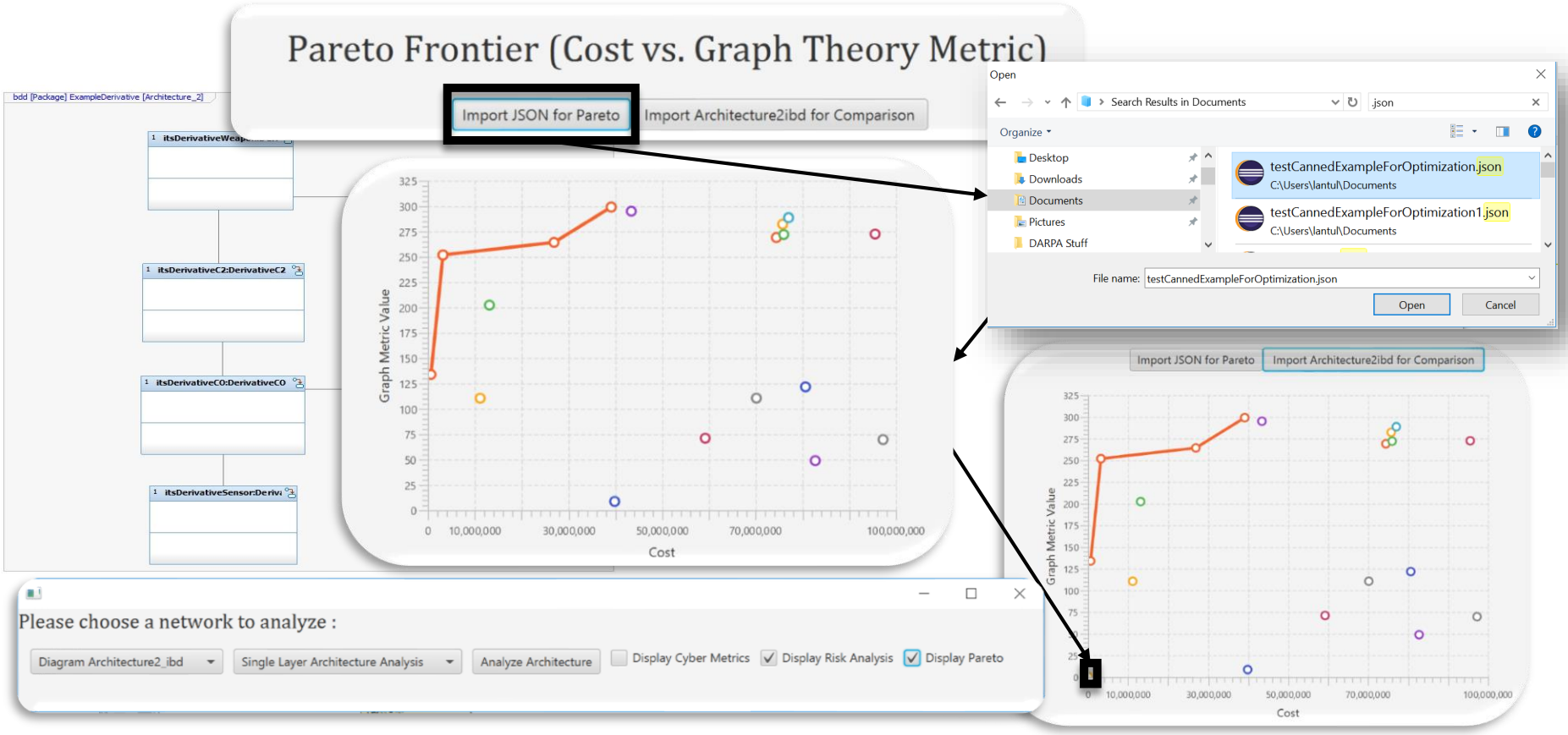
Network Analysis GUI (9 of 9)



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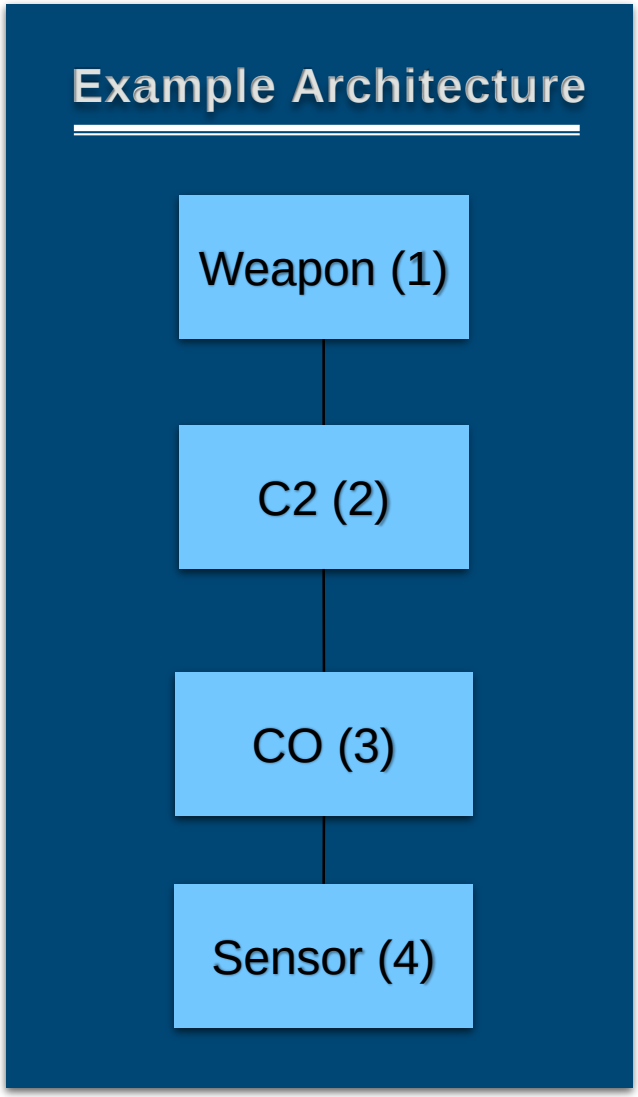
Multi-layer Architectural Derivation Example

Example Architecture



Available Communication Methods

Weapon (1)	• Link 16 • SATCOM • HF Radio • VHF Radio
C2 (2)	• Link 16 • SATCOM • HF Radio • VHF Radio • Link 11
CO (3)	• Link 16 • SATCOM • Link 11
Sensor (4)	• Link 16 • SATCOM • HF Radio • VHF Radio • Link 11

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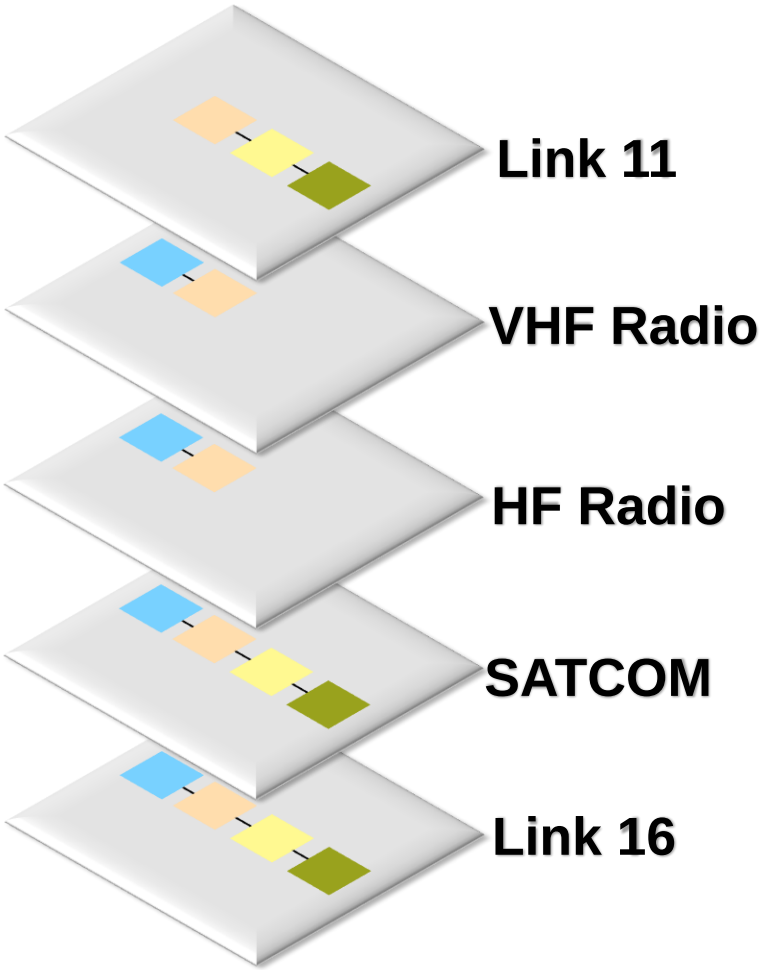
Mapping Architecture to Multilayer Graph – Intralayer Graph Representation



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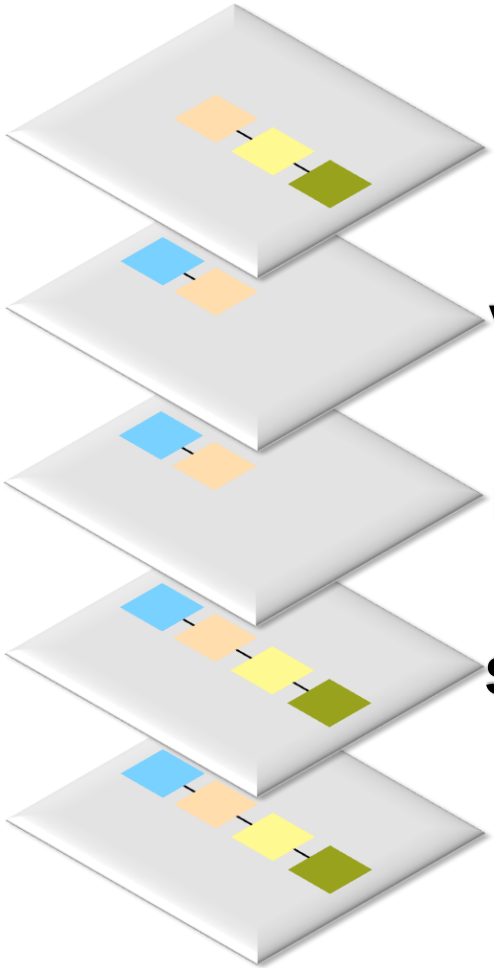
Mapping Architecture to Multilayer Graph – Intralayer Adjacency Representation



VHF Radio

	1	2
1	0	1
2	1	0

HF Radio

	1	2
1	0	1
2	1	0

Link 11

	2	3	4
2	0	1	0
3	1	0	1
4	0	1	0

SATCOM

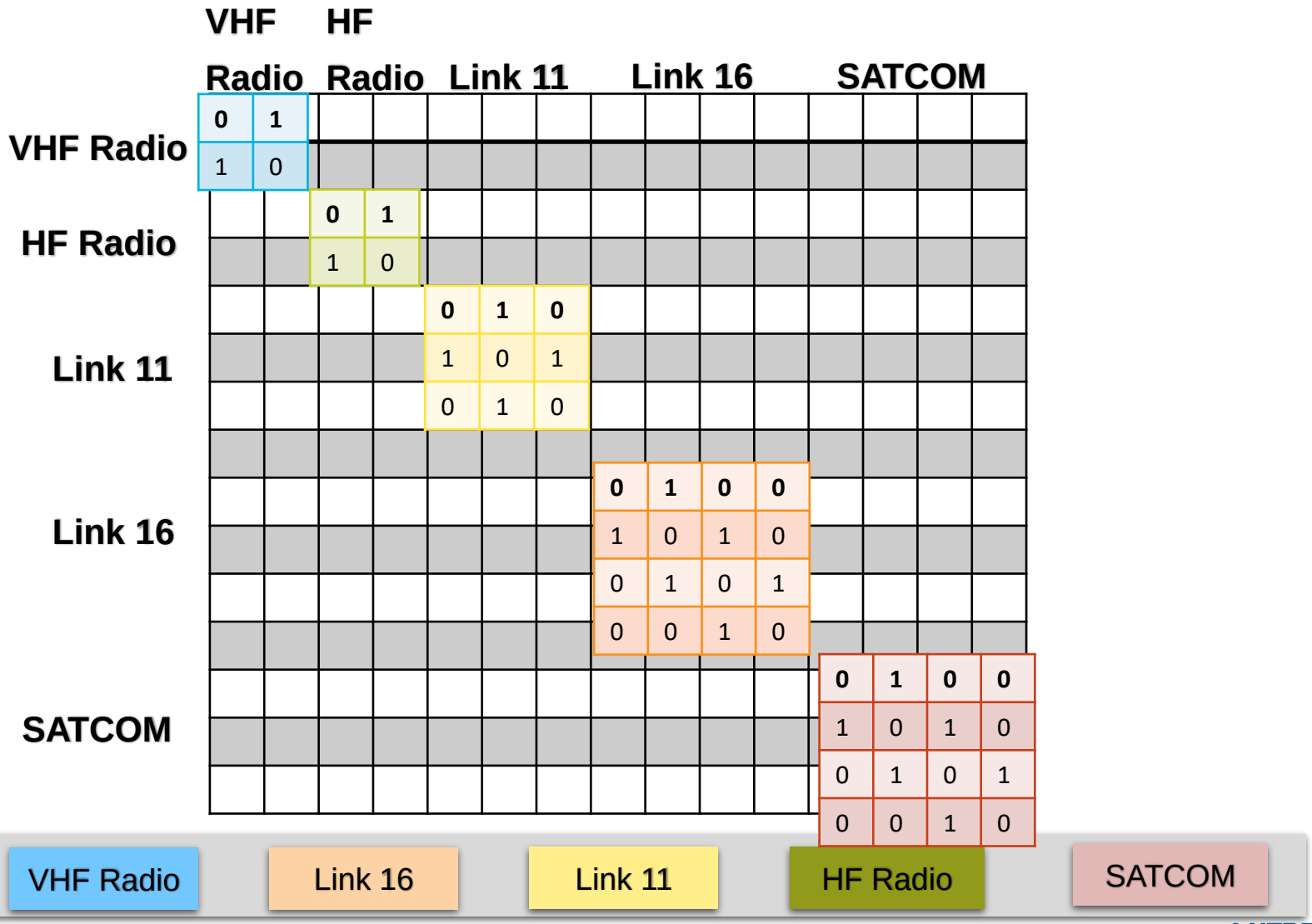
	1	2	3	4
1	0	1	0	0
2	1	0	1	0
3	0	1	0	1
4	0	0	1	0

Link 16

	1	2	3	4
1	0	1	0	0
2	1	0	1	0
3	0	1	0	1
4	0	0	1	0

Weapon (1) | C2 (2) | CO (3) | Sensor (4)

Mapping Architecture to Multilayer Graph – Intralayer Adjacency Representation



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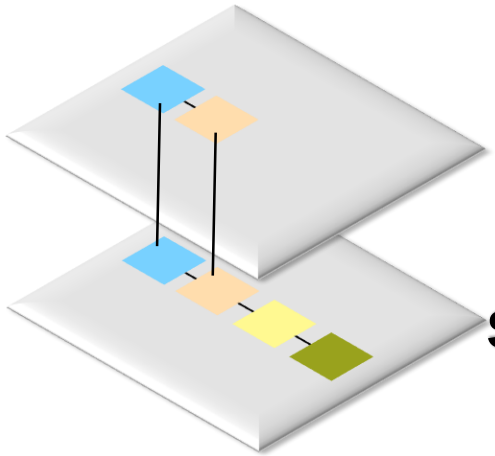
Mapping Architecture to Multilayer Graph – Interlayer Matrix Representation



SATCOM

HF Radio	1	2	3	4
1	1	0	0	0
2	0	1	0	0

HF Radio

SATCOM	1	2
1	1	0
2	0	1
3	0	0
4	0	0

Weapon (1) | C2 (2) | CO (3) | Sensor (4)

Mapping Architecture to Multilayer Graph – Adding Interlayer to Intralayer in Matrix

	VHF Radio	HF Radio	Link 11			Link 16				SATCOM			
VHF Radio	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**
	1	0	0	1	0	0	0	0	1	0	0	0	1	0	0
HF Radio	1	0	**0**	**1**	0	0	0	1	0	0	0	1	0	0	0
	0	1	1	0	0	0	0	0	1	0	0	0	1	0	0
	0	0	0	0	**0**	**1**	**0**	0	1	0	0	0	1	0	0
Link 11	0	0	0	0	1	0	1	0	0	1	0	0	0	1	0
	0	0	0	0	0	1	0	0	0	0	1	0	0	0	1
	1	0	1	0	0	0	0	**0**	**1**	**0**	**0**	1	0	0	0
Link 16	0	1	0	1	1	0	0	1	0	1	0	0	1	0	0
	0	0	0	0	0	1	0	0	1	0	1	0	0	1	0
	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1
	1	0	1	0	0	0	0	1	0	0	0	**0**	**1**	**0**	**0**
SATCOM	0	1	0	1	1	0	0	0	1	0	0	1	0	1	0
	0	0	0	0	0	1	0	0	0	1	0	0	1	0	1
	0	0	0	0	0	0	1	0	0	0	1	0	0	1	0

VHF Radio | Link 16 | Link 11 | HF Radio | SATCOM

Network Analysis Tool: Conclusion

- **Quantitative Low Fidelity Analysis Techniques**
  - **Objective** – Reduces the difficulty of determining probabilities and weightings when high fidelity data is not available
  - **Lightweight** – All techniques utilize basic matrix manipulation ensuring scalability of the methods
  - **Repeatable** – No matter who runs the analysis the results will be consistent unless the network changes
- **Analysis Methods Applicable to all Domains**
  - Optimal value for metrics may vary based on domain
- **Integrated directly into Rhapsody**
  - Ensures no architectural information is lost in translation
- **Enables rapid comparison of alternative architectures**

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Thank You