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Through a Glass, Darkly?

Taking a Network Perspective on System-of-Systems Architectures

Matthew Potts[1], Pia Sartor,[1] Angus Johnson[2] and Seth Bullock[1]

[1] University of Bristol

[2] Thales

Presented By: Matthew Potts

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Abstract

- A system-of-systems (SoS) architecture can thought of as a complex *network*
  - *entities* of different types connected by *relationships* of different types.
- Taking a "*network perspective*" might offer insights into architecture structure using analytic tools associated with network science.
- However, for real-world architectures this is fraught with challenges, e.g.,
  - Modelling the heterogeneity of system entities and their relationships.
  - Modelling the richness of entity behaviour.
  - Capturing the role of context in an architecture.
- Therefore, more mature conceptualizations of the relationship between architectures and their network representations is needed.

Motivation

"OV1a High Level Operational Concept Graphic View" 2016 NAFv4 Chapter 2 Example,. Libert & Garnier J-L

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Network Perspectives on System Architectures

- Identifying important entities:
  - Highly connected entities
  - Entities in the “core” of the system
  - Entities that mediate between many parts of an architecture
  - Entities that are key to resource flows across the architecture
- Practical limitations, lack of consensus, potential to be mislead.
  1. What makes an entity important in a complex SoS architecture, and how might that be reflected in the network representation of it?
  2. What properties are network metrics capturing, and what are their implications for my understanding of the architecture itself?

Evaluating Structure

- SAR architecture nearly an order of magnitude more connected than the MComms architecture.
- SAR had “core” of two separate components (35% of entities).
  - But MComms had no such structure – three components (6% of entities).
- SAR has five “communities”, MComms had nine “communities”.
- Failure of network view to capture relevant contextual information, e.g.;
  - “Core” and “periphery” structure.
  - “Community” structure.
  - Reciprocity.
- Require closer appreciation of the role of these concepts in real-world architectures.

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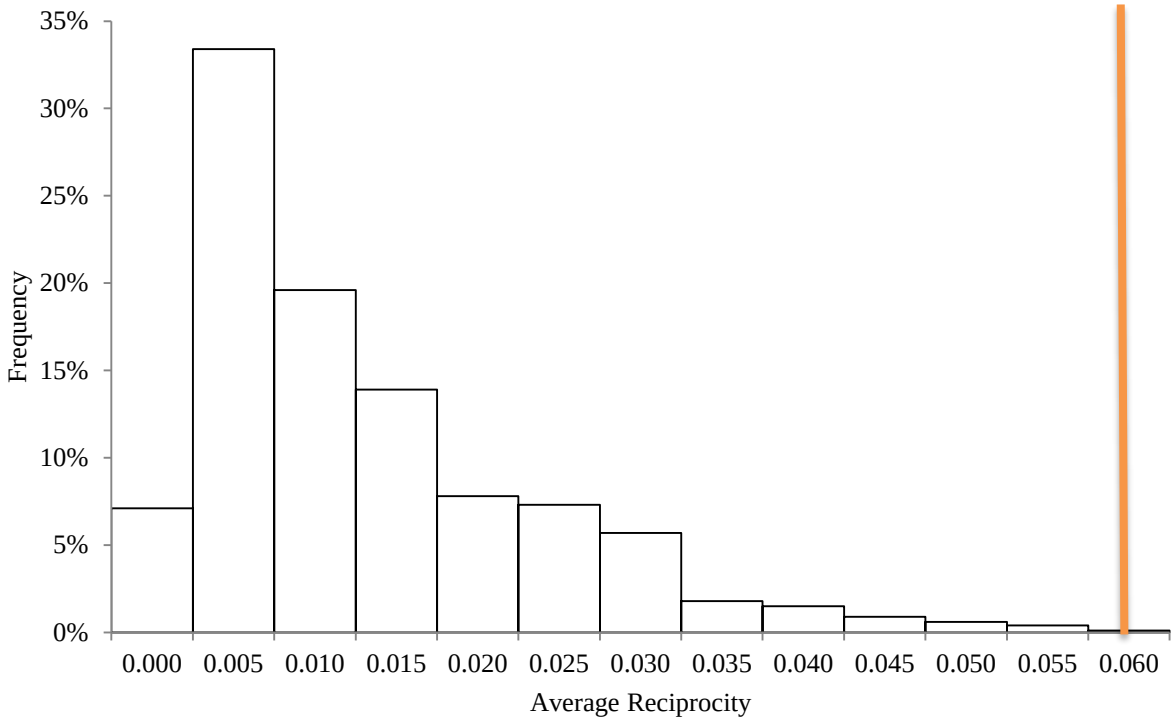
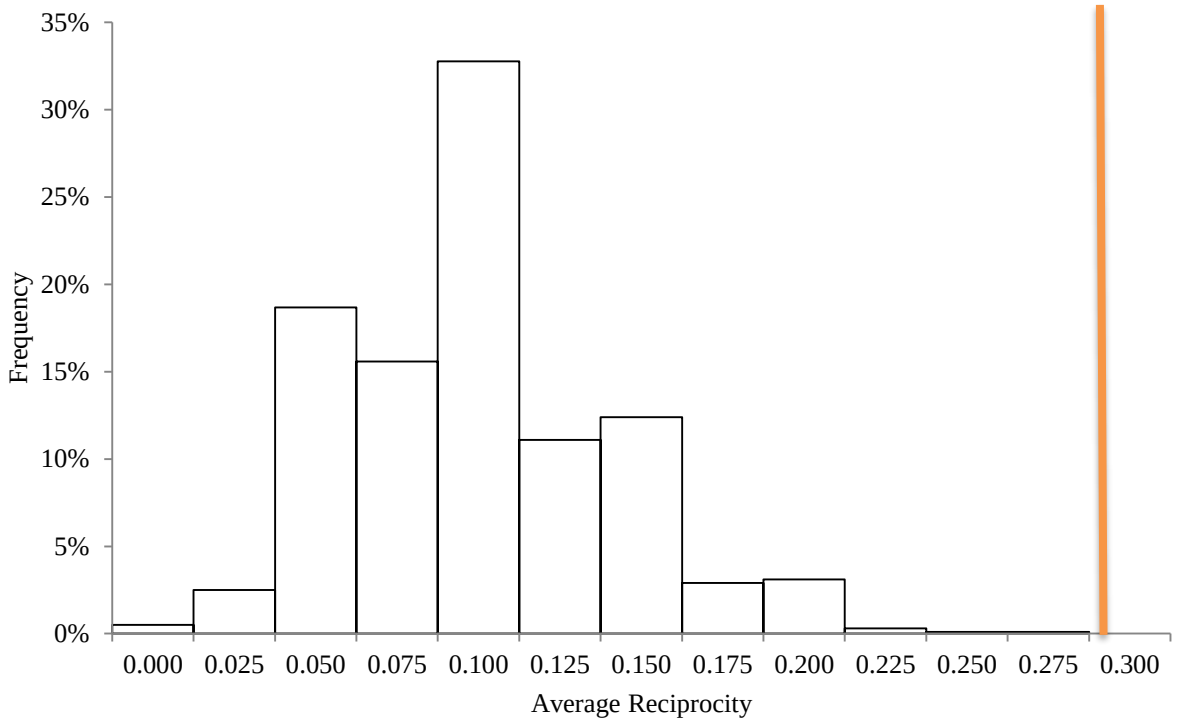
Evaluating Structure





Reciprocity of the MComms (left) and SAR (right) use case networks (orange bars) vs. a random null model distribution.

Network Perturbation

- Results seem positive
  - E.g., both architectures have significantly greater vulnerability to removal of high-degree vertices.
- However, we require a suitable measure of architecture effectiveness:
  - Averaged centrality scores may not reflect topology of surviving architecture or different importance of entities and their relationships.
  - Network diameter and size of largest component are similarly naïve.
  - System entities may have inherent resiliency and adaptability - not captured in the network perspective but may be present in the full system architecture.

Cascading Failure

- Evaluating vulnerability to failure cascades requires knowledge about failure dynamics:
  - Is this feasible early in a system lifecycle?
  - How is this conceptualised?
- Tempting to evaluate susceptibility to failure cascades in a stochastic manner:
  - Perhaps to provide confidence in a design.
  - Perhaps to explicitly design against cascading failure.
  - Fundamentally, these hinge on the nuanced failure models used.

Challenges to Progress

- Respecting heterogeneity
  - Extending graph-theoretic models, e.g., weighted edges, vertex attributes, multiple types of vertices, multiple types of edges, nested, interdependent subnetworks, etc.
  - However, more complicated representations make interpretation more challenging.
  - How much confidence is there in early-lifecycle data? How to choose where to focus?
- A chance to reflect:
  - SoS scale, diversity and connectivity suggests value in network science approaches
  - What makes a system entity important? Connectivity? The effect of removal? Their utility in brokering services from diverse and geographically separated entities?
  - Network perspectives are not a silver bullet, but they will challenge and enrich our understanding of how complex SoS architectures relate to their Systems of Interest.

Conclusion

- Network science has had huge impact across many fields, and a network perspective on SoS architectures has the potential to deliver useful insights:
  - Which entities in an architecture are most important?
  - Which architectures are most robust, efficient, or effective?
  - How might an architecture be vulnerable to failure?
- However, SoS diversity, richness and context-dependence must be successfully captured in network representations of SoS architectures.
- The social sciences spent considerable time and effort developing social networks concepts that enabled the exploitation of networks science tools.
- Developing an equivalent set of conceptual tools for the analysis of complex SoS architectures remains an open research challenge.