

From Structural Opacity to Engineering Legibility: HOW CAN AI RELIABLY ASSIST SoS ARCHITECTING AND GOVERNANCE?

Mohamed Mogahed and Mo Mansouri · Stevens Institute of Technology

1 EMERGENCE



Systems of systems emerge

Independent systems need to collaborate to achieve capabilities **none could achieve alone**. **Such collaboration** gives rise to SoS, emerging **incrementally** through dependencies, data exchanges, contracts, policies, standards, workflow handoffs & shared risks.

→ In these dynamic environments, however...

2 OPACITY



Real before recognized

An SoS can become **operationally real** before it is fully recognized and formally represented: **structural & architectural opacity**. **The field problem** is not simply complexity. The SoS is real, even **socially indispensable**, yet structurally opaque & architecturally informal.

→ As a result...

3 CONSEQUENCES



Hard to architect, to govern

As a result, it cannot be reliably **modeled, analyzed, simulated, or redesigned**. **Governance becomes similarly difficult**: *Who is bound by which obligations, where? Which interactions are governed? Which dependencies are unmanaged? Where would intervention yield systemic benefit?*

→ There is, of course, an SE response...

4 THE SE RESPONSE



SoS architecting frameworks

I will give you a second to think about the ones you know.

What came to your mind? How many produce an architecture formal enough to be directly inspected, reasoned over, or simulated?

My purpose is not to review the toolkit or argue which framework should resolve opacity.

→ Rather, this discussion is targeted at...

5 THE CORE ARGUMENT

How can AI reliably assist SoS architecting and governance?

AI-assisted systems engineering may need to begin **further upstream** than many current discussions assume.

FURTHER UPSTREAM

WHERE MANY DISCUSSIONS BEGIN

Recognition



Formalization



Reasoning



Intervention

6 WHAT WOULD THAT MEAN?



Recognized, then formally captured

Before AI can responsibly support analysis, modeling, simulation, or intervention, the SoS must first be recognized and formally captured.

At minimum, a formal, computable architecture connecting **entities, interactions, dependencies, governance instruments, obligations & conformance conditions**.

Another question: *do such architectures already exist?*

→ And this is where AI's potential role becomes interesting.

7 AI'S POTENTIAL ROLE



Making it legible, then using it

Making an opaque SoS computationally legible: identify entities & relationships from scattered evidence, interpret contracts & policy, recognize dependencies & obligations, suggest missing structures.

And much more!

Once a sufficiently formal architecture exists: explain formal constructs, support reasoning & simulation, identify gaps, generate candidate interventions.

→ But these possibilities create a deeper set of questions...

8 DEEPER QUESTIONS FOR THE FIELD



Recognition to intervention

- 1 What evidence is sufficient to recognize an SoS?
- 2 How to bootstrap it with no authoritative architecture?
- 3 What must be represented for reliable AI reasoning?
- 4 How to represent obligations, standards, contracts, policies & dependencies together?
- 5 Where can AI assist without itself becoming authoritative?

→ Intentionally, more questions than answers.

9 The field-level problem: How can we make structurally and architecturally opaque SoS sufficiently computationally legible for reliable AI assistance, without overstating AI autonomy or displacing human, legal, and organizational accountability?

One way this has been enabled → **my demonstration**