SERC DOCTORAL STUDENT FORUM 2023 | NOVEMBER 14, 2023

Closed Systems Precepts in Systems Engineering for Artificial Intelligent (SE4AI)

Niloofar Shadab, Advised by Dr. Peter Beling and Dr. Alejandro Salado

15 YEARS

SYSTEMS ENGINEERING RESEARCH CENTER

Agenda

- Current Gaps in SE4AI
- Unique Nature of Intelligent Property
- Complementary Precepts- Closed Systems Precepts
- Core and Periphery Concept
- Evidence in Real-world Applications

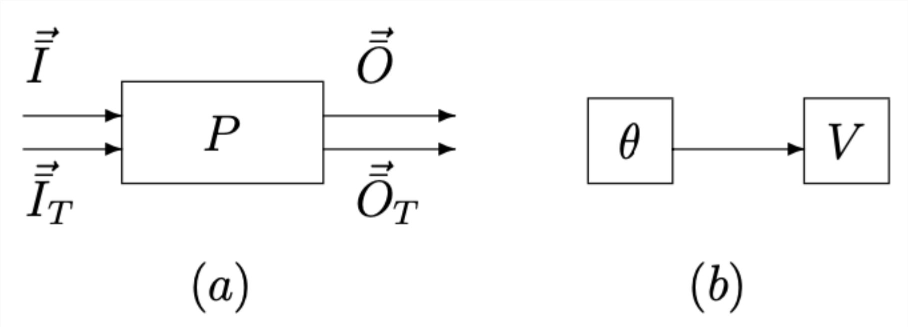
Current Gaps in SE4AI

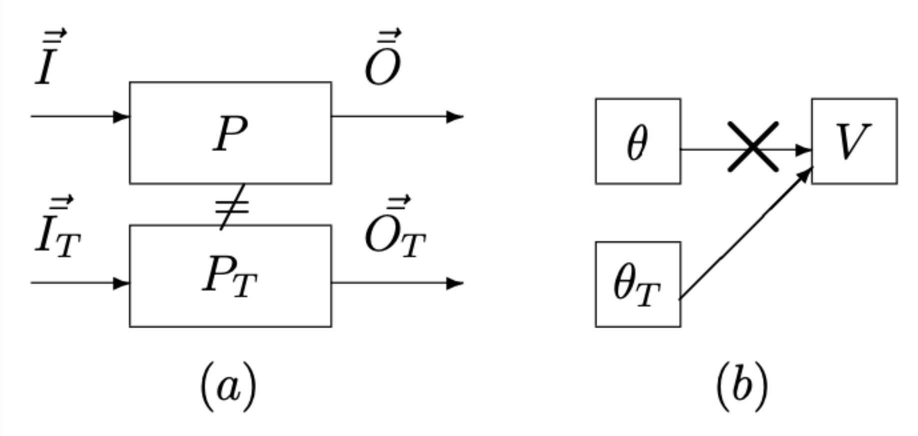
- AI Fragility to Environmental Changes

- Small change in inputs set would have unpredicted consequences
- No direct relation between the changes in inputs and outputs.

Current Gaps in SE4AI

- Continuous Learning Aspects

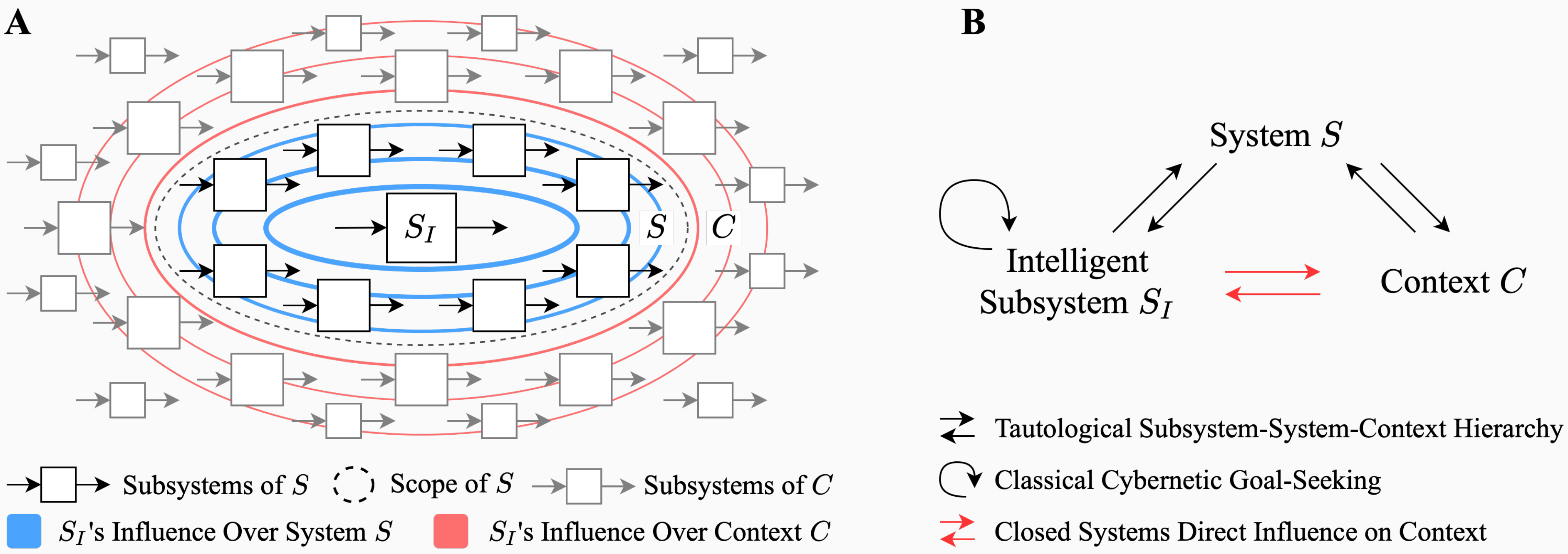




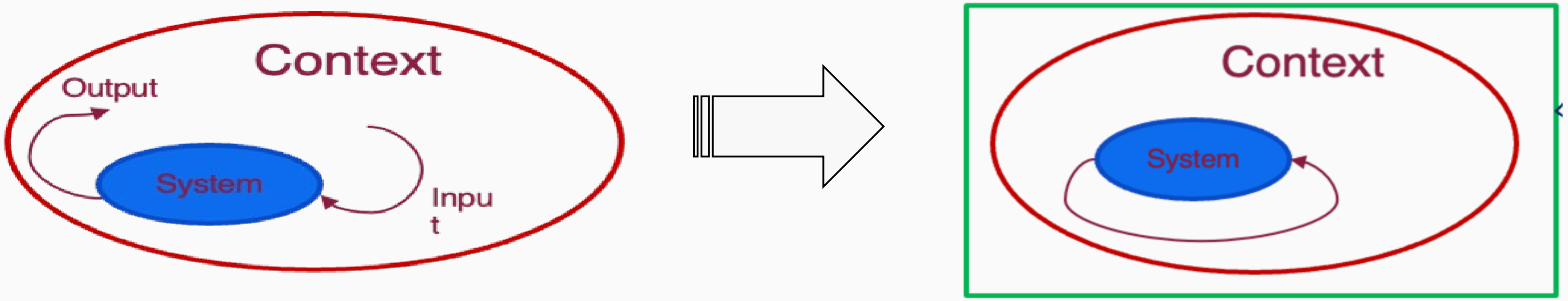
- Similar problem can appear in other SE activities such as manufacturing, design, and requirements engineering

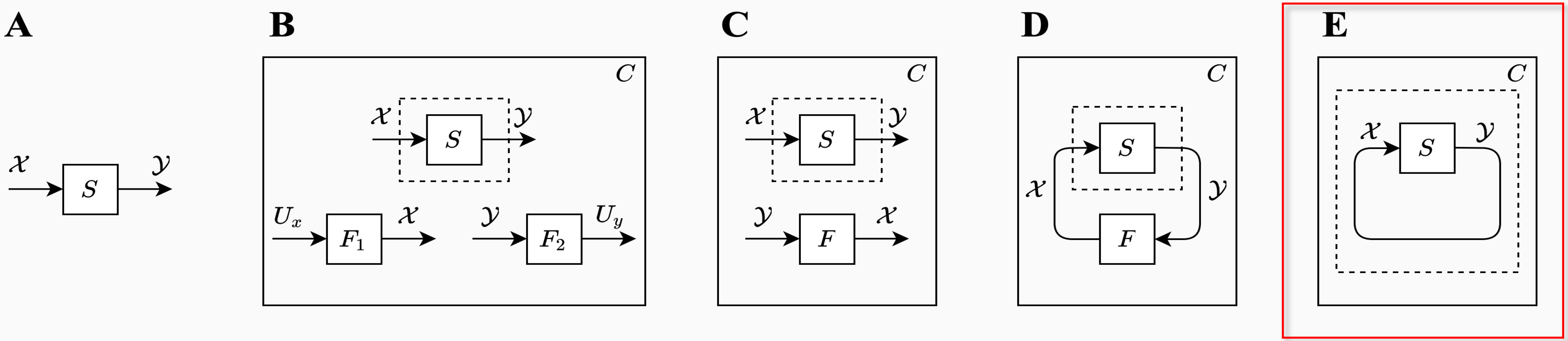
Unique Nature of Intelligence Property

- Closed Relation between the system and its environment
- Dissolution of boundary of intelligence
- Intelligence as a system-level relational property to its environment



Closed Systems Precepts





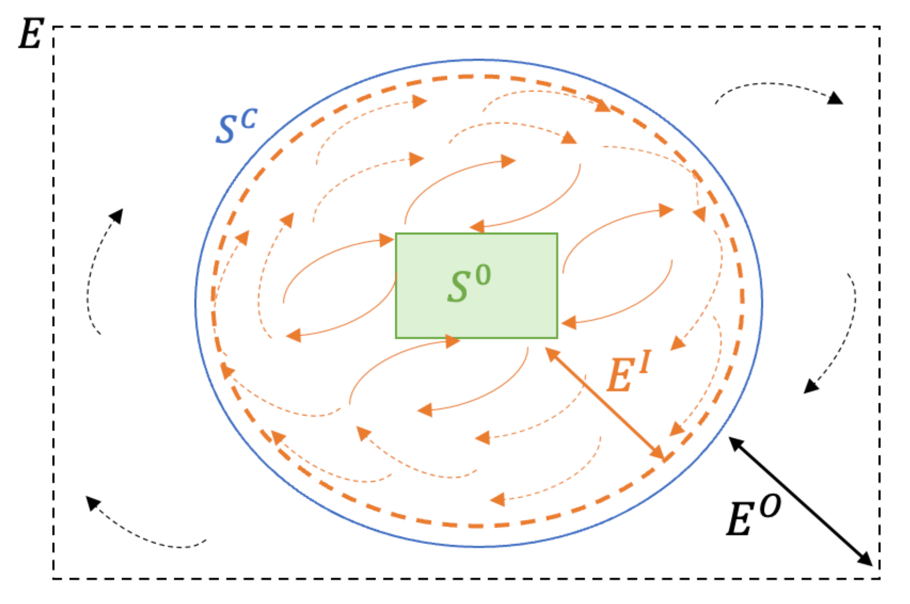
$$S \subset \times\{\mathcal{X}, \mathcal{Y}\}$$

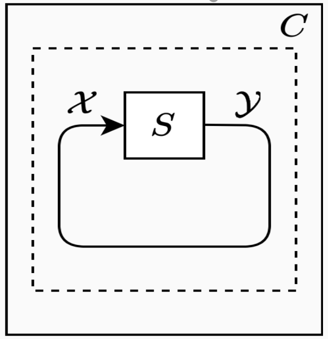
$$\mathcal{X} \cap \mathcal{Y} = \emptyset$$

$$S \subset \times\{\mathcal{X}, \mathcal{Y}\}$$

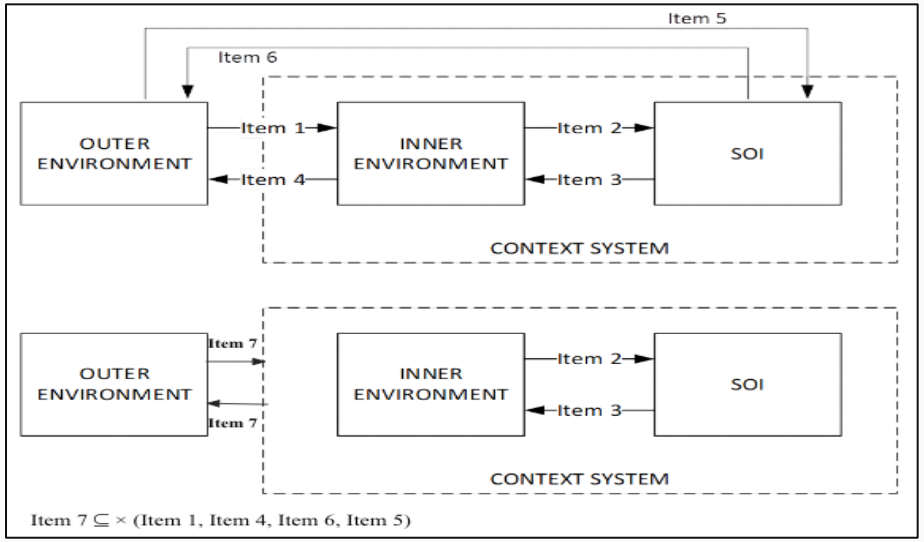
$$\exists f : \mathcal{Y} \to \mathcal{X}.$$

Closed Systems Precepts in SE Practices

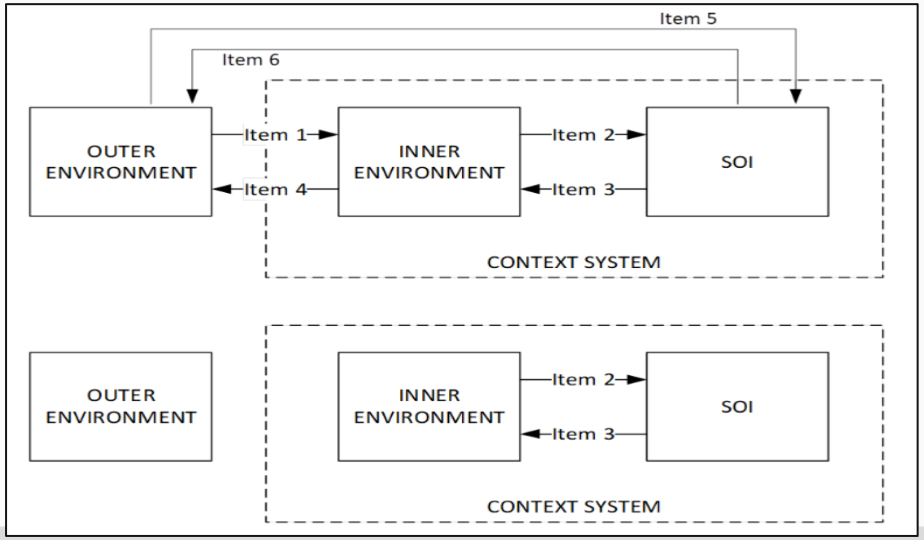




Informational Closure



Functional Closure



Closed Systems Precept Formalism

Functionally Closed System

$$F \subseteq \times \{F_i | i \in I\} \; s.t \; F: X_m \to Y_m$$

Where: $X_m \subseteq M \quad Y_m \subseteq M$

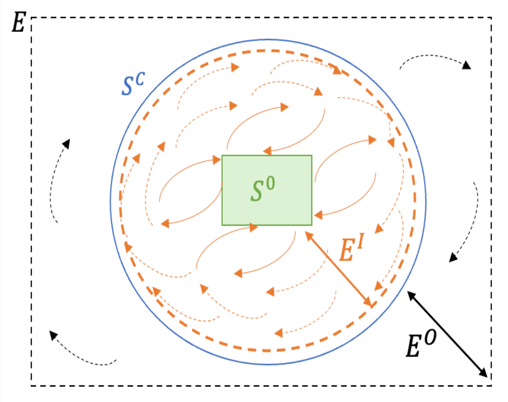
If: $\exists X_E, \; \exists Y_E, \quad s.t \quad X_m \subseteq X_E, \; Y_m \subseteq Y_E$

We have: $F: X_E \to Y_m$

If: S is defined as $S \subseteq \times \{F_i | i \in I\}$

Let: $X = X_E \backslash \mathrm{M} \;\; \& \;\; Y = Y_E \backslash \mathrm{M}$

We have: $S \not\subset \times \{X, Y\}$



Informationally Closed System

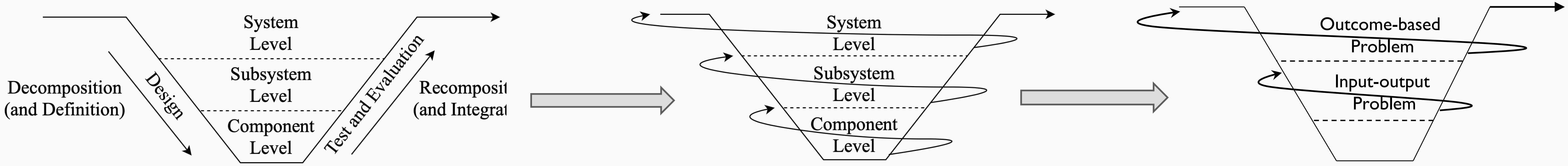
$$I\left(S^C_{\{n+1\}}; E^O_n \middle| S^C_n\right) = 0$$

$$I\left(S^C_{\{n+1\}}; E^O_n, S^C_n\right) = I(S^C_{\{n+1\}}; S^C_n)$$

Theorem 1 (Inequality for mutual information In closure):

$$I(S^C_n; E^O_n) \geq H\left(S^C_{\{n+1\}}, S^C_n\right) - H(S^C_{\{n+1\}}, S^C_n | E^O_n)$$

Different Level of Abstraction in SE



Ashby's Law of Requisite Variety:

$$\min V_Z = \max(V_{X_E \setminus S} - V_Y, 0)$$

$$S \text{ is stable } \rightarrow Variety(S) > Variety\ (C)$$

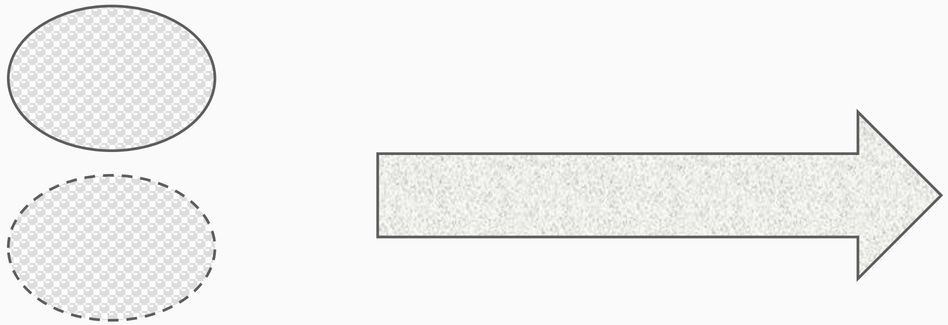
$$Variety(O) \geq Variety(C) - Variety(S)$$

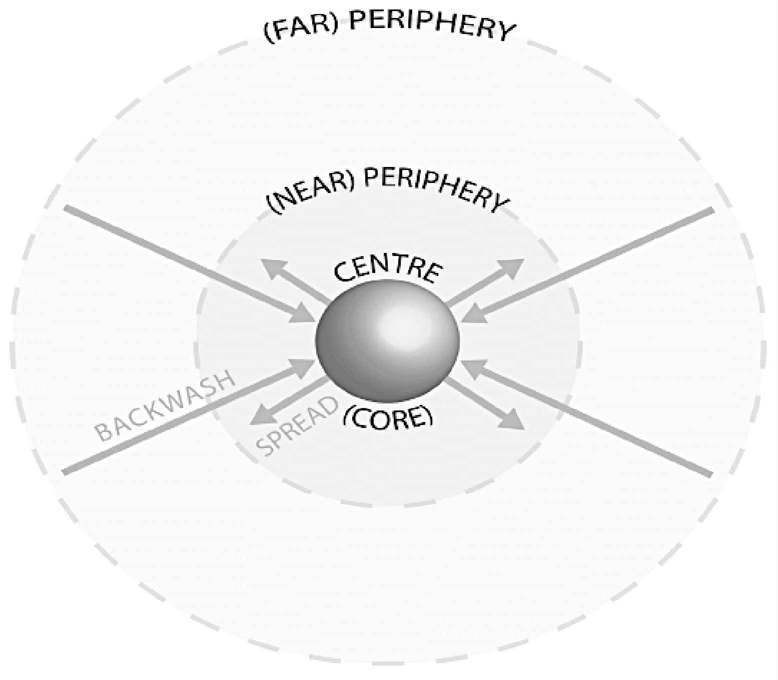
Law of Requisite Variety states that given $V_{X_E \setminus S}$, the minimum variety of outcomes $\min V_Z$ only decreases if V_Y increases.

Core And Periphery Precepts

Bounded Variety:

Unbounded Variety:





Residual Change: $$R_{S}^{t,t'} = \{X^{t'} \setminus X^{t}, Y^{t'} \setminus Y^{t}\}$$

Consider a system S at time t and at a later time t', The **core** of S from t to t' is

$$C = \bar{S} \setminus R_{S}^{t,t'}$$

The **Periphery** of S from t to t':

$$\mathcal{P} = R_{S}^{t,t'}$$

Evidence of Core And Periphery in Biological Intelligence

- **Homeostasis and Homeodynamics**
  - Homeostasis: It refers to the body's ability to maintain a stable and balanced internal environment, despite external changes and fluctuations.
  - Homeodynamics: It describe a state of dynamic equilibrium or balance within a biological system.

  - Homeostatis variables → **core** homeodynamic variables → **periphery**

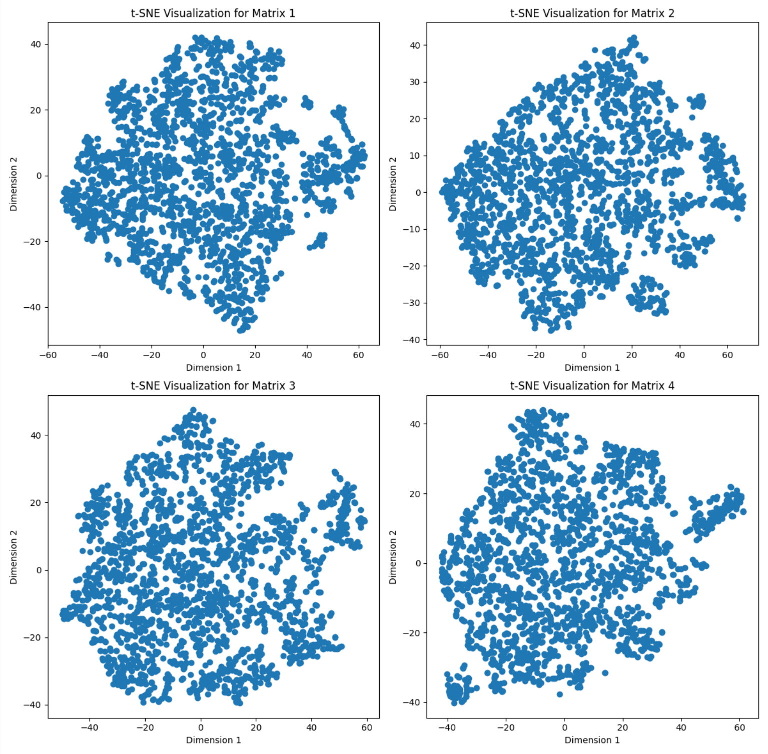
- **Belief and Attitude**
  - Attitude can transfer to belief and vice versa through the conduct of inquiry due to suspension of judgment.

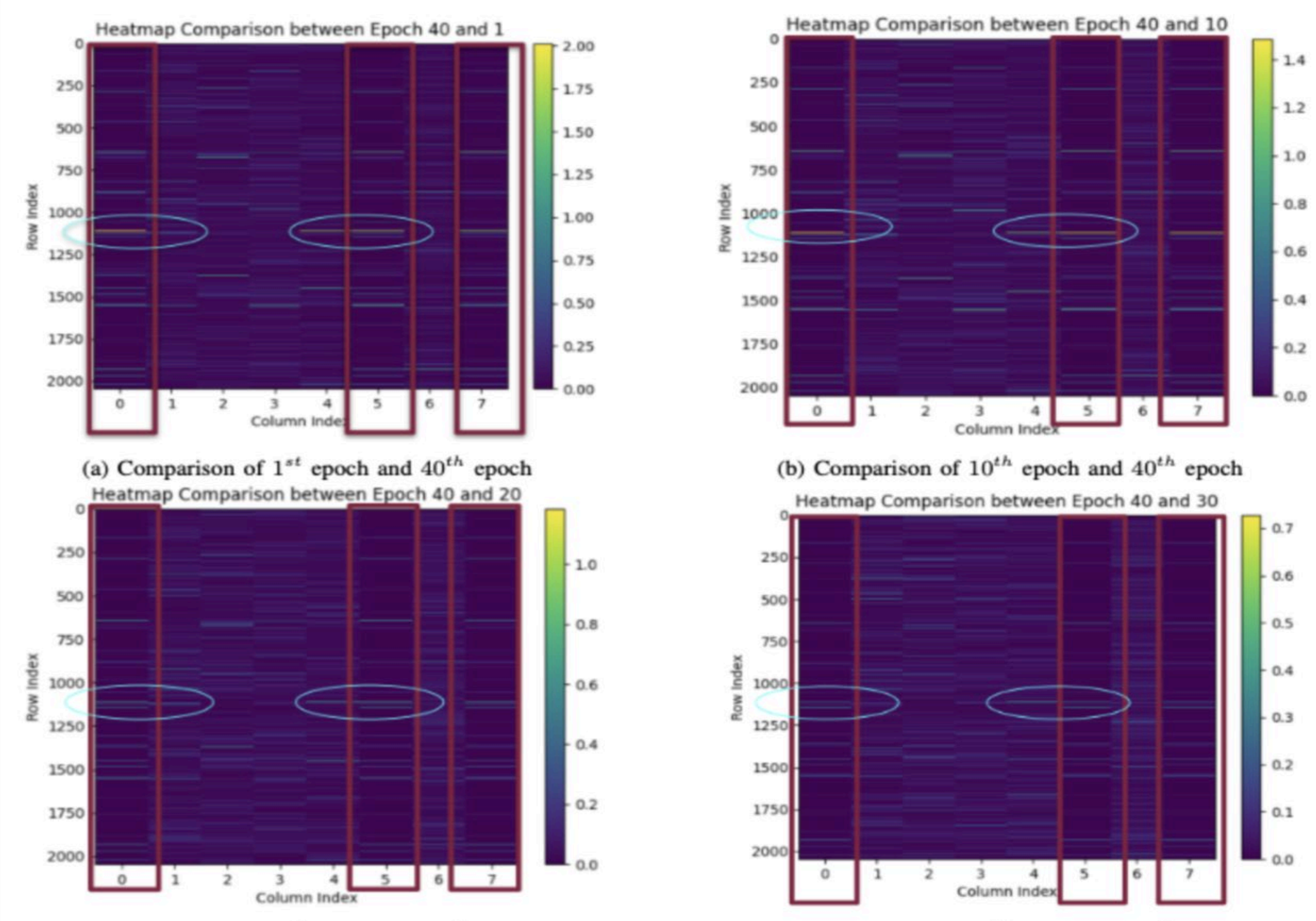
  - Belief → **core** Attitude → **periphery**

Evidence of Core And Periphery in Artificial Intelligence

ENGINEERED INTELLIGENCE

- CNN (CFAR-10 and CFAR-100)





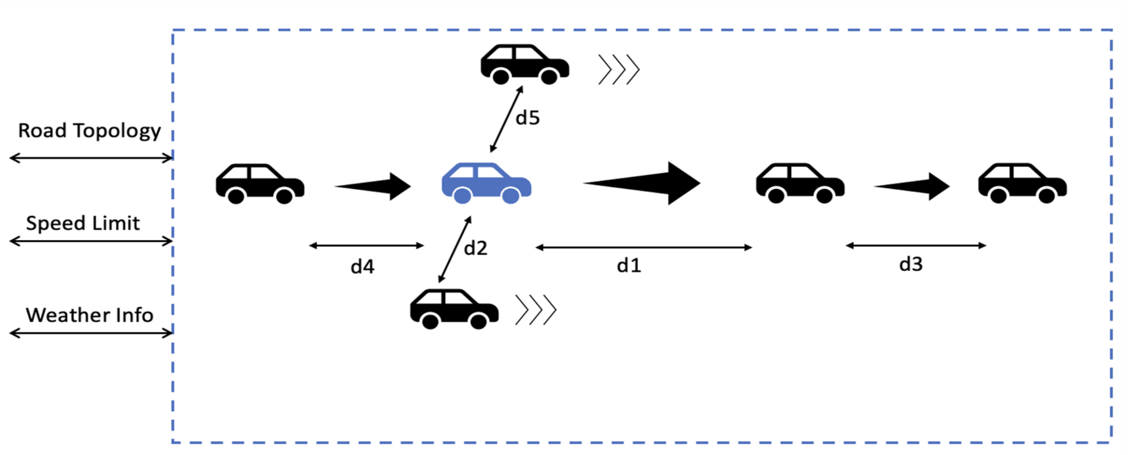
(a) Comparison of 1^{st} epoch and 40^{th} epoch

(b) Comparison of 10^{th} epoch and 40^{th} epoch

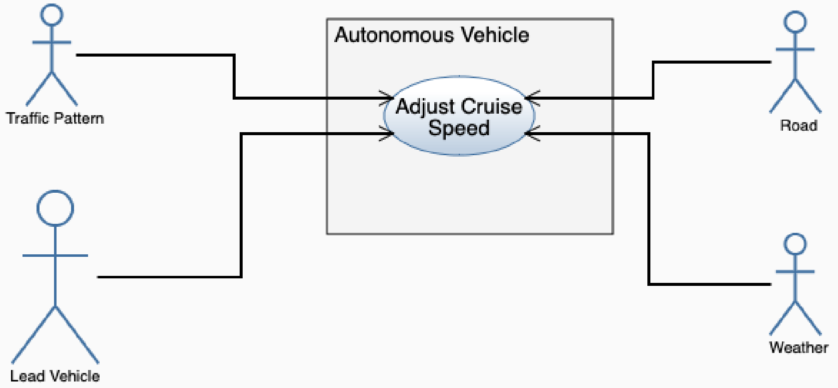
(c) Comparison of 20^{th} epoch and 40^{th} epoch

(d) Comparison of 30^{th} epoch and 40^{th} epoch

Example of Informational Closure in SE



$$Theorem\ 1:\ I(S_n^C; E_n^O) \geq H\left(S_{\{n+1\}}^C, S_n^C\right) - H(S_{\{n+1\}}^C, S_n^C | E_n^O)$$



Initial Modelling Assumptions:

$$I(S_n^C; E_n^O) = \{V_{limit}, R^0, W^0\}$$

$$I(E_n^O) = \{V_{limit}, R^0, W^0, RU\}$$

Calculation of Entropy in The Proposed Model:

$$H(S_n^C) = -\sum_{x \in S_n^C} P(x) \log P(x) = -\sum_{d_n^1}^{d_n^5} p(d_n^i) \log(d_n^i)$$

where: $p(d_n^i) = p(V_n^i, a_n^i, V_n^0, a_n^0)$

$$H(S_{n+1}^C) = -\sum_{y \in S_{n+1}^C} P(y) \log P(y)$$

$$= -\sum_{d_{n+1}^1}^{d_{n+1}^5} p(d_{n+1}^i) \log(d_{n+1}^i)$$

where:

$$p(d_{n+1}^i) = p((V_{n+1}^i, a_{n+1}^i | V_n^i, a_n^i), (V_{n+1}^0, a_{n+1}^0 | a_n^0, V_n^0))$$

Final Calculation of Inequality:

First: $I(S_n^C, E_n^0) = H(S_n^C) - H(S_n^C | E_n^0)$

Second: $H(S_{n+1}^C, S_n^C | E_n^O) =$

$$H(S_{n+1}^C) + H(S_n^C | E_n^O) - I(S_{n+1}^C; S_n^C | E_n^O)$$

Third: $H(S_n^C, S_{n+1}^C) = H(S_n^C) + H(S_{n+1}^C | S_n^C)$

Application of This Research

- This research contributes to the theory of SE by providing formal definitions of the closed systems concepts, and variety at different abstraction levels of system (core and periphery)

- This research will help pave the way for systems engineers to build methodologies to engineer intelligent systems.

- This research provides an avenue to enable direct engineering of outcome-based problems

- This research proposes a concept that can help scaling and scoping intelligence property as a property of the whole.

- This research will provide a framework that introduces an additional layer of abstraction in SE of intelligent systems that can result in reduction of the number use-case models in the SE process.

Thank you

Niloofar Shadab

nshadab@vt.edu

Advised by

Peter Beling, Alejandro Salado

beling@vt.edu alejandrosalado@arizona.edu

Co-author:

Tyler Cody

tcody@vt.edu

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