THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

Theoretical Feasibility of Graph Neural Networks for Augmented Intelligence in Systems Engineering

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Background

- Due to their power in creating fluent text, LLMs have been a frequent tool for building augmented intelligence agents for SE
- However, LLMs are primarily text-based and may not be suitable for all types of SE data or certain SE augmented intelligence agent tasks
- Graph Neural Networks (GNNs) may offer another path for building AI agents using SE data

Background - What is GNN?

- GNNs are a way to incorporate graph structure and relationships into building AI agents
- GNNs view the graph as having information “flow” and train to weight that “flow”
- Previous applications have included:
  - Computer vision
  - Natural language processing
  - Traffic prediction
  - Recommender systems
  - Drug interaction prediction

Background - Research Questions

This work seeks to answer:

1. How can systems be represented as graphs?
2. How might GNNs be trained on these graph systems representations?
3. Which augmented intelligence SE tasks might GNNs be well suited for?

Methodology

Methodology

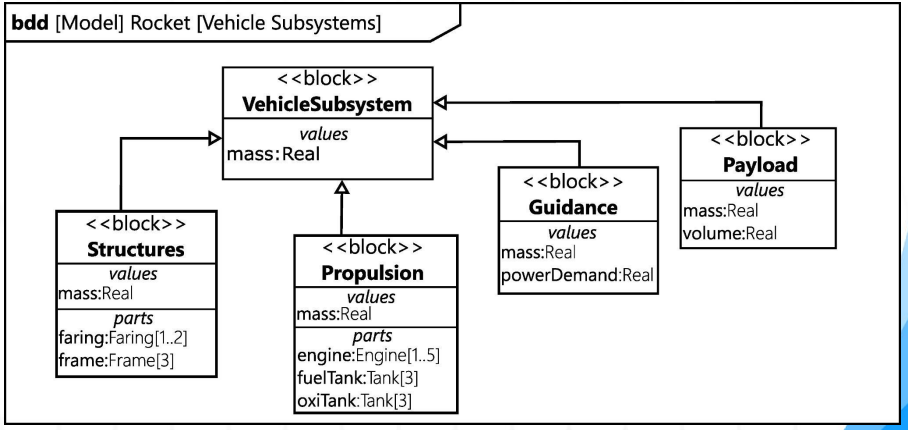
- Identify commonly used graph-representable system models
- GNN literature review
  - How do GNNs work?
  - What are the challenges GNNs face?
- AI for augmented intelligence in SE task identification

Results

Identification of Common Graph-Representation System Models

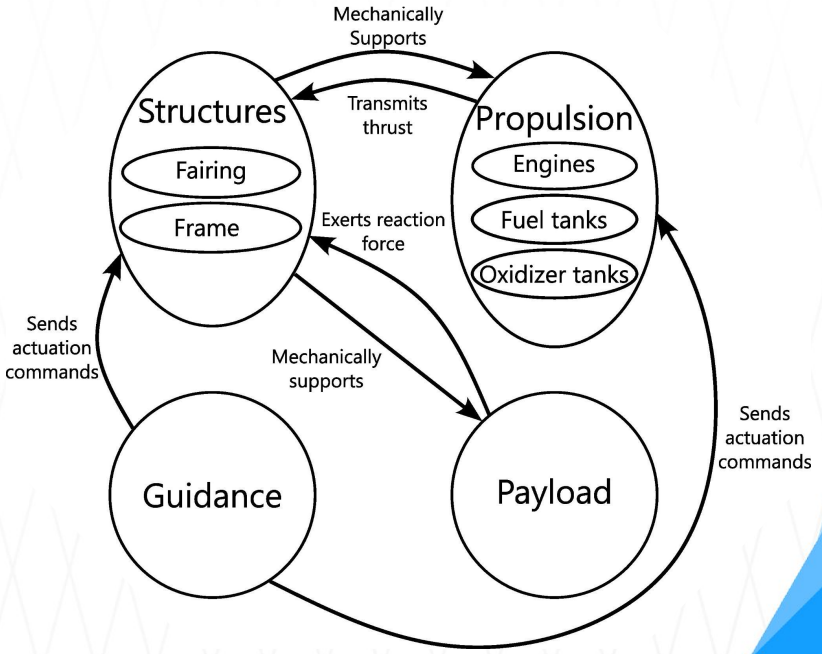
SysML

- Directed graph
- Heterogeneous node and edge types
- Perhaps most widely used system representation
- Often taken to be synonymous with SE



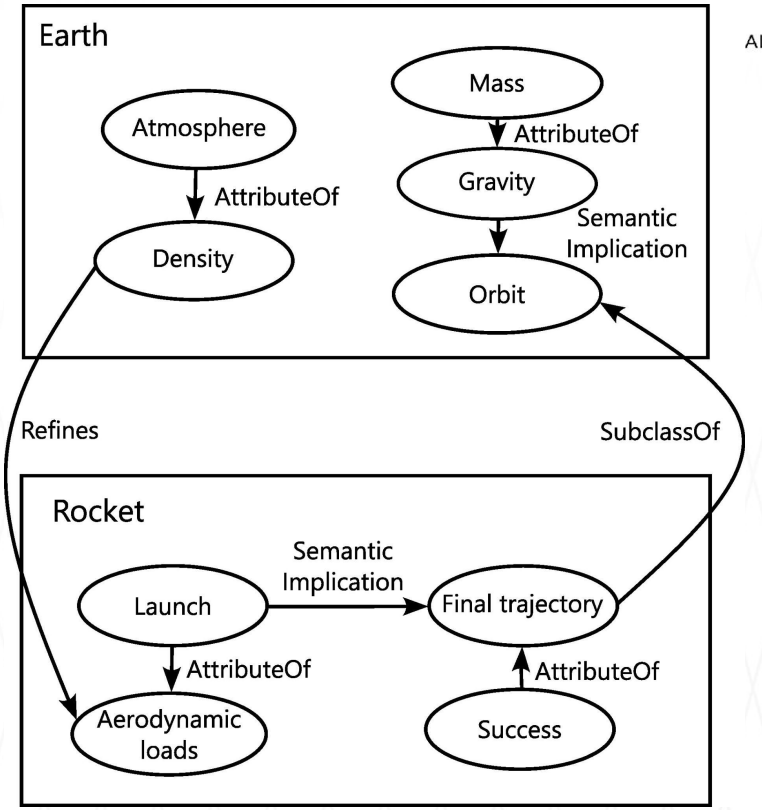
Systemigrams

- Directed graph
- Heterogeneous node and edge types
- A “soft” system representation, helpful for conceptual exploration



Ontologies

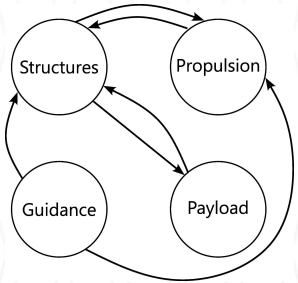
- Directed graph
- Heterogeneous node and edge types
- More formalized that systemigrams, but not standardized like SysML



Design Structure Matrices (DSMs)

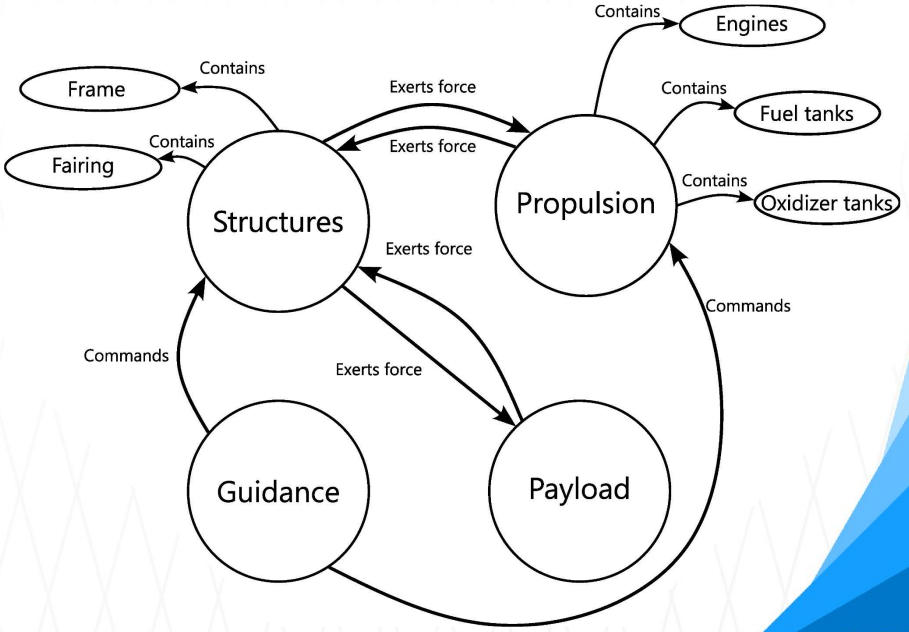
- Directed graph (undirected if matrix is symmetric)
- Homogeneous node and edge types
- Simplest of system representations, showing connections between subsystems

	Structures	Propulsion	Guidance	Payload
Structures		X		X
Propulsion	X			
Guidance	X	X		
Payload	X			



Knowledge graphs

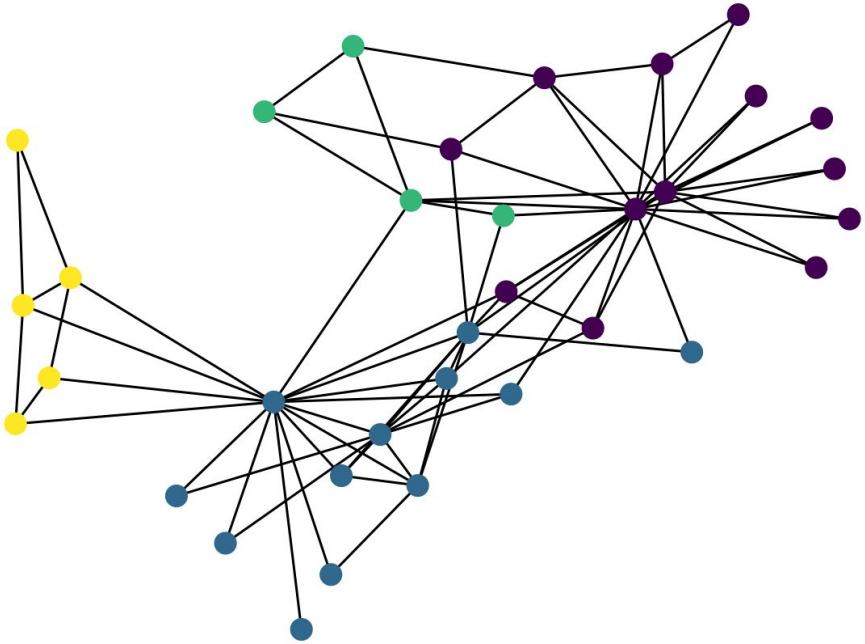
- Directed graph
- Heterogeneous node and edge types
- Similar to ontologies, but less formal

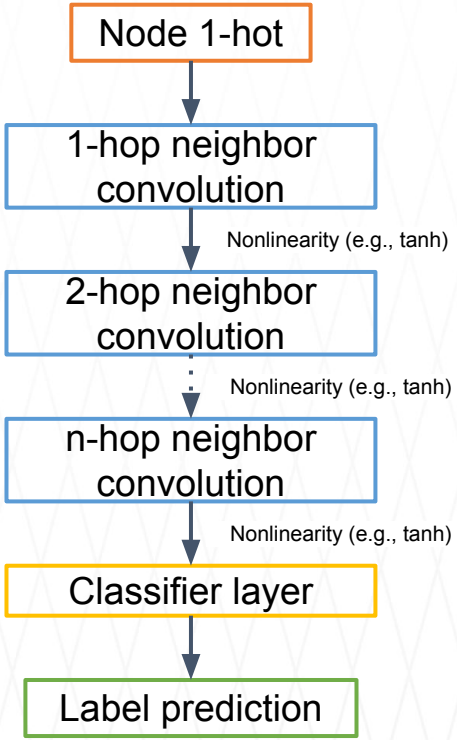


Results

GNN Literature Review

How do GNNs work?

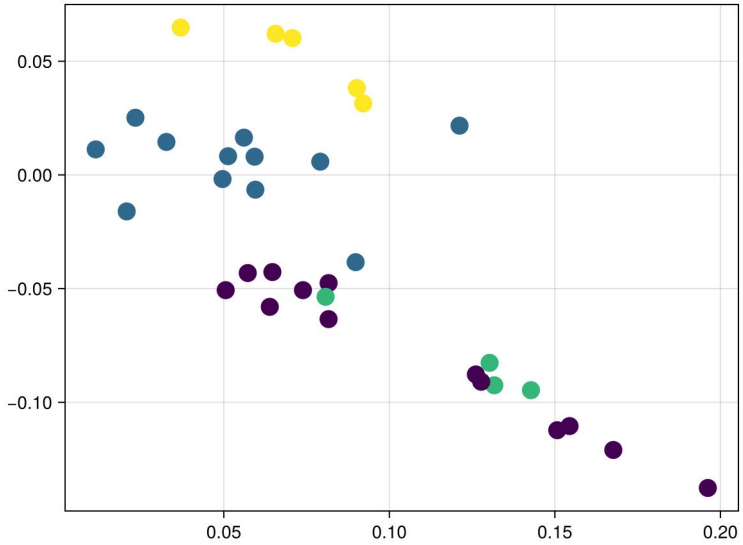




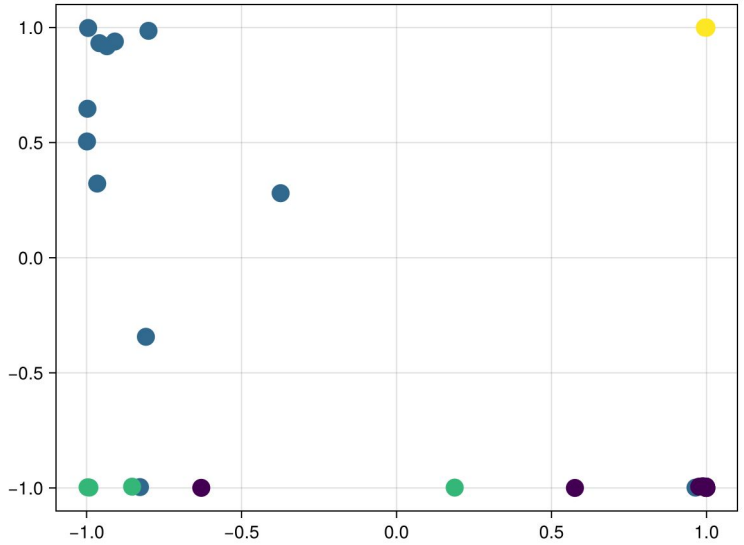
Zachary, Wayne W. “An Information Flow Model for Conflict and Fission in Small Groups.” *Journal of Anthropological Research* 33, no. 4 (1977): 452–73. http://www.jstor.org/stable/3629752.

GNN Training for Label Prediction

Untrained



Trained



5 training nodes
3 convolution layers

What are the challenges GNNs face?

- Heterogeneity of nodes and edges
- Trade offs in low- or high-level graph features
- Dynamic nature of system representation for a system under development

Results

AI for augmented intelligence in SE task identification

SERC augmented engineering

- Depends on what is meant by “applying ML”
- Can aid in exploration and perhaps boilerplate model construction
- Additionally, HMI may be more broad than conversation

AI task	*Description*
Automated search	Applying ML to historical data and relationships in the engineering domains
Conversational data entry	Human/computer interaction processes to convert natural language and other media to formal models
Automated evidence	Automation of certification and accreditation processes via models and automation of quality assurance data
Assurance models	Automation of evidence- based models for assuring correctness and completeness of system requirements and design
Automated model building/checking	Automated construction of models from features in semantic data, used in both creation of new models and correctness of developed models
Cognitive assistants	Conversational systems automating many mundane data entry, exploration, and engineering calculation tasks, and many workflows

[*Research Roadmaps 2019-2020*, SERC]

Likely suited to GNNs
Possibly suited to GNNs

Madni AI augmented SE

- Several areas call out ML specifically
- Ontologies can be covered by GNNs, but uncertain how ontologies were meant to be used according to this source

Level	*SE Activity*	*AI Technologies*
System	Modeling	Machine learning
	Verification	Formal logic
	Reuse	Ontologies
Infrastructure support	Context management	Context ontology
	Search/info retrieval	Metadata tagging with ontology assets
	Interoperability	Ontologies
Process	Intelligent information logistics	Context-aware information pre-fetching
	Adaptive execution	Resilience contract/machine learning
	Reuse	Ontologies
	Integration	Ontologies

Likely suited to GNNs
Possibly suited to GNNs

[A. M. Madni, "Exploiting Augmented Intelligence in Systems Engineering and Engineered Systems," *INSIGHT*, vol. 23, no. 1, pp. 31–36, 2020, doi: 10.1002/inst.12282.]

Rouse augmented intelligence interface

- GNNs have been used for recommendation systems, which is similar to the support roles seen here.
- GNNs may not explicitly frame human roles or adapt to skill levels

Frames human's roles and tasks and provide support accordingly
Retrieve information and control needed for inferred, human-intended tasks
Through inference of human skill level, provide just-in-time training or inform adaptive aiding
Provide recommended actions and decisions, as well as explanations
Determine the amount of adaptive aiding the human requires, from manual to automatic control

Likely suited to GNNs
Possibly suited to GNNs

[W. B. Rouse, "AI as Systems Engineering Augmented Intelligence for Systems Engineers," *INSIGHT*, vol. 23, no. 1, pp. 52–54, 2020, doi: 10.1002/inst.12286.]

Discussion & Conclusion

Discussion

- Graphs appear to be a common means of expressing system information, but vary in their properties as graphs
- GNNs appear able to capture the kinds of graph information used in representing systems, but may struggle with features like heterogeneity
- GNNs appear well suited to at least some of the tasks described in literature, but the tasks are often broad and vaguely defined
- Some system representations (like systemigrams) may be too small and/or varied to train on successfully

Conclusion

- How can systems be represented as graphs?
  - Systems have a number of graph representations, including SysML, systemigrams, ontologies, DSMs, and knowledge graphs
- How might GNNs be trained on these graph systems representations?
  - GNNs can use recurrent, convolutive, auto-encoding approaches, and more to train on graphs
- Which augmented intelligence SE tasks might GNNs be well suited for?
  - GNNs are likely suited for plain text model conversion, system and process reuse, among others

Conclusion and Future Work

- GNNs may be a new way to approach using SE data to train an augmented intelligence agent and may more easily be able to use and combine SE data than existing approaches
- Future work could include training on real world data
  - Larger models/model databases would be preferred in order to give the GNN the most training data possible
- SysML is a likely candidate for GNN application since the models can be large, but with consistent semantics. It is also widely used and so would have the most generalizable results

Questions?

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