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Use of Natural Language Processing in Digital Engineering Context to Aid Tagging of Model

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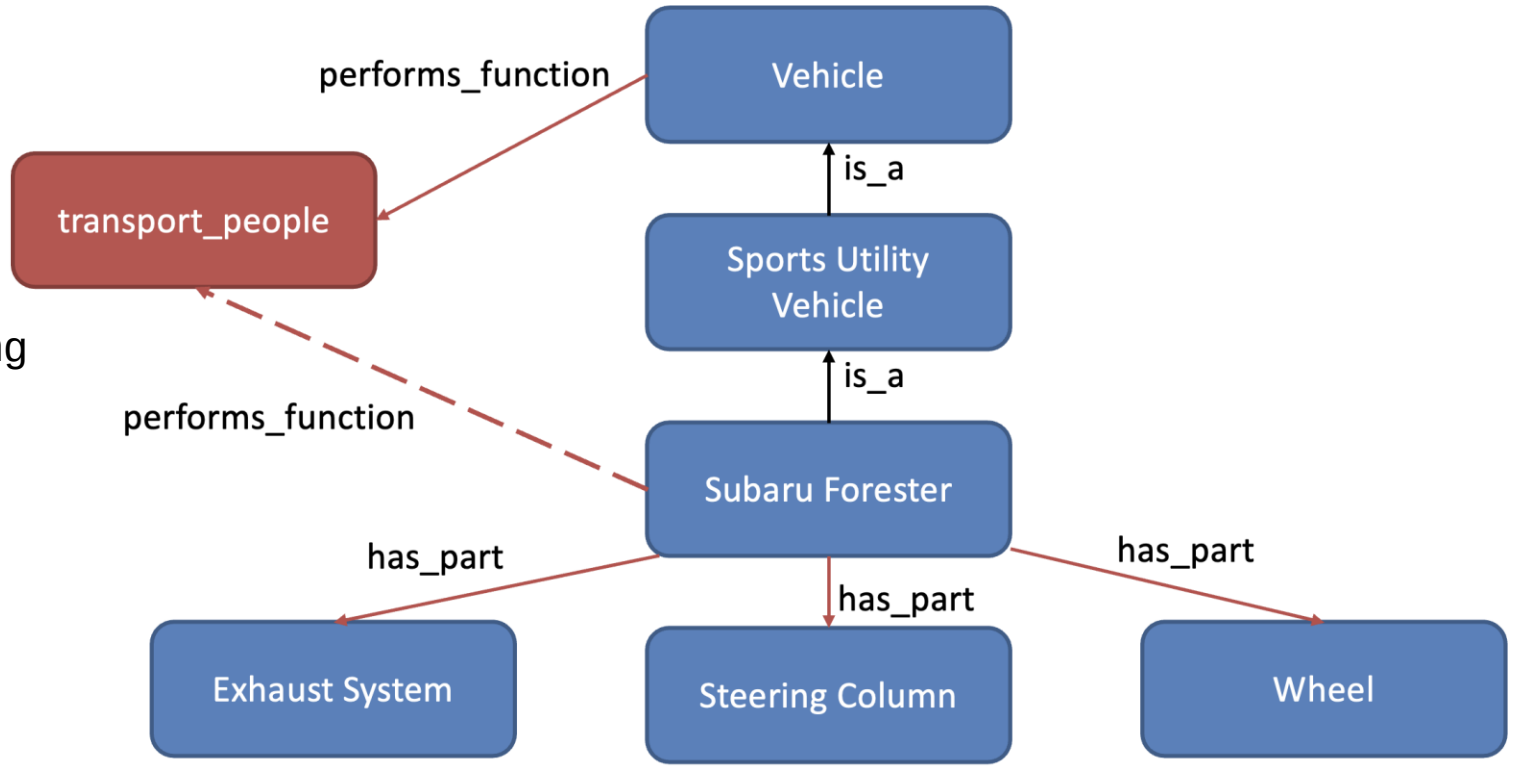
Ontologies – What are they?

- “Ontologies are label taxonomies corresponding to classes of things and a permissible relation between these types” (T. Hagedorn et al., 2020)

- Can encode data in manner that allows for formal mathematical logic to perform reasoning on the data
  - Consistency Checks
  - Semantic Expansion



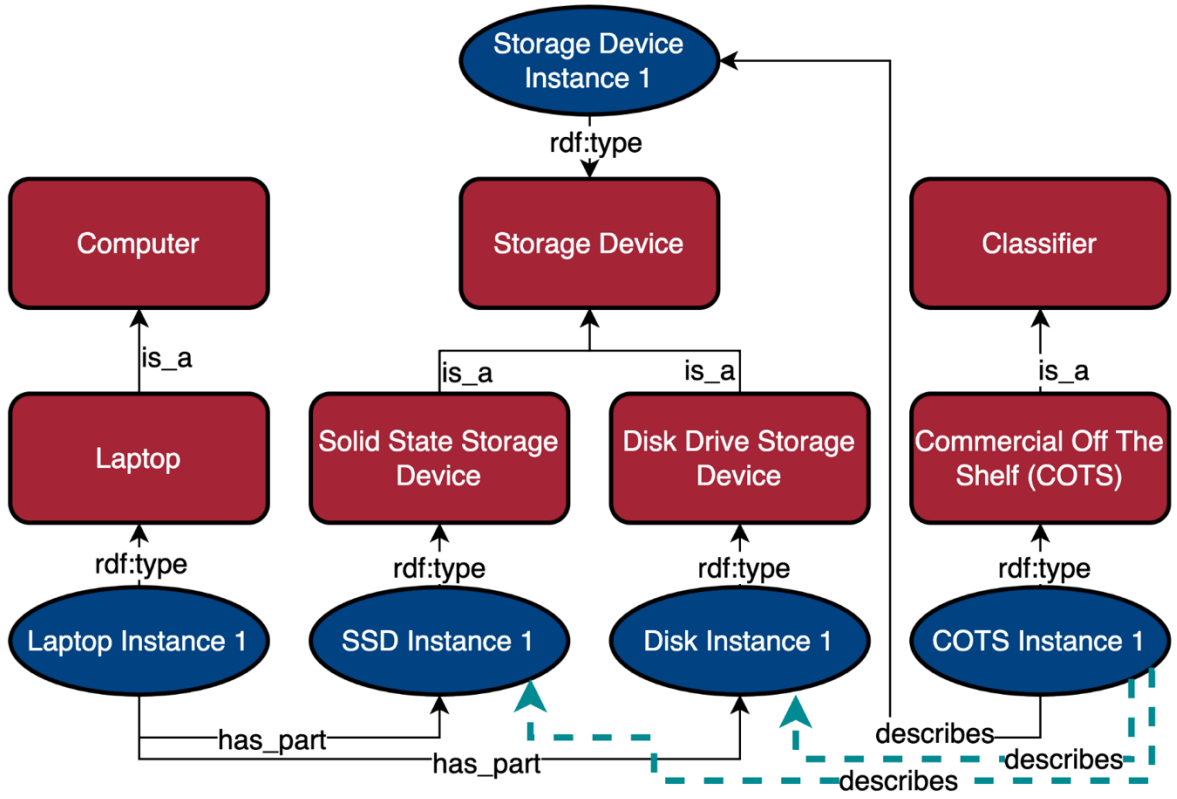
Hagedorn, T., Bone, M., Kruse, B., Grosse, I., & Blackburn, M. (2020). Knowledge Representation with Ontologies and Semantic Web Technologies to Promote Augmented and Artificial Intelligence in Systems Engineering. *INSIGHT*, *23*(1), 15–20. https://doi.org/10.1002/inst.12279

Natural Language Processing for Requirements Engineering (NLP4RE)

- NLP can be used to parse textual requirements into graphs
- Graphs can be analyzed for things like complexity

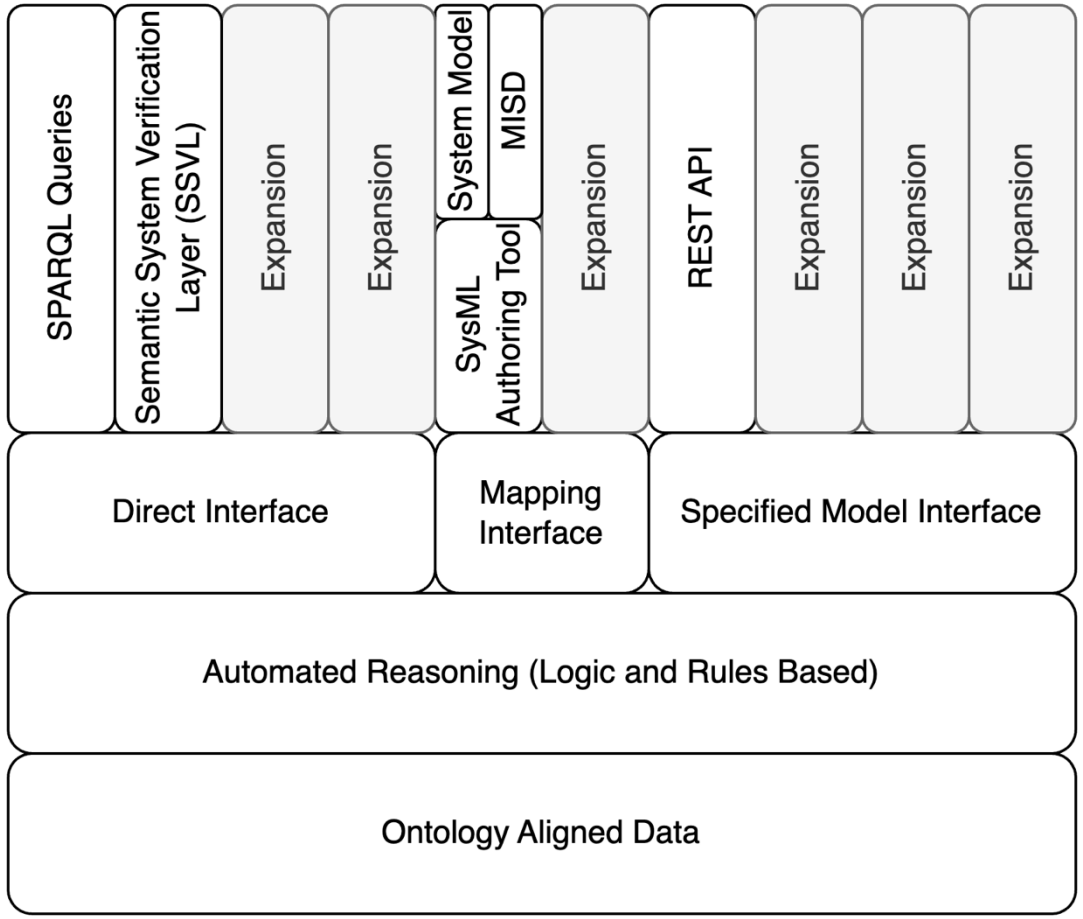
Consider the following requirements:

- The laptop shall have a solid state storage device.
- The laptop shall have a backup disk drive storage device.
- The system shall utilize commercial off-the-shelf (COTS) storage devices.



Vierlboeck, M., Dunbar, D., & Nilchiani, R. (2022). Natural Language Processing to Extract Contextual Structure from Requirements. *2022 IEEE International Systems Conference (SysCon)*, 1–8. https://doi.org/10.1109/SysCon53536.2022.9773855

Digital Engineering Framework for Integration and Interoperability



- Uses ontology-aligned data as Authoritative Source of Truth (AST)
- Enables reasoning and semantic expansion
- Semantic System Verification Layer (SSVL) uses semantic technologies to perform verification tasks on ontology-aligned data
- Interfaces allow for interoperability across many different tools
- Mapping interface uses custom SysML stereotypes to match SysML elements with ontology classes

Dunbar, D., Hagedorn, T., Blackburn, M., Dzielski, J., Hespelt, S., Kruse, B., Verma, D., & Yu, Z. (2023). Driving digital engineering integration and interoperability through semantic integration of models with ontologies. *Systems Engineering*, sys.21662. https://doi.org/10.1002/sys.21662
Dunbar, D., Hagedorn, T., Blackburn, M., & Verma, D. (2022). Use of Semantic Web Technologies to Enable System Level Verification in Multi-Disciplinary Models. In B. R. Moser, P. Koomsap, & J. Stjepandić (Eds.), *Advances in Transdisciplinary Engineering*. IOS Press. https://doi.org/10.3233/ATDE220632

The Problem - Scale

Requirements

- Large complex systems don’t have just 10 requirements
- Hundreds? Thousands?

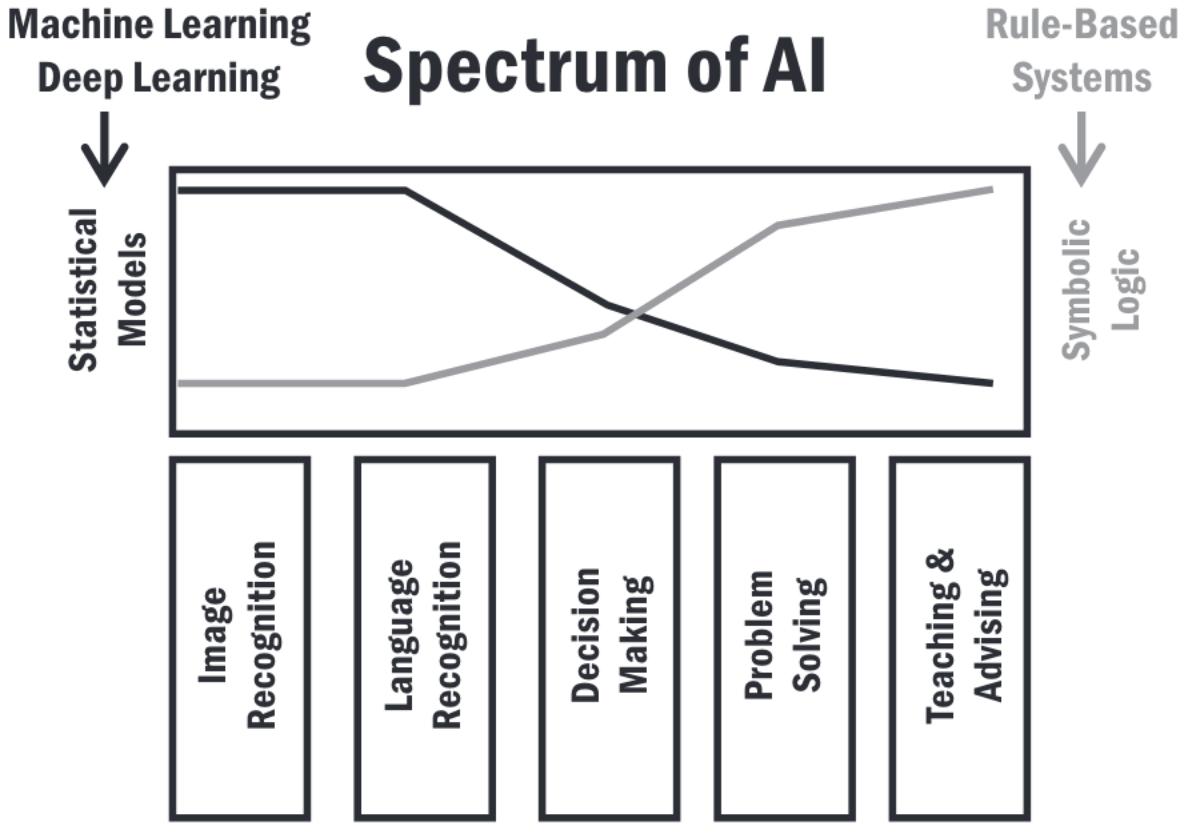
System Models

- Large complex systems don’t have 30 elements in a system model and two BDDs
- Hundreds? Thousands?

Alexa, help!

Natural Language Processing (NLP)

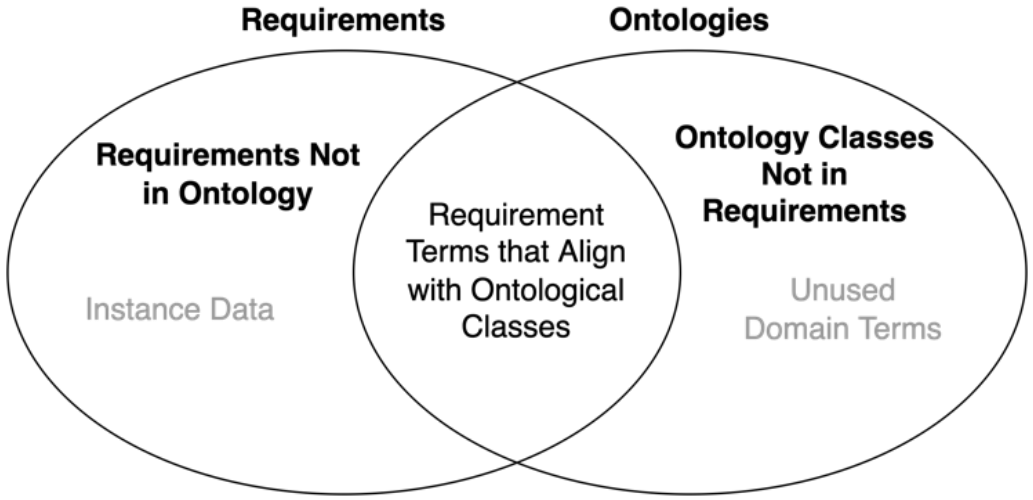
- NLP used as Augmented Intelligence agent
  - Statistical approach by itself is unacceptable
  - Coupled with Expert Verification

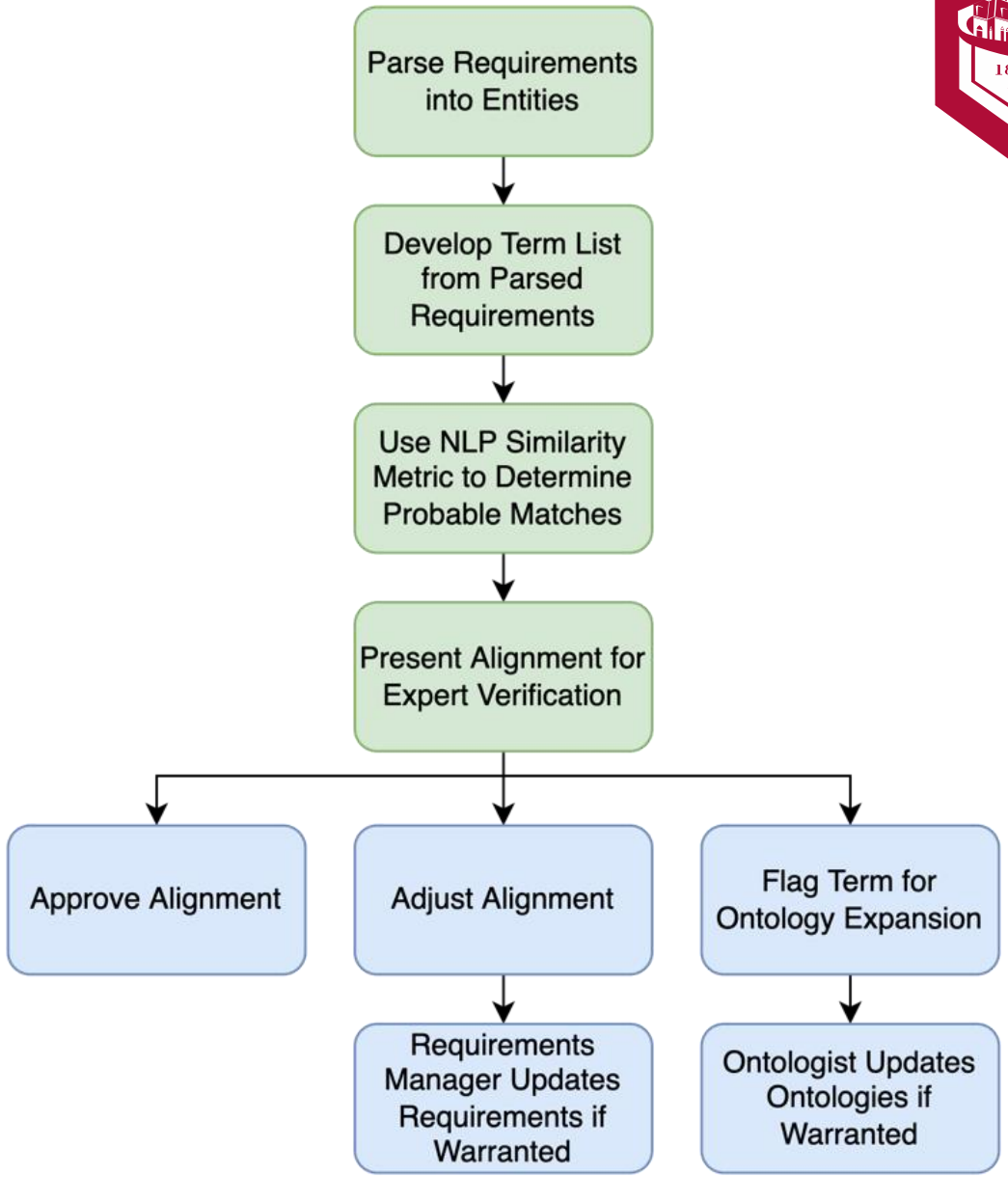


Rouse, W. B. (2020). AI as Systems Engineering Augmented Intelligence for Systems Engineers. *INSIGHT*, *23*(1), 52–54. https://doi.org/10.1002/inst.12286

Requirements Tagging Algorithm

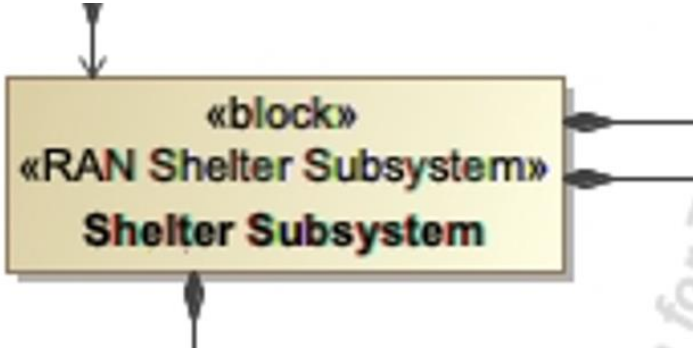
- Aligns NLP extraction of requirements with ontology classes associated with requirement terms
- Uses an additional NLP algorithm (viewed as a black box) to analyze the two sets of data for similarity metrics and provide a best guess for how they align
- Subjected to expert verification
- Expectation is not for complete overlap

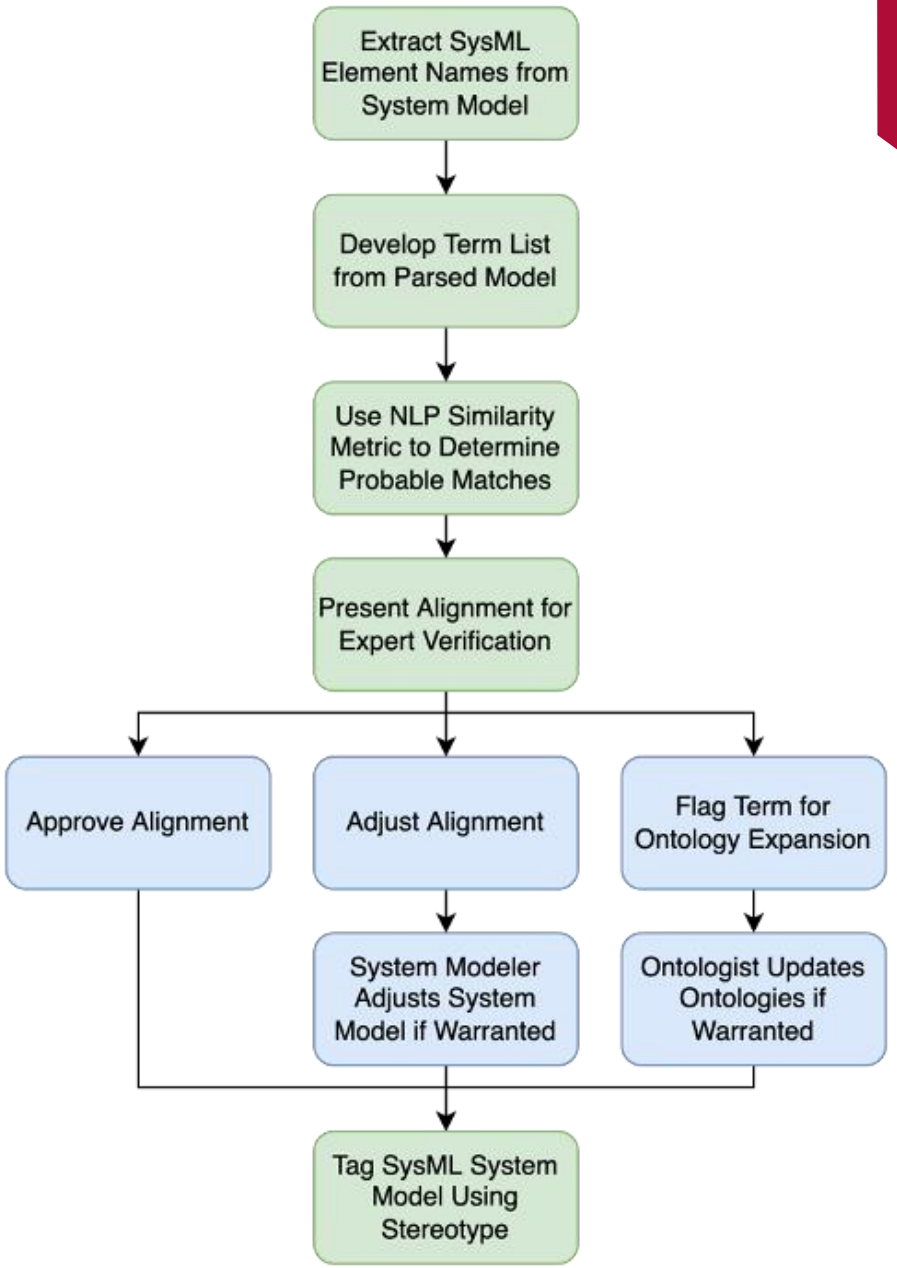




SysML Model Tagging Algorithm

- Aligns SysML element names with associated ontology classes
- Uses NLP algorithm (viewed as a black box) to analyze the two sets of data for similarity metrics and provide a best guess for how they align
- Subjected to expert verification
- Fed back into the SysML model as custom stereotypes





Telecommunications System Example

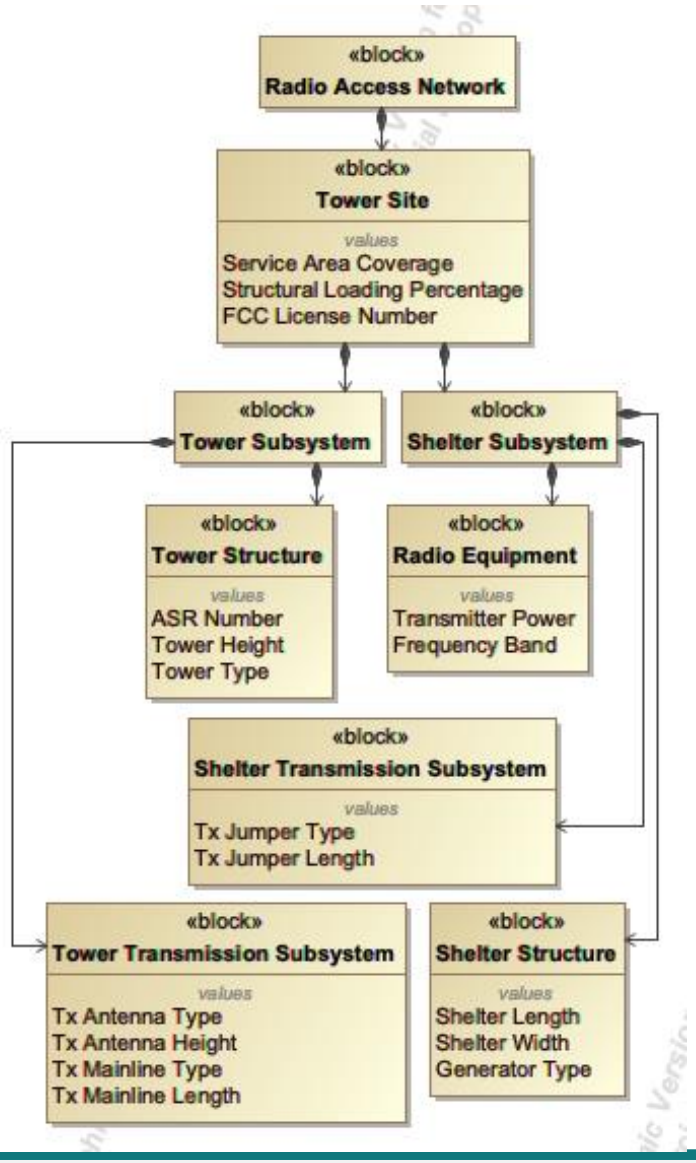
Req Num	Requirement Text
1	The Transmit Antenna shall provide a minimum of 9 dB of gain.
2	The RAN Tower shall provide a minimum of 92% Service Area Covered.
3	The frequency band used by the RAN equipment shall use the 700 MHz Public Safety band.

Req Num	Term List		
1	Transmit Antenna	Gain	
2	RAN Tower	Service Area Coverage	
3	Frequency Band	RAN equipment	Public Safety band

Req Num	Requirement Term List	Ontology Term	Notes to Req E
1	Transmit Antenna	RAN Tx Antenna Type	
1	Gain	Antenna Gain	
2	RAN Tower	RAN Tower Structure	
2	Service Area Coverage	RAN Service Area Coverage	
3	Frequency Band	RAN Frequency Band	
3	RAN Equipment	RAN Radio Equipment	
3	Public Safey Band		

- Radio Access Network
- RAN Tower Site
- RAN Tower Subsystem
- RAN Shelter Subsystem
- RAN Tower Structure
- RAN Radio Equipment
- RAN Shelter Transmission Subsystem
- RAN Tower Transmission Subsystem
- RAN Service Area Coverage
- RAN Tower Structural Percentage
- FCC Frequency License Number
- FCC ASR Number

Telecommunications System Example

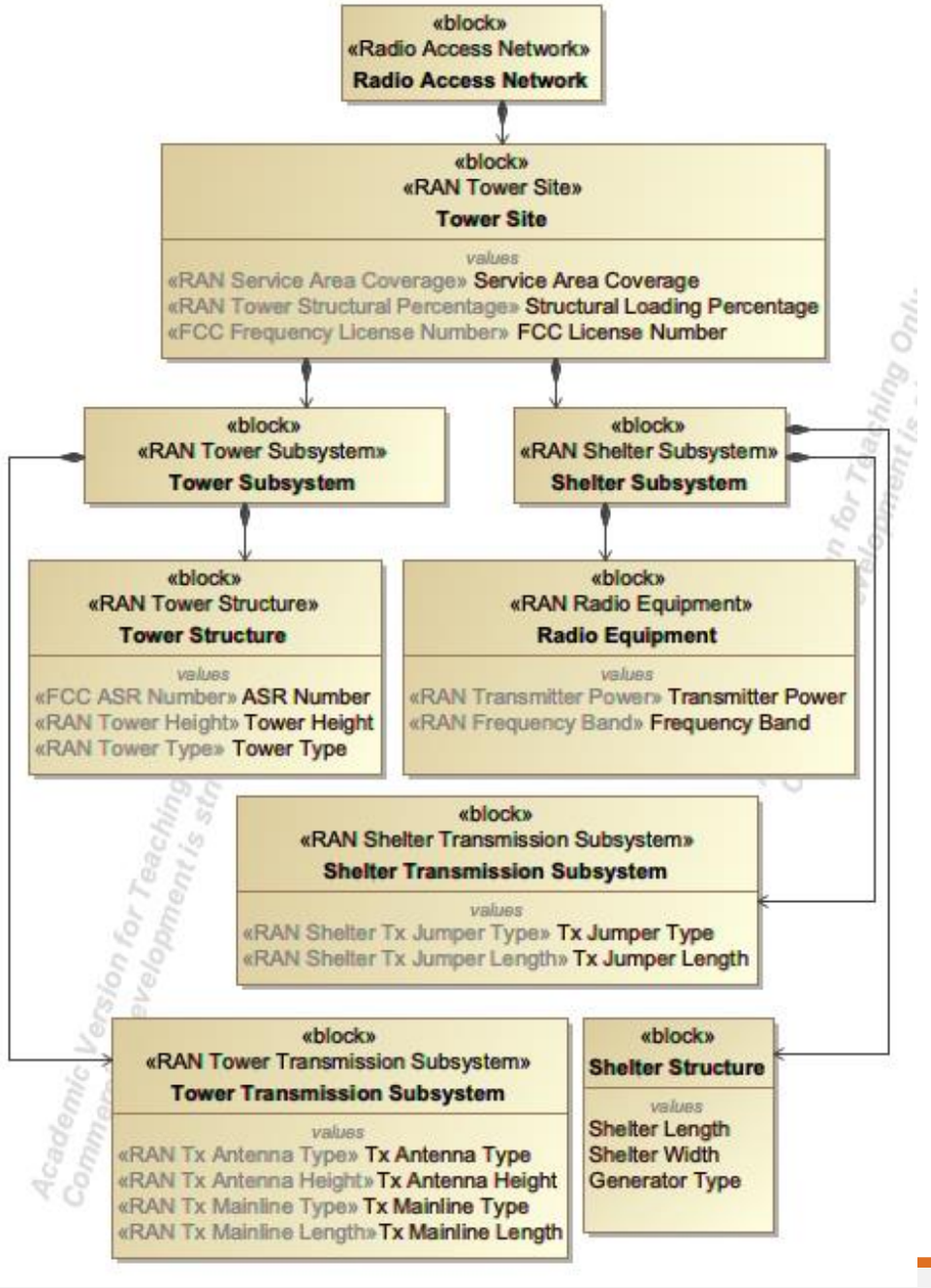


Element ID	SysML Model Term List	Ontology Term	Notes to Archit
bad7g	Radio Access Network	Radio Access Network	
kqwb8	Tower Site	RAN Tower Site	
jaa7v	Tower Subsystem	RAN Tower Subsystem	
xn1h2	Shelter Subsystem	RAN Shelter Transmission Subsystem	
ppaj2	Tower Structure	RAN Tower Structure	
vnah3	Tower Transmission Subsystem	RAN Tower Transmission Subsystem	
11bvh	Radio Equipment		
abueo	Shelter Transmission Subsystem		
ajhx3	Shelter Structure		
cbl7a	Service Area Coverage		
pqbv7	Structural Loading Percentage		
ah2hd	FCC License Number		
pqhv4	ASR Number		
ab3ya	Tower Height		
pwxn2	Tower Type		
8dh73	Tx Antenna Type		
bagg2	Tx Antenna Height		
pganb	Tx Mainline Type		
pa7vb	Tx Mainline Length		
jfsm7	Transmitter Power		
absyg	Frequency Band		

- Radio Access Network
- RAN Tower Site
- RAN Tower Subsystem
- RAN Shelter Subsystem
- RAN Tower Structure
- RAN Radio Equipment
- RAN Shelter Transmission Subsystem
- RAN Tower Transmission Subsystem
- RAN Service Area Coverage
- RAN Tower Structural Percentage
- FCC Frequency License Number
- FCC ASR Number

Telecommunications System Example

- Ontology-aligned is captured in the SysML model by custom stereotypes aligned with ontology classes
- These stereotypes do not have to match the names of entities they describe
- Not all entities must have ontology-aligned stereotypes
  - Those that do not will be skipped in the mapping process
  - Allows for extension of the model as needed instead of an “all or nothing” approach



Conclusion

- Use of ontologies can enhance knowledge representation of various system artifacts
- Manual alignment processes to enable usage of ontologies can be arduous to the point of impossible
- Use of NLP as an augmented intelligence agent can combine the time efficiencies of a statistical AI model with the accuracy needs of a rules-based system.

Future Work

- Develop similarity metric techniques to enable field use of the concepts presented

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