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When Language Meets the Physical World: Semantic Representation for Robots

Presenter: Sonia Raychaudhuri
March 30, 2026


TESLA
TESLA
TESLA


PERSONAL AI ROBOTS PET

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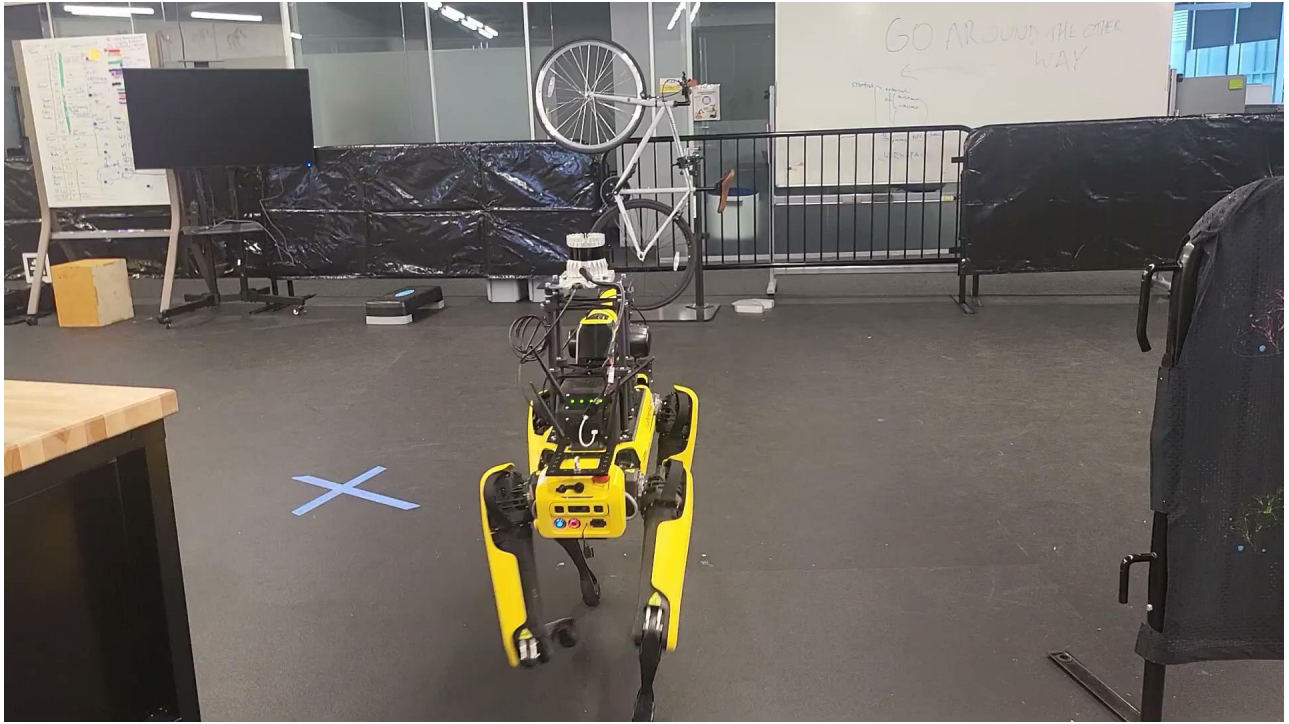
Move forward to the bicycle. Turn right, then move to the chair. Turn left, and stop near the potted plant.



Raychaudhuri et al. Zero-shot Object-Centric Instruction Following: Integrating Foundation Models with Traditional Navigation. 2025

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Language must be grounded in perception

Move forward to the bicycle. Turn right, then move to the chair. Turn left, and stop near the potted plant.

- What does *move forward* mean?
- What is a *bicycle*?
- How does it look?

— Robots need grounding

Raychaudhuri et al. Zero-shot Object-Centric Instruction Following: Integrating Foundation Models with Traditional Navigation. 2025

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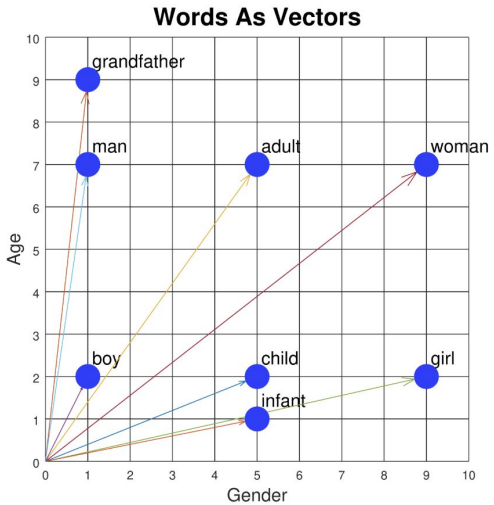
From NLP to Robotics

NLP:

Text → Embeddings → Meaning



https://www.cs.cmu.edu/~dst/WordEmbeddingDemo/tutorial.html

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From NLP to Robotics

NLP:

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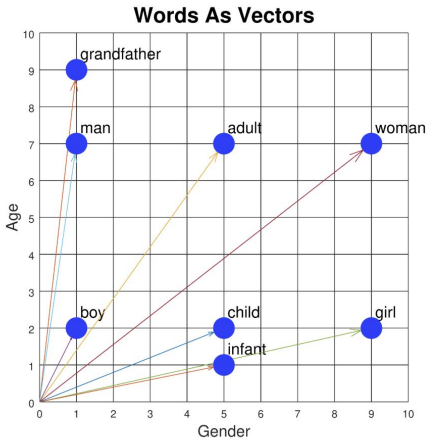
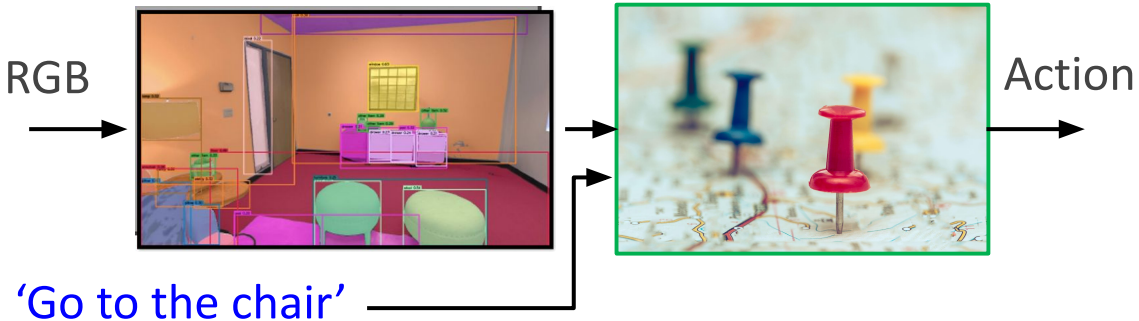


Robotics:

Images → Perception →
Language → Embedding →
Semantic Map → Action



https://www.cs.cmu.edu/~dst/WordEmbeddingDemo/tutorial.html

Gu et al. ConceptGraphs: Open-Vocabulary 3D Scene Graphs for Perception and Planning. 2023.

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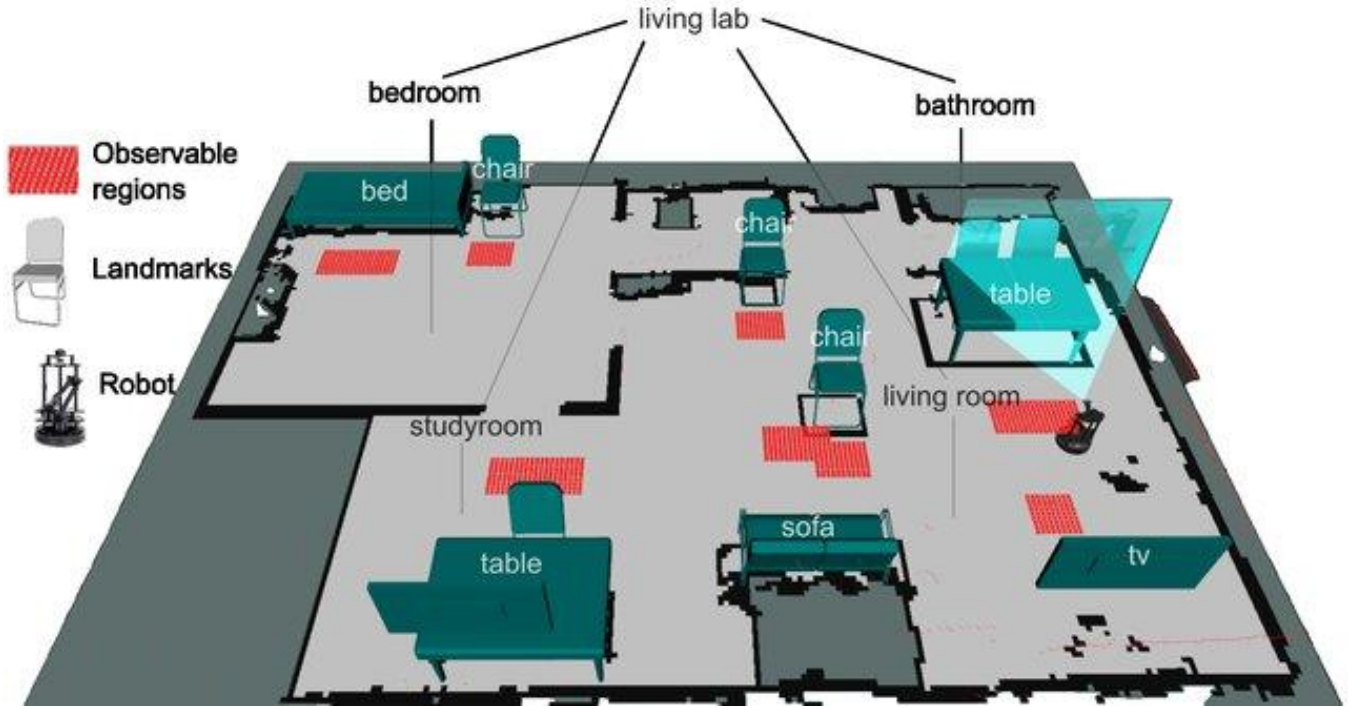
What is a Semantic Map?



Semantic-Based Multi-Object Search Optimization in Service Robots Using Probabilistic and Contextual Priors. 2024

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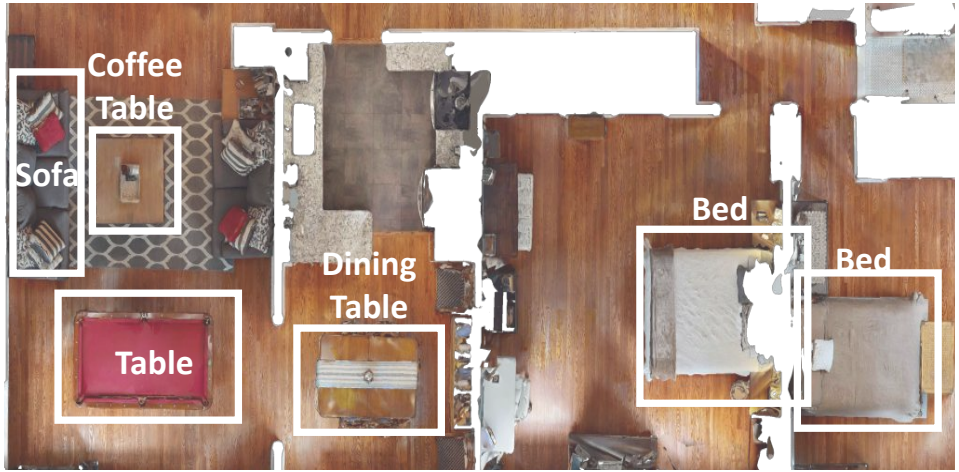
Map Structure



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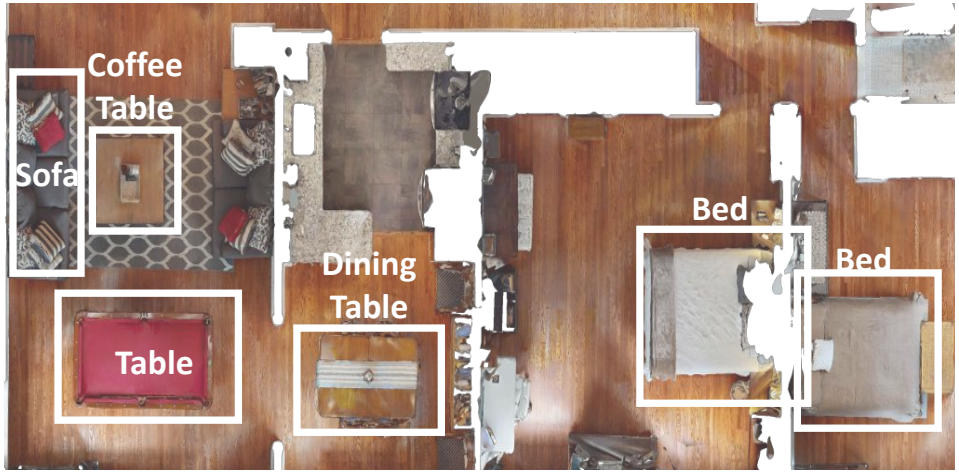
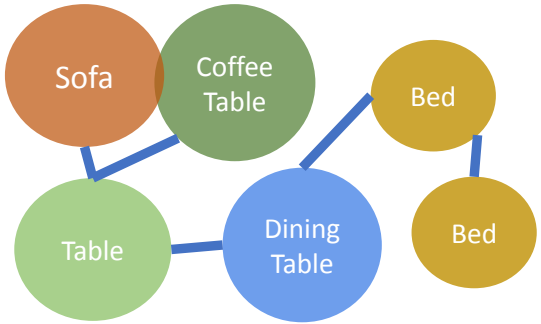


Topological Map



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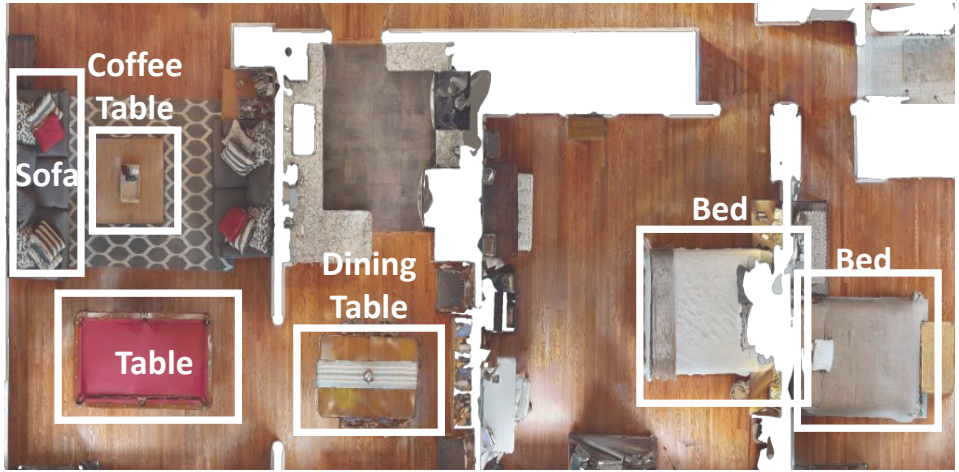

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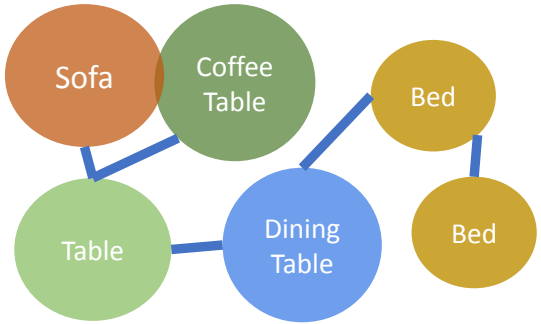
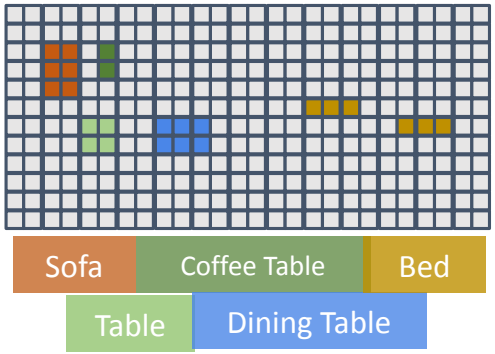


Grid Map



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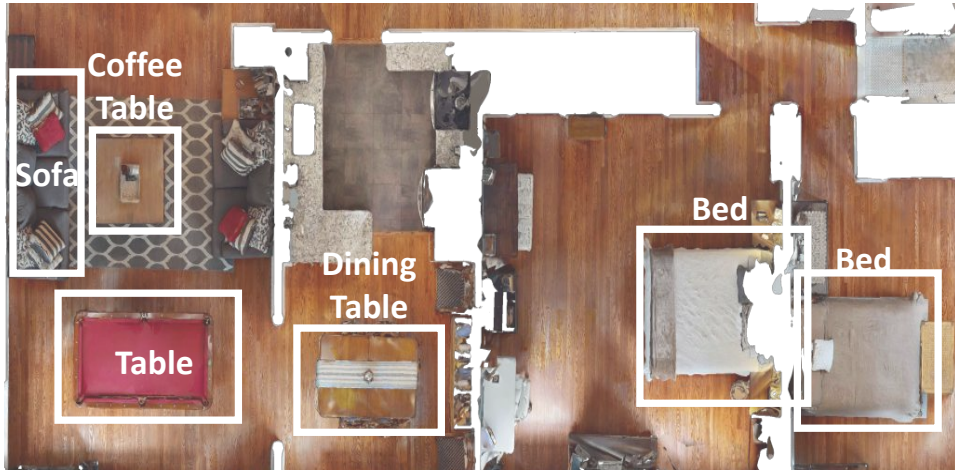

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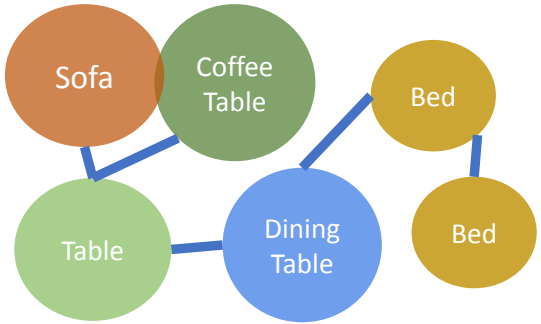

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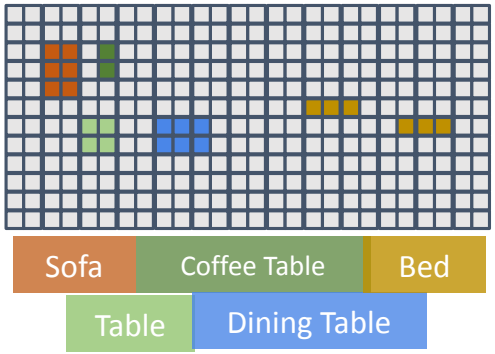
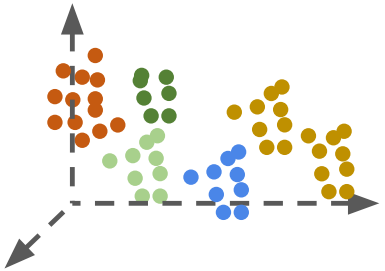


Geometric Map



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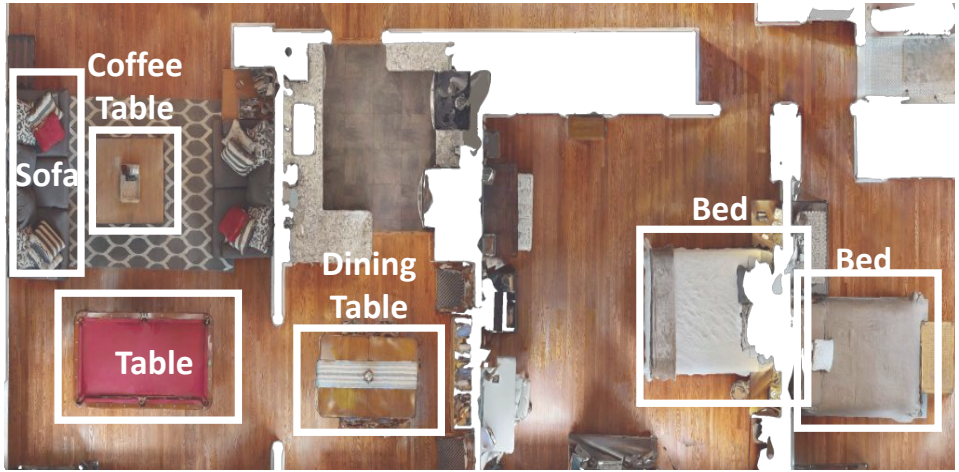

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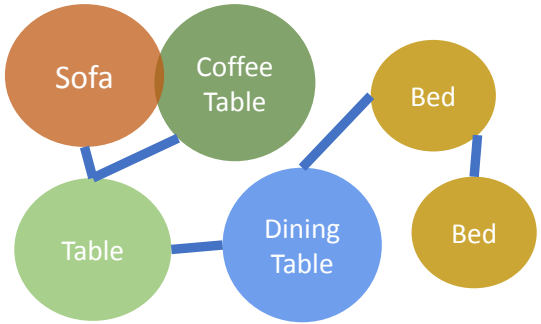

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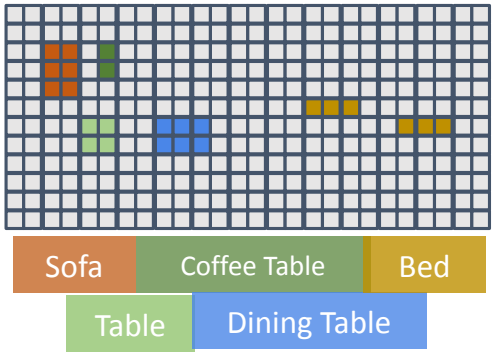

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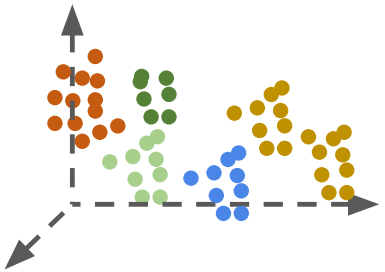
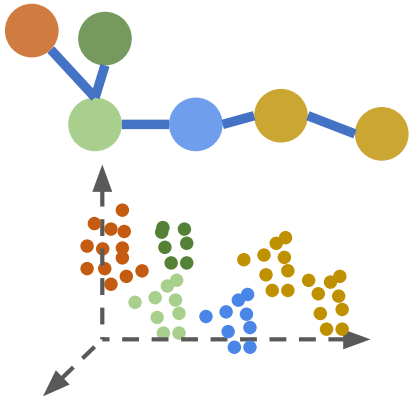


Hybrid



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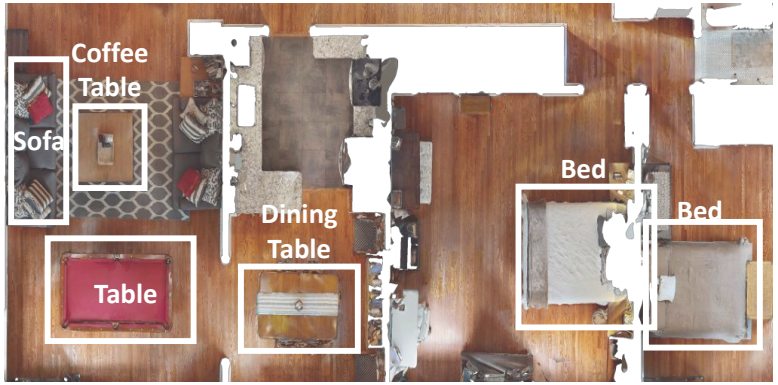
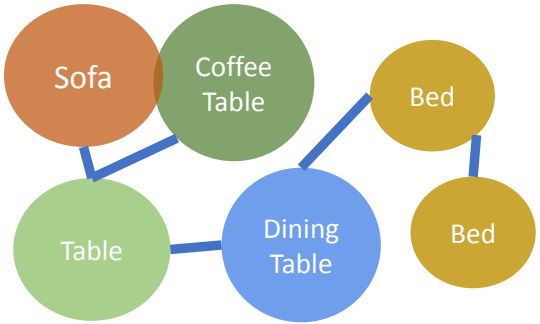


Sparse ⟷ Dense

Topological Map



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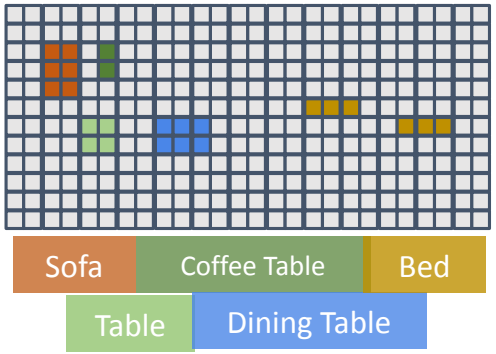

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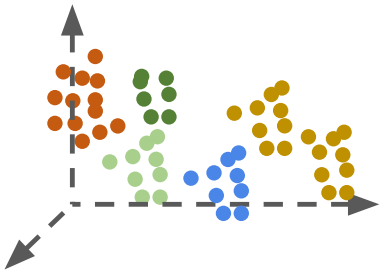

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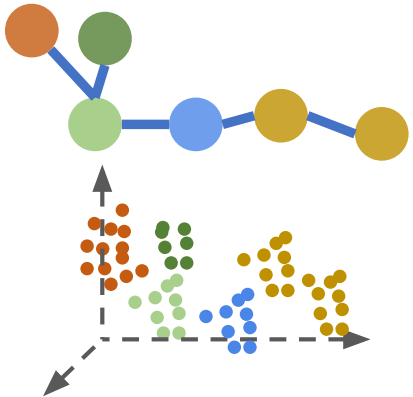

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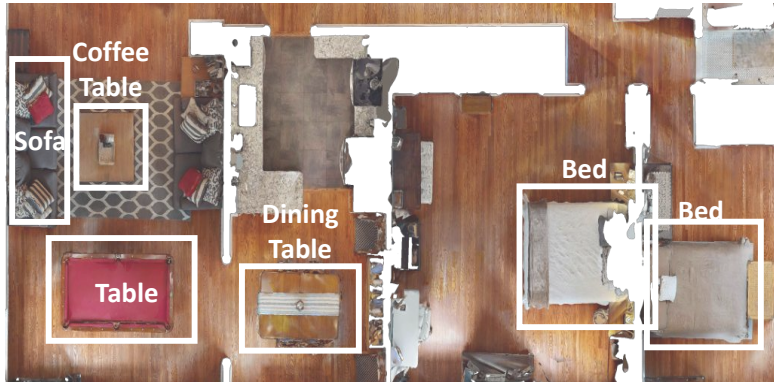
Map Encoding



Explicit Encoding

Occupancy	Binary	[0,1]
Image	RGB pixel values	
Objects	RGB pixel values	
	One-hot for n predefined object types	
	Text labels for object types	“bed”
	room types	
	Text labels for room types	“bedroom”
Audio Intensity	Single value in the range	[0-1]

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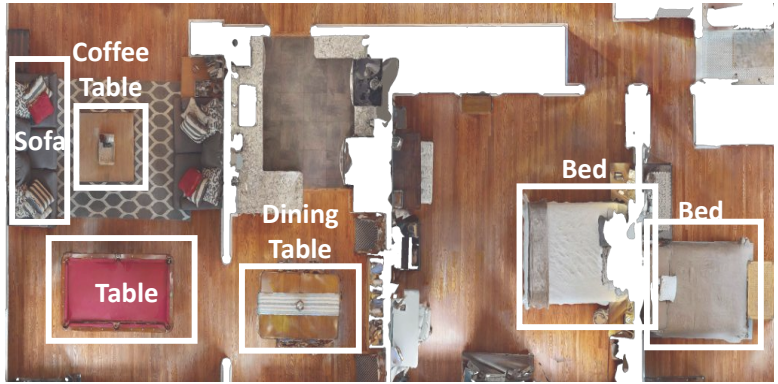
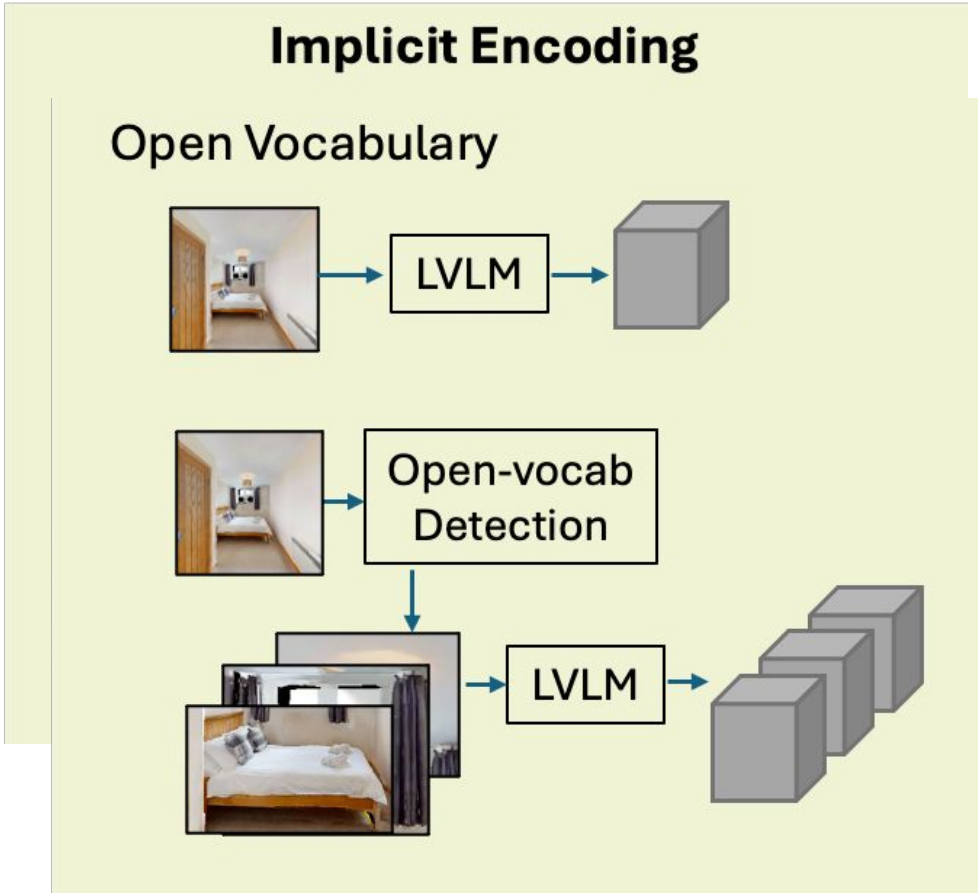
Map Encoding





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How It Enables Robot Tasks

goal becomes meaningful, not just geometric

Navigation
“go to kitchen”

Object search
“find mug”

Interaction
“pick up object”

Without semantics

- random exploration
- inefficient search

With semantics

- directed navigation
- intelligent search

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Key Challenges

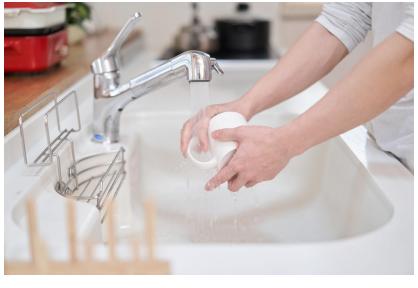
Why is this still an open research problem?

Language is Ambiguous

'go to the orange scooter'

Dynamic Environments

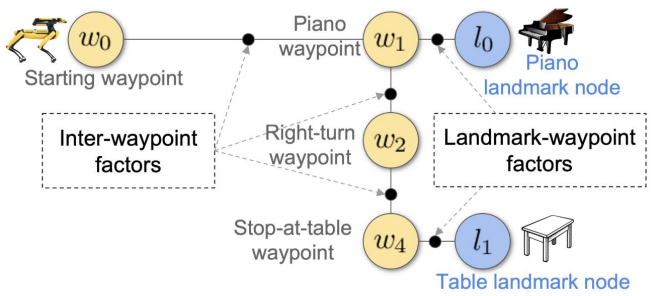
mug on the table → mug in sink



Generalization

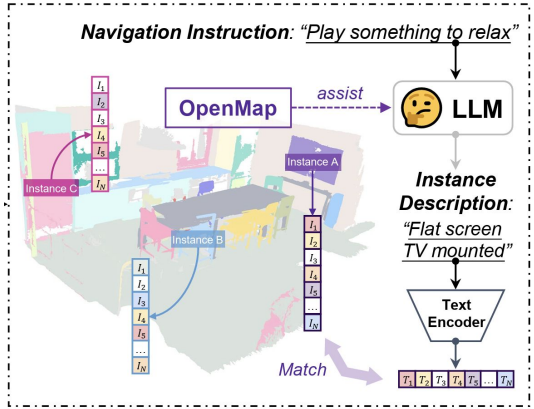
Future Directions

Language as Knowledge (LLMs for Robots)



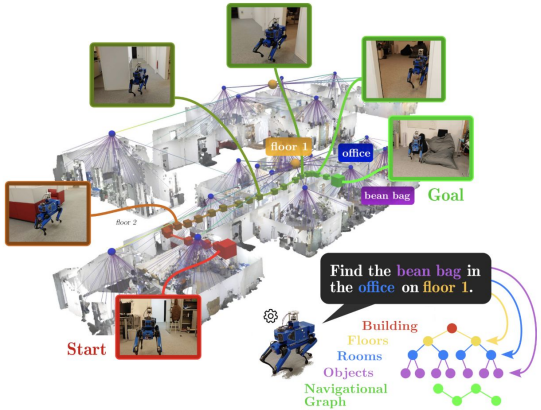
Raychaudhuri et al. “Zero-shot Object-Centric Instruction Following: Integrating Foundation Models with Traditional Navigation.” [2025]

Open-World Understanding



Li et al. "OpenMap: Instruction Grounding via Open-Vocabulary Visual-Language Mapping." [2025]

Hierarchical Representations



Werby et al. “Hierarchical Open-Vocabulary 3D Scene Graphs for Language-Grounded Robot Navigation.” [2024]

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Takeaways

The next step for NLP is not just understanding text — but understanding the world

and semantic representations are the bridge between language and physical world