Modeling and Using the Context of Navigation: Towards Context-Aware Navigation of Autonomous Vehicles

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IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2022)
13th Workshop on Planning, Perception, Navigation for Intelligent Vehicle (PPNIV 2022)

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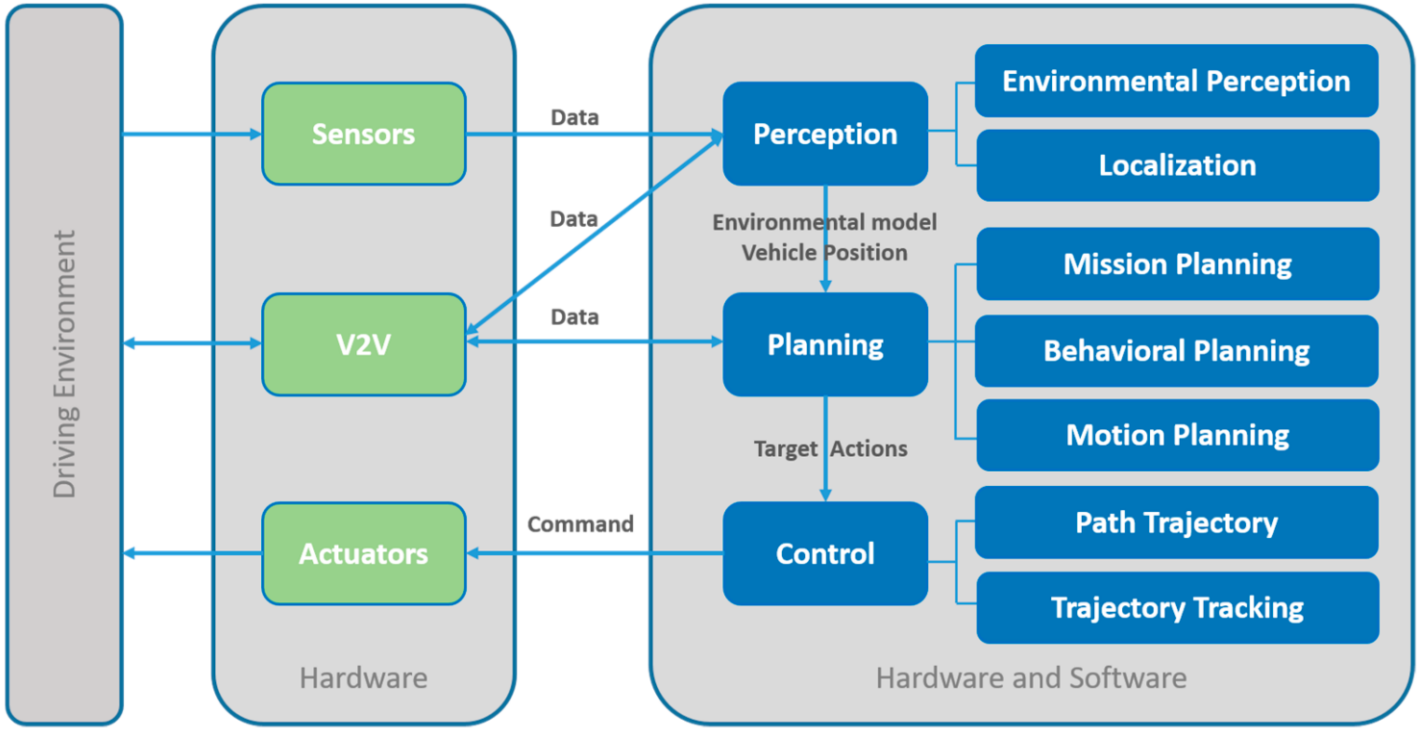
Introduction

- Typical autonomous vehicle system:



Rosique, F.; Navarro, P.J.; Fernández, C.; Padilla, A. A Systematic Review of Perception System and Simulators for Autonomous Vehicles Research. *Sensors* 2019, *19*, 648. https://doi.org/10.3390/s19030648

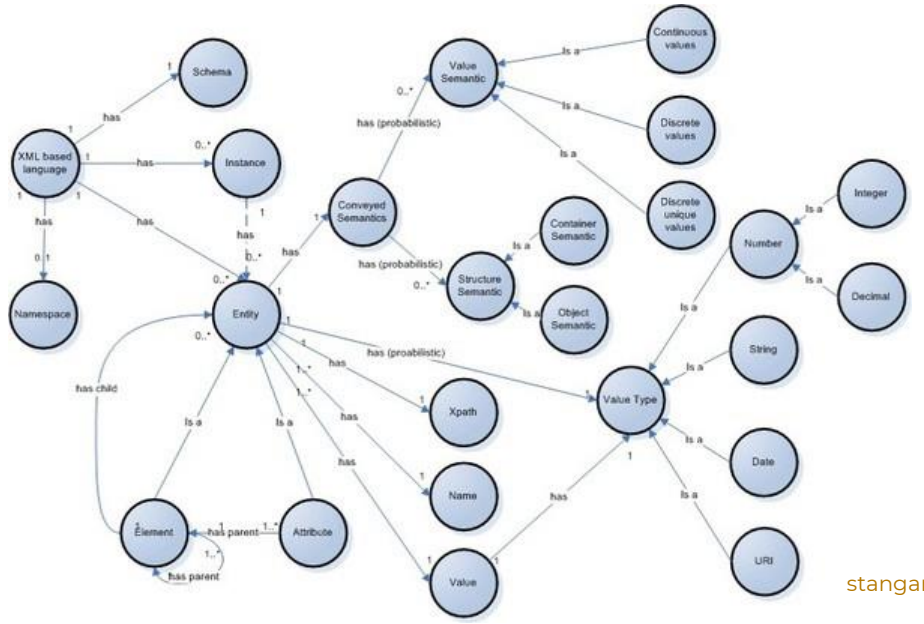
Introduction

- Typical autonomous vehicle system:
  - Perception
  - Planning
  - Control

- But lack of context awareness:
  - Example: the vehicle has a fragile passenger or load
    - The vehicle speed needs to be adapted
  - Two problems:
    - How to model this information?
    - How to consider it in?

Introduction

- Our idea:
  - Using ontologies

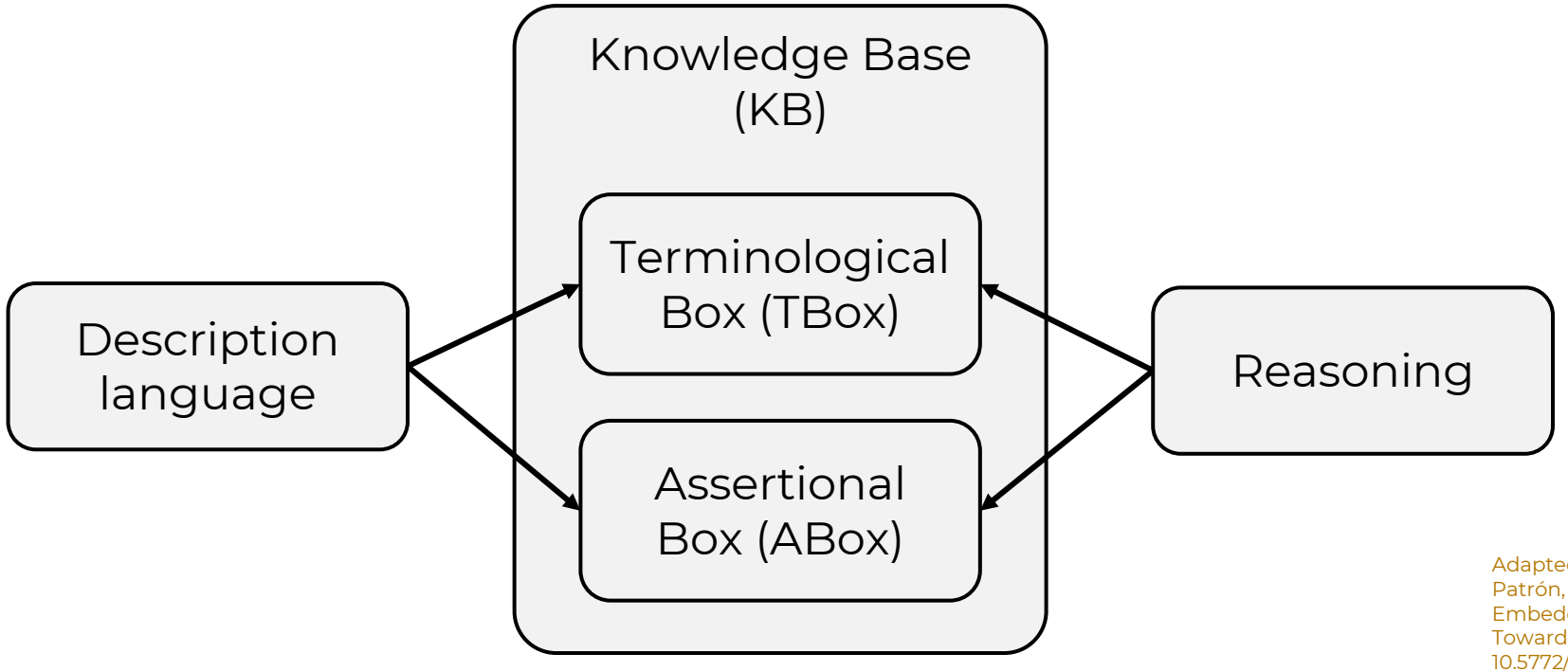


stangarfield.medium.com

- Method:
  - Modeling the context with ontologies
  - Considering the context model in the navigation modules

Context Modeling with Ontologies

- Ontology:
  - semantic data model of concepts and relations between them



Adapted from:
Patrón, Pedro & Miguelañez, Emilio & Petillot, Yvan. (2011). Embedded Knowledge and Autonomous Planning: The Path Towards Permanent Presence of Underwater Networks. 10.5772/24649.

Context Modeling with Ontologies

- Our model
  - Models the context of navigation
  - Extension of the previous model from *F. Farrufini et al*[1]:
    - More contextual elements
    - Models Local and Global context

control mission planning

Local Context

Vehicle
Passengers
Road

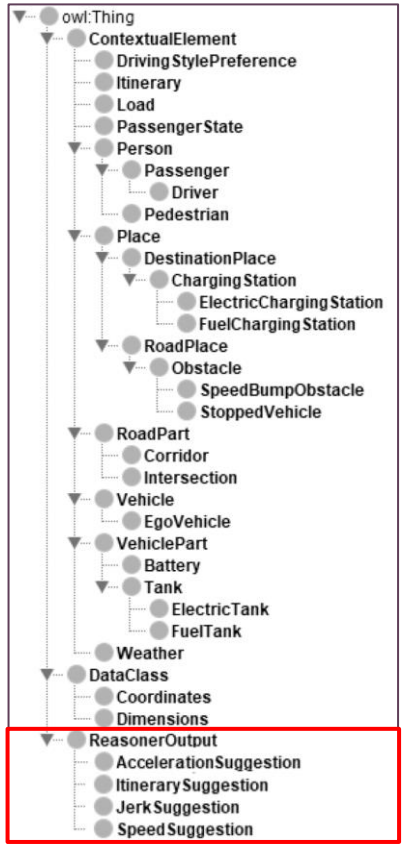
Global Context

Localization
Itinerary

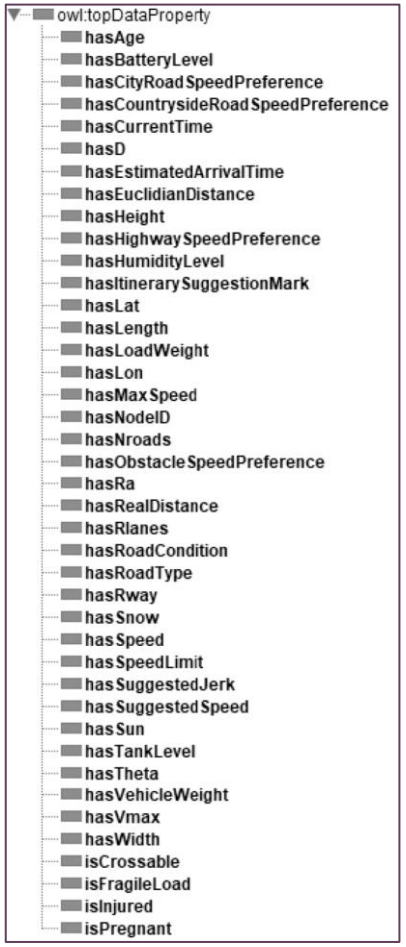
1. F. Faruffini, H. Pousseur, A. Corrêa Victorino, and M.-H. Abel, "Context Modelling applied to the Intelligent Vehicle Navigation," in 47th Annual Conference of the IEEE Industrial Electronics Society (IECON 2021). Toronto, Canada: IEEE, Oct. 2021, pp. 1–6

Context Modeling with Ontologies

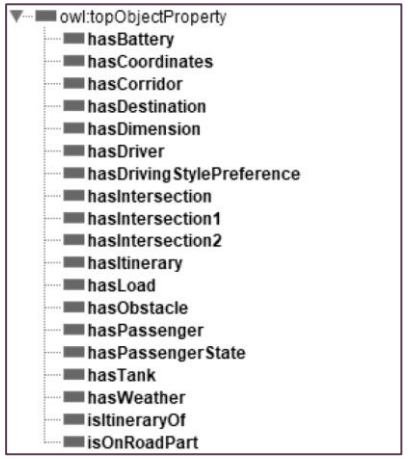
- Our context of navigation:



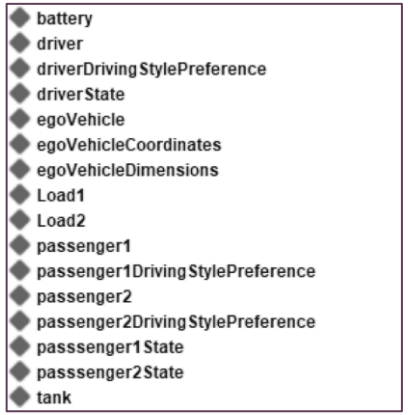
Classes



Data properties



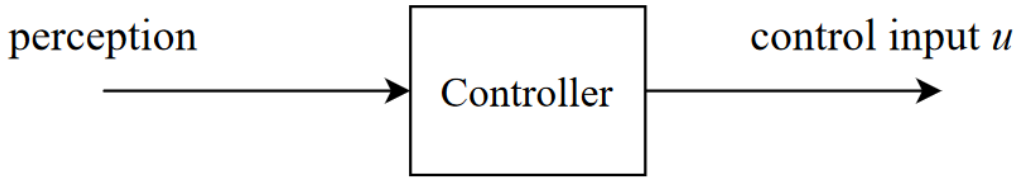
Object properties



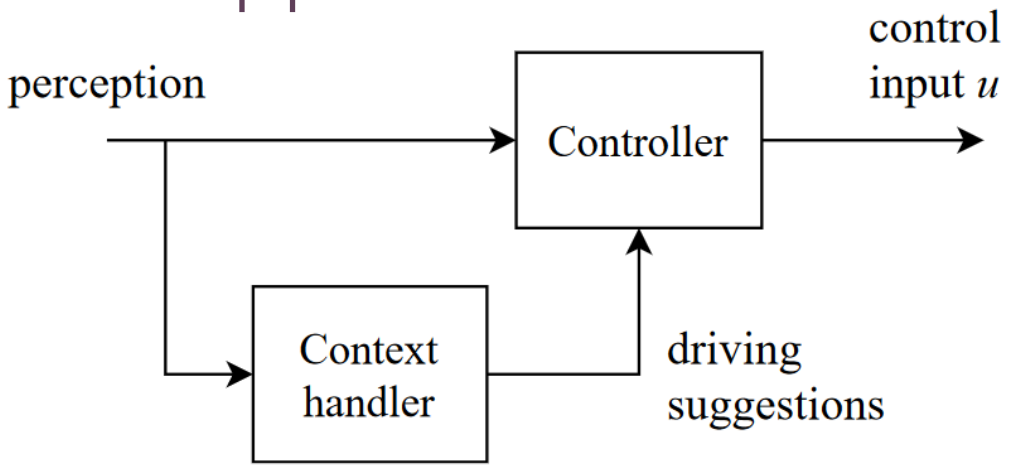
Individuals

Using the Context

- Standard approach:



- Context-aware approach:



Methodology

1. Use the reasoner to provide suggestions
2. Use the suggestion in optimization function

Using the Context

1. Providing suggestions:
   - Reasoner (Pellet) uses *SWRL rules* to infer new information
   - We define rules that impacts the suggestions of control inputs:
     - speed
     - jerk
     - acceleration
     - itenerary

Example rule:

$$
\begin{aligned}
&\text{EgoVehicle}(?v) \wedge \\
&\text{SpeedSuggestion}(?sg) \wedge \\
&\text{hasPassenger}(?v, ?p) \wedge \\
&\text{hasDrivingStylePreference}(?p, ?dsp) \wedge \\
&\text{hasRoadType}(?rp, \text{"CityRoad"}) \wedge \\
&\text{hasCityRoadSpeedPreference}(?sp) \wedge \\
&\text{isOnRoadPart}(?v, ?rp) \\
&\rightarrow \text{hasSuggestedSpeed}(?sg, ?sp)
\end{aligned}
$$

Using the Context

2. Considering the suggestions in the navigation task:
   - Optimization problem for control or planning:

$$\mathbf{u}_{\text{opt}} = \arg\max_{\mathbf{u}}[f(\mathbf{u})]$$

   - Adding function to represent the *contextual suggestions*:

$$\mathbf{u}_{\text{opt}} = \arg\max_{\mathbf{u}}[\alpha \cdot f(\mathbf{u}) + (1-\alpha) \cdot c(\mathbf{u})]$$

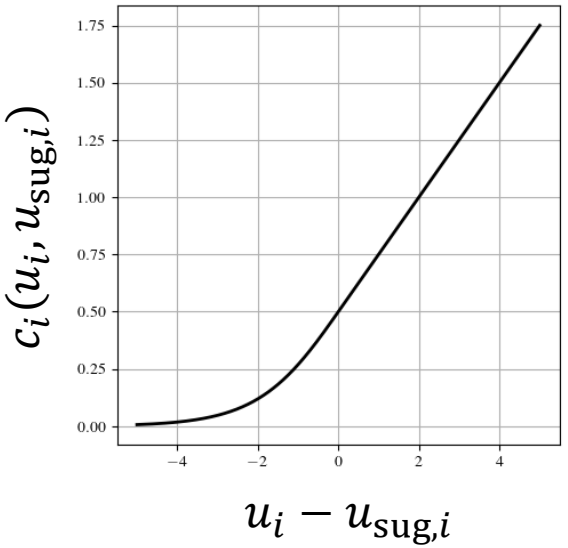
Using the Context

- Separate context functions to consider each control input:

$$\mathbf{u} = \begin{bmatrix} u_1 \\ u_2 \\ \vdots \\ u_n \end{bmatrix} \qquad \mathbf{u}_{\text{sug}} = \begin{bmatrix} u_{\text{sug},1} \\ u_{\text{sug},2} \\ \vdots \\ u_{\text{sug},n} \end{bmatrix} \qquad c(\mathbf{u}) = \sum_{i=0}^{n} w_i \cdot c_i\left(u_i, u_{\text{sug},i}\right)$$

- Partial context functions:

$$c_i(u_i, u_{\text{sug},i}) = \begin{cases} \dfrac{1}{1 + e^{-(u_i - u_{\text{sug},i})}} & \text{if } u_i \leq u_{\text{sug},i} \\ \dfrac{1}{2} + \dfrac{1}{4}\left(u_i, u_{\text{sug},i}\right) & \text{otherwise} \end{cases}$$



Tests and Results

- Image and Context-based Dynamic Window Approach (ICDWA) [1]:
  - visual servoing controller with context awareness
  - example of our methodology

- Front-wheel car model (Ackerman's approximation):

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \\ \dot{\phi} \end{bmatrix} = \begin{bmatrix} \cos\theta \sin\phi \\ \sin\theta \cos\phi \\ (1/l)\sin\theta \\ 0 \end{bmatrix} v + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} \omega$$

1. F. Faruffini, H. Pousseur, A. Corrêa Victorino, and M.-H. Abel, "Context Modelling applied to the Intelligent Vehicle Navigation," in 47th Annual Conference of the IEEE Industrial Electronics Society (IECON 2021). Toronto, Canada: IEEE, Oct. 2021, pp. 1–6

Tests and Results

- Control input:
  - linear and angular velocities

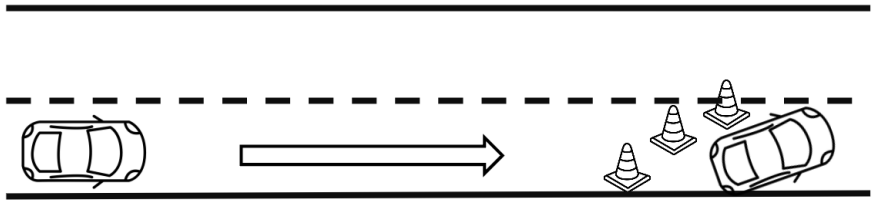
$$\mathbf{u} = \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} = \begin{bmatrix} v \\ \omega \end{bmatrix}$$

- Optimization function:
  - adapted DWA computed with image features
  - with additional function $c(\mathbf{u})$ for context awareness

$$f(\mathbf{u}) = \alpha \cdot \text{heading}(\mathbf{u}) + \beta \cdot \text{dist}(\mathbf{u}) + \gamma \cdot \text{velocity}(\mathbf{u}) + \delta \cdot c(\mathbf{u})$$

Tests and Results

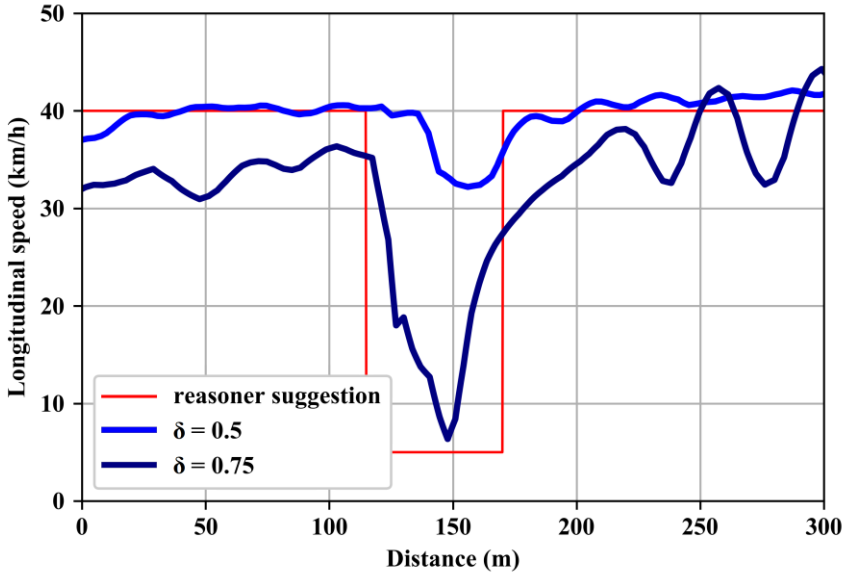
- Test scenario:
  - Vehicle driving on a city with obstacle in front of it



  - The passenger has the following speed preferences:
    - 110 km/h on highways
    - 70 km/h on countryside roads
    - 40 km/h on cities
    - 5 km/h when crossing an obstacle

Tests and Results

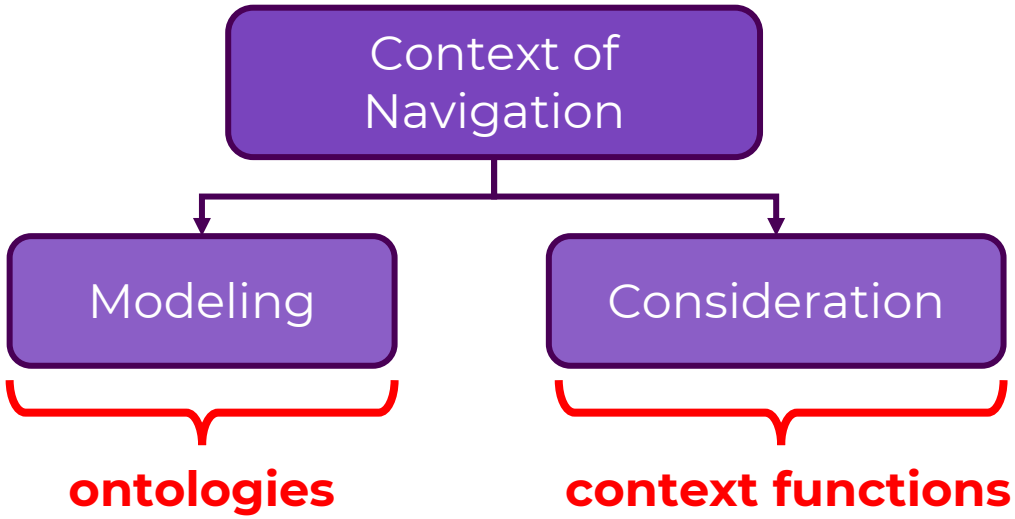
- Results on SCANeR Studio:



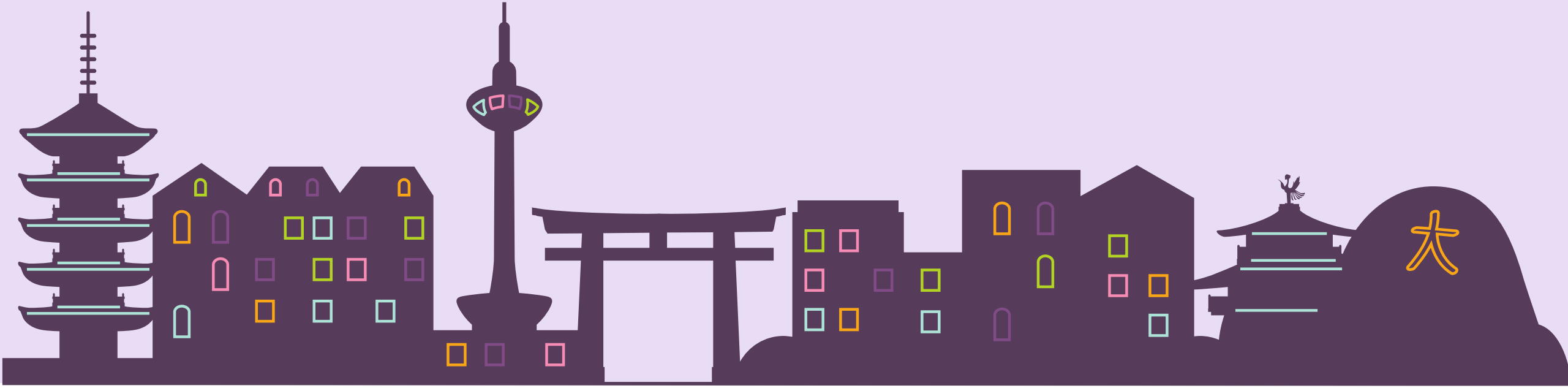
- Need to tune properly coefficient $\delta = 1 - \alpha$ for appropriate context consideration

Conclusion

- Context-aware navigation:



- Further considerations:
  - reasoning and real-time
  - parameter tuning
  - other implementations (planning)



Thank you for your attention!

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