Towards a Cognitive Model of the Semantics of Spatial Prepositions

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Background

- Ideal Meaning:
  - Use is often motivated by notions of an *ideal* geometric meaning [1]
- Vagueness:
  - Spatial prepositions exhibit *vagueness* and in practice are used to denote a vast array of configurations which greatly diverge from these idealized meanings
- Non-Geometric Features:
  - Non-geometric features also affect preposition use e.g. functionality and convention [1,2]
- Directions:
  - Existing models do not both explicitly account for non-geometric features and deal with issues of vagueness
  - While addressing these problems we aim for *cognitive adequacy* [3] of the semantic model

Cognitive Adequacy

- Cognition & Discourse:
  - To understand the meaning of terms in situated discourse we must understand the meaning the speaker intends
  - An ideal semantic representation should therefore capture potential speakers' conceptualizations of terms i.e should be cognitively adequate [3]
- Individual Preference:
  - Acceptability of a given preposition varies greatly from person to person [6]
  - The model should be sensitive to the speaker's preference as well as usual aspects of context
  - In reality this means the model should update itself in a natural way to better model the speaker's representation
- We work towards this in three ways:
  - Include appropriate salient features which are identified as relevant in the literature on cognitive science
  - Employ the cognitively motivated semantic framework of Conceptual Spaces [7]
  - Create the representation in an empirical manner to capture and understand genuine uses

Creation

- Data collection
  - To better understand how spatial prepositions are used in practice we take an empirical approach
  - We are creating a spatial preposition annotation tool that allows subjects to navigate a 3D environment and label the spatial relations between pairs of objects (to appear shortly at https://github.com/alrichardbollans)
- Geometric representation
  - Include geometric, functional and conventional 'domains'
  - Metric in the space should represent conceptual similarity
    - Euclidean metric is appropriate for many dimensions of the space
    - Non-standard metrics may be required for dimensions that represent qualitative descriptions. See Fig 1 for the example of 'containment'

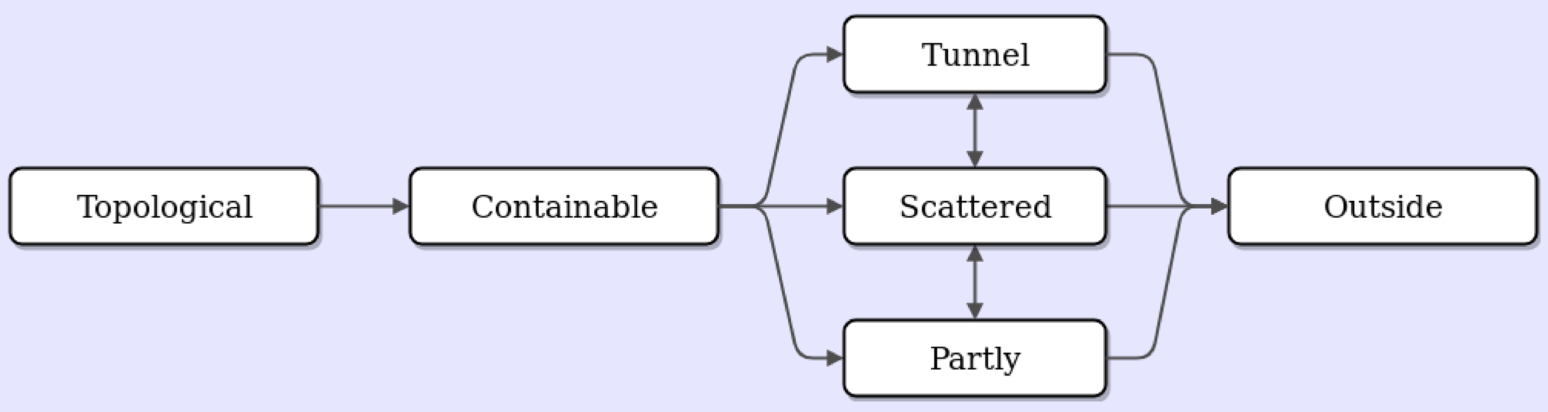

Figure 1. Example qualitative distinctions of 'containment'. From left to right moves from stronger to weaker degrees of containment. Distance represents similarity. Motivated by distinctions presented in [9].

Future Work

- After annotation tool is complete and data collected
  - Cluster instances to form concepts while identifying polysemes
  - Identify prototypical instances or regions in the space
  - Adjust metrics on dimensions and weightings to provide a meaningful similarity measure on the space
- Investigate pragmatic aspects
  - How can concepts be updated during discourse?
  - How can prototypes and similarity measures aid pragmatic inferences?

Motivation

- Improve human-robot interaction
- Spatial prepositions are ubiquitous:
  - Humans often prefer brief descriptions over lengthy ones, even if this introduces ambiguity. Locative expressions often fulfil this desire for brevity [4]
- We consider two related tasks:
  1. Select appropriate objects from a visual scene when given a locative description
  2. Generate appropriate locative referring expressions for objects in a visual scene

Vagueness

- Meaning is not static
  - In general, meaning is highly dependent on *context* and *use*
  - Language is a *tool* [5]. In situated discourse terms are used to the extent that they imply the intention of the speaker
- Semantic model must allow for pragmatic judgments:
  - Blue cube/table configuration in Fig 2(a) is close enough to the prototypical case that one may be happy to say 'the blue cube is on the table'. Would certainly identify the blue cube when hearing 'the cube on the table'
  - Adding a second cube to this scene, as in Fig 2(c), 'the cube on the table' presumably no longer refers to the blue cube but instead the green cube as it is clearly a better fit for 'on the table'
  - In Fig 2(d) is it acceptable to describe the cube on the chair as being 'on the table'?
    - Chair itself being useful ground object in this scene and large distance between the blue cube and table make it strange to choose this description
    - However, 'the cube on the table' is still relatively unambiguous
    - Key factor: one of the cubes is closer to an idealized notion of 'on' than the other

Salient Features

- A specific example, 'on':
  - 'on' is generally associated with the functional notion of 'support' [8] with a geometric prototype being that of the green cube on the table in Fig 2(c)
  - In Fig 2(a) most would agree that it is acceptable to use 'on the table' to refer to the blue cube, and would certainly identify the blue cube when hearing 'the cube on the table'
  - However, the relative positions of the table and cube are not sufficient to define 'on', as seen in Fig 2(b)
- Evaluating 'support'
  - Automatically assessing support relations in reality is a large research challenge
  - We may model this in virtual environments by running simulations and assessing if a movement of the ground (table) causes the figure (cube) to move
  - For some features (e.g. containment) it may be more appropriate to provide qualitative evaluations. See Fig 1
- Convention
  - Particularly for language generation, convention must also be accounted for

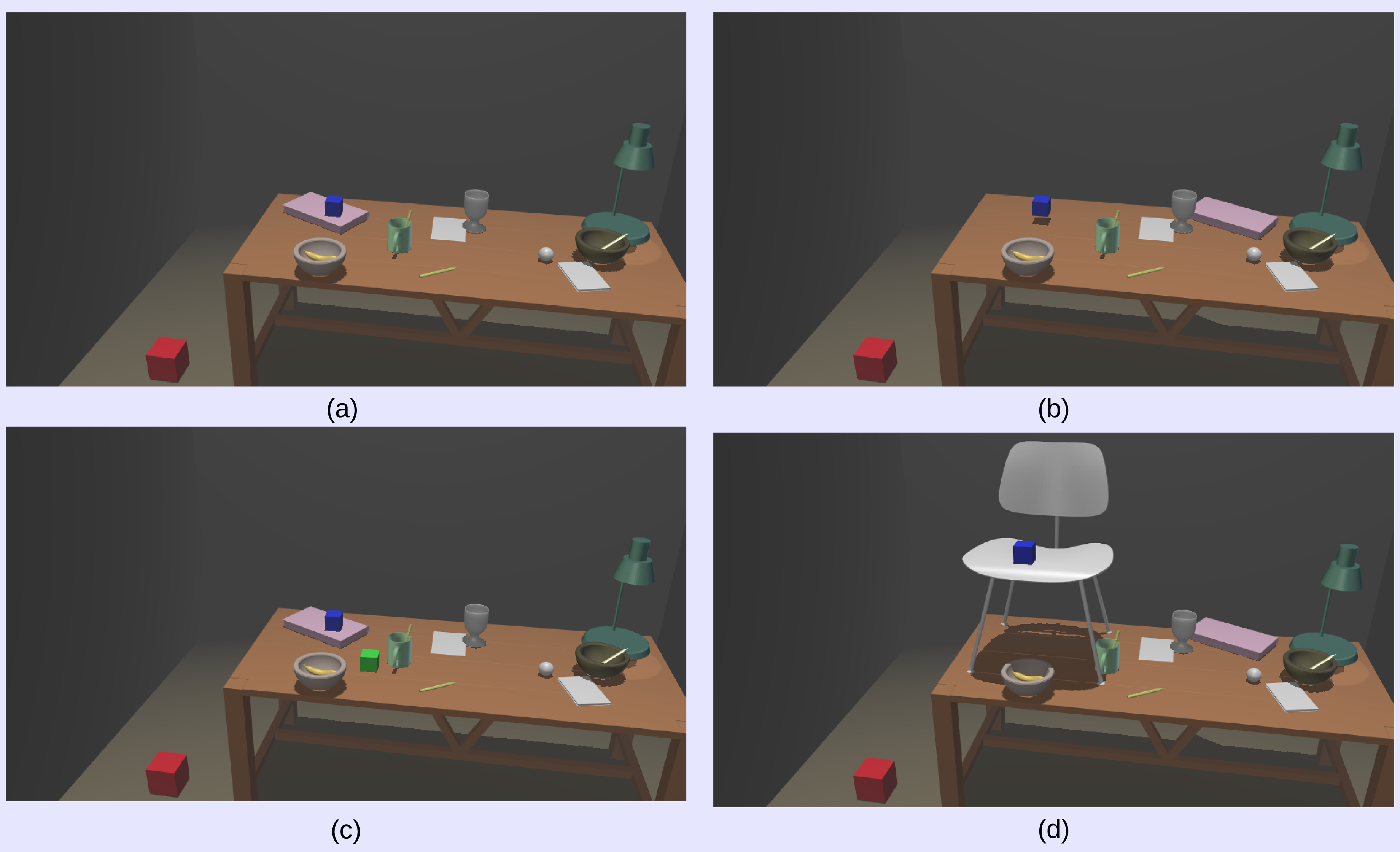

Figure 2. Example 3D scenes to highlight differing uses of 'on'. (a) Blue cube on the table (b) Blue cube above the table (c) Cube on the table (d) Blue cube on the table?

References

[1] Herskovits, A. (1987). *Language and spatial cognition*. Cambridge University Press. **[2]** Garrod, S., Ferrier, G., & Campbell, S. (1999). In and on: investigating the functional geometry of spatial prepositions. *Cognition*, 72(2), 167-189. **[3]** Strube, G. (1992). The role of cognitive science in knowledge engineering. In *Contemporary Knowledge Engineering and Cognition* (pp. 159-174). Springer, Berlin, Heidelberg **[4]** Rohde, H., Seyfarth, S., Clark, B., Jäger, G., and Kaufmann, S. (2012). Communicating with cost-based implicature: A game-theoretic approach to ambiguity. In *Proceedings of the 16th Workshop on the Semantics and Pragmatics of Dialogue* **[5]** Austin, J. L (1975). *How to do things with words*. Oxford University Press. **[6]** Platonov, G., & Schubert, L. (2018). Computational Models for Spatial Prepositions. In *Proceedings of the First International Workshop on Spatial Language Understanding* **[7]** Gärdenfors, P. (2004). *Conceptual spaces: The geometry of thought.* MIT press. **[8]** Bateman, J. A., Hois, J., Ross, R., & Tenbrink, T. (2010). A linguistic ontology of space for natural language processing. *Artificial Intelligence*, 174(14), 1027-1071. **[9]** Cohn, A. G., Bennett, B., Gooday, J., & Gotts, N. M. (1997). Qualitative spatial representation and reasoning with the region connection calculus. *GeoInformatica*, 1(3), 275-316.