

Towards Concept Formation in Conceptual Spaces

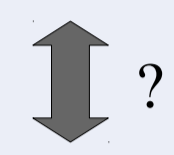
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1. Motivation

Gap Between Symbolic and Subsymbolic Processing

Symbolic Layer $\forall x: \text{apple}(x) \Rightarrow \text{red}(x)$

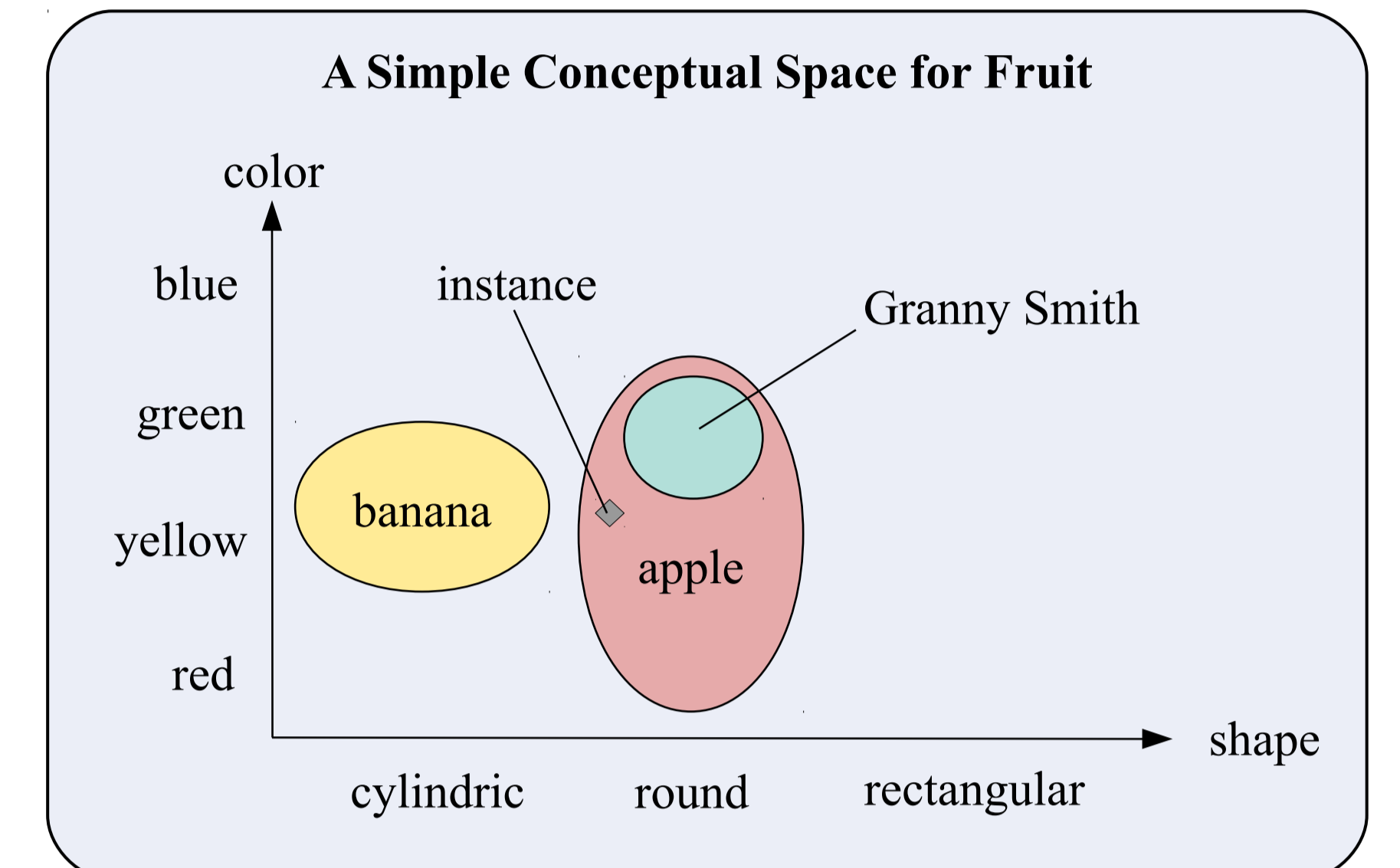


Subsymbolic Layer [0.42; 1.337; -1.234; 0.99; -3.14]

- Symbol grounding problem [1]:
 - How can abstract symbols contain any meaning?
- Concept formation [2] might be an answer:
 - Discover meaningful concepts based on perception (bottom-up process)

2. Conceptual Spaces

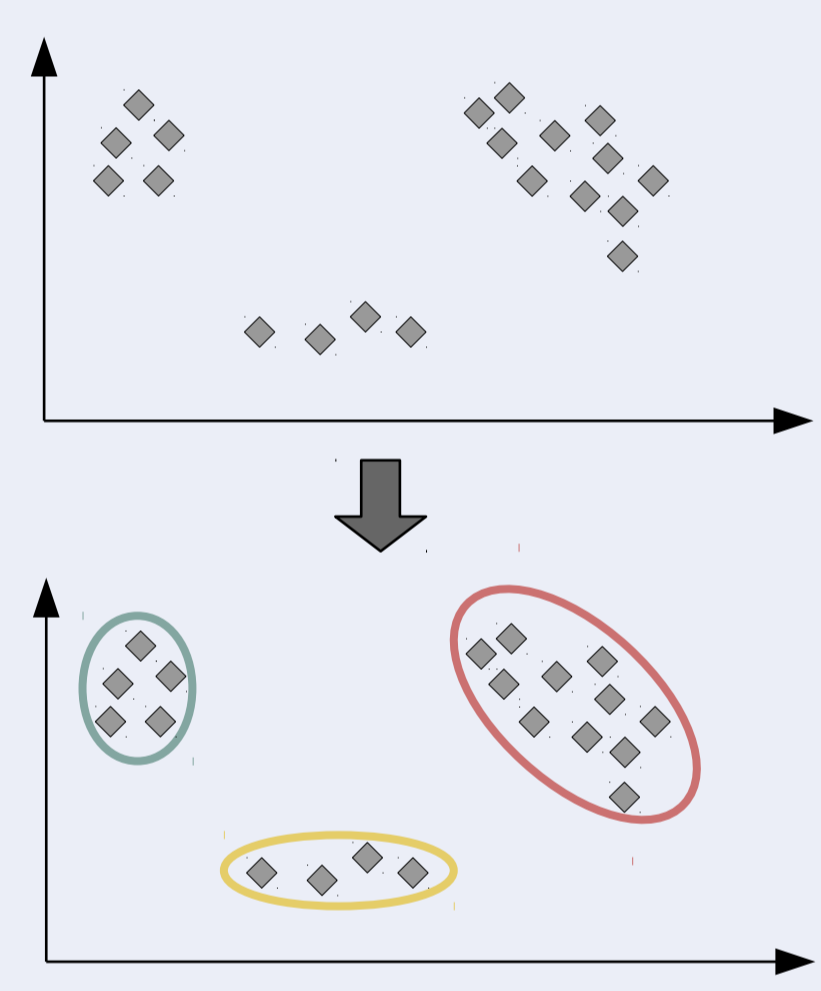
- Geometric representation of knowledge [3]:
 - Dimensions: salient features
 - Points: observed instances/objects
 - Regions: concepts/categories
- Distance:
 - Defined based on the dimension-wise distance
 - Combination of Euclidean and Manhattan metric
 - Similarity is inversely related to distance
- Connecting symbolic and subsymbolic layer:
 - Subsymbolic layer provides dimensions and points
 - Conceptual layer defines concepts as regions
 - Symbolic layer refers to concepts



3. My Research Project

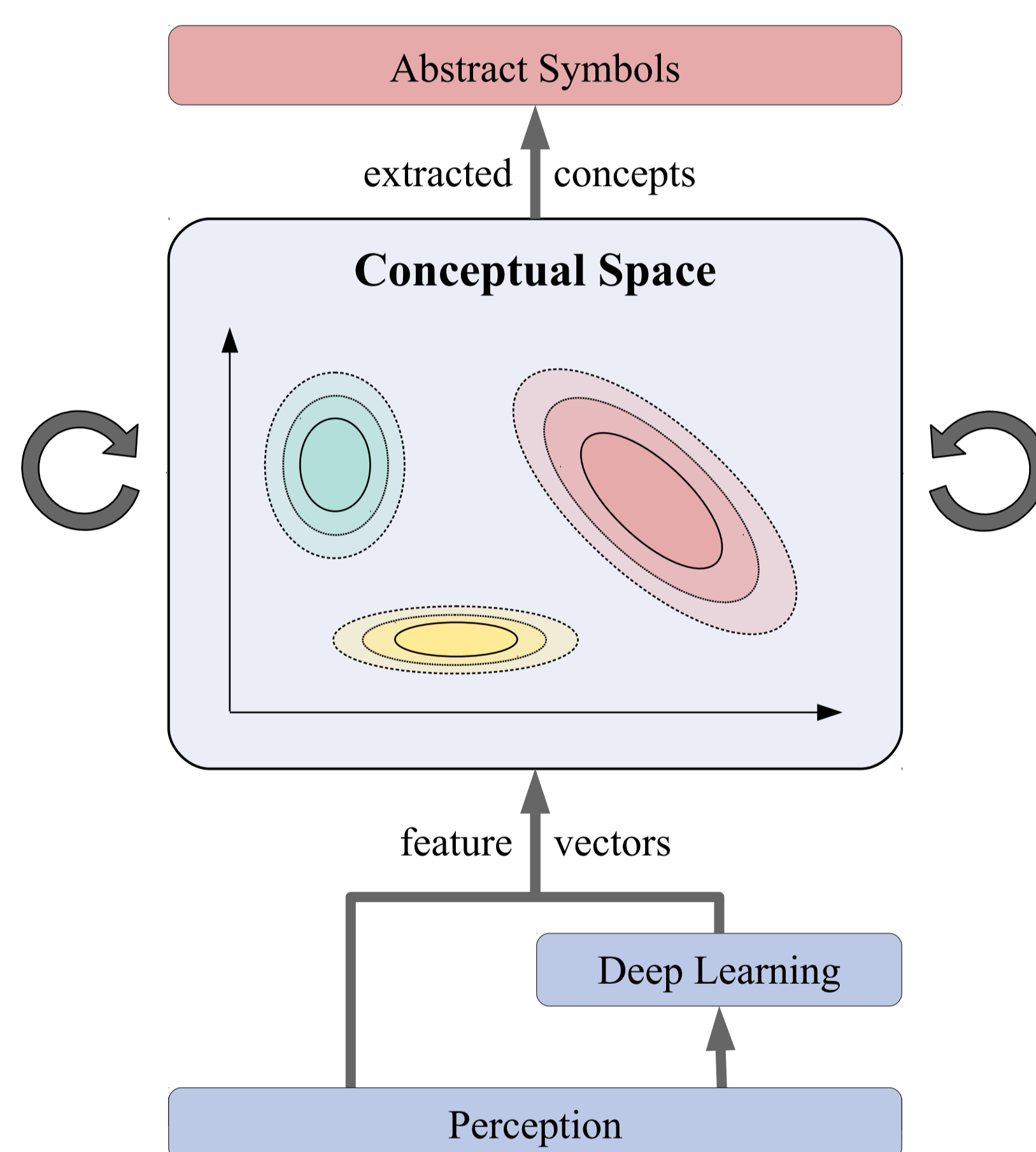
Clustering Algorithm

- Task: organize a set of data points into meaningful groups
- Assumption: closeness indicates similarity

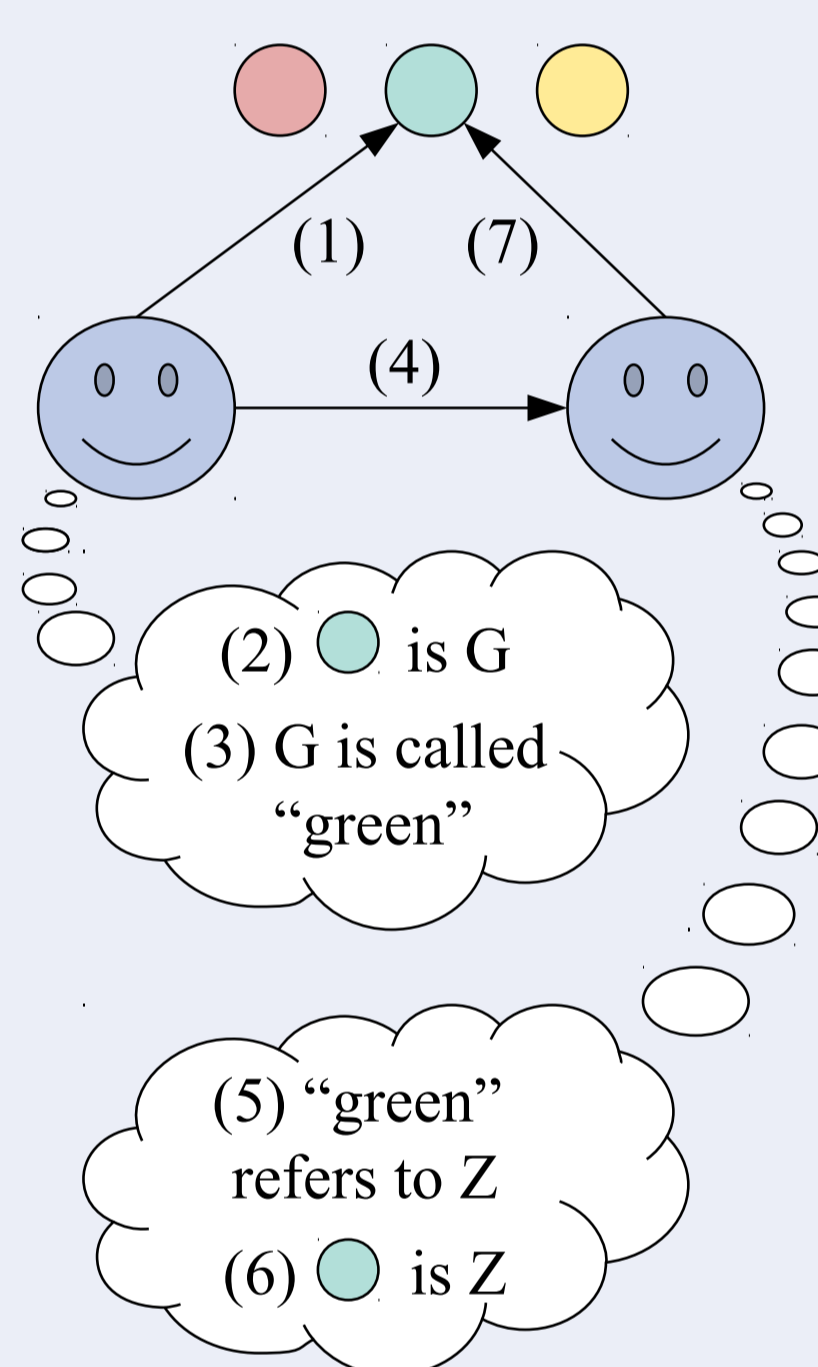


My requirements:

- Incremental
- Fuzzy
- Hierarchical
- Unknown number of clusters
- Incomplete feature vectors
- Occasional feedback



Language Games [6]



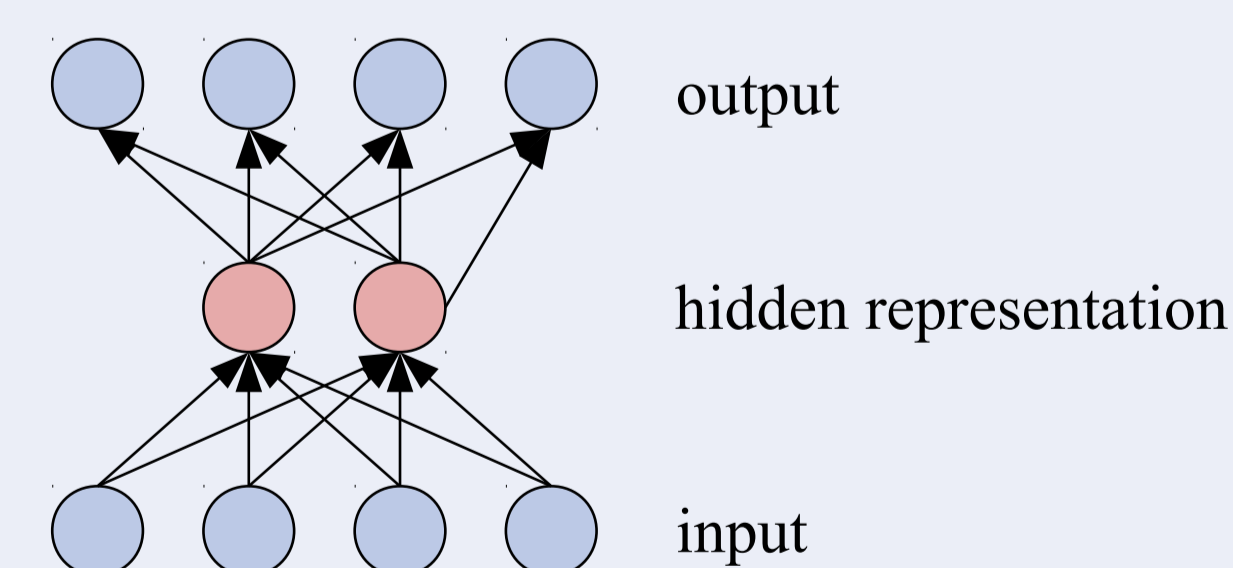
- (7) = (1): reinforce concepts
- (7) ≠ (1): modify concepts
- Repeated games result in shared conceptualization
- Concepts are grounded in communication

Bounded Rationality

“An intelligent system should be able to solve problems with insufficient knowledge and resources” [4]

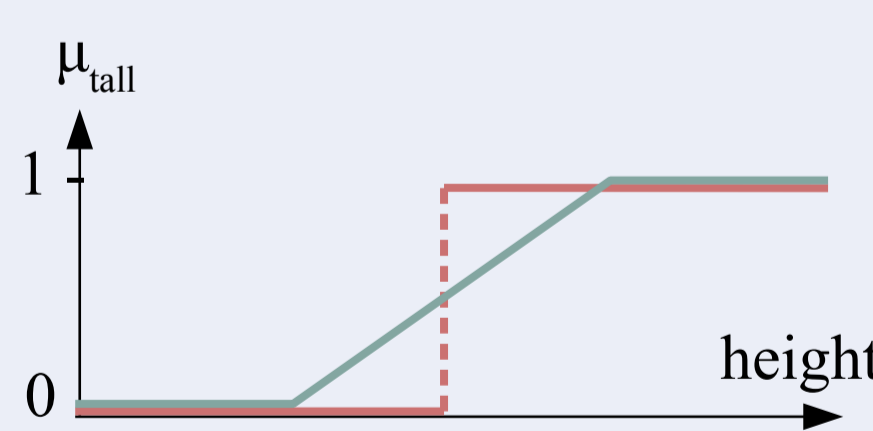
- Insufficient knowledge
 - Incomplete feature vectors
 - Only occasional feedback
- Insufficient resources
 - Limited memory size
 - Always need a working hypothesis

Deep Representation Learning [5]



- Autoencoder: reconstructs its input
- Hidden representation:
 - Summary representation of input
 - Neurons can be interpreted as dimensions

Fuzzy Sets [7]



- **Crisp set:** precise borders
 - Binary membership
 - μ_{tall} is not continuous
- **Fuzzy set:** imprecise borders
 - Gradual membership
 - μ_{tall} is continuous

4. Ways of Evaluation

- Communicative success in language games
 - Population of learning agents
 - Learning agent and gold standard agent
- Hyperparameter settings
 - Hyperparameters of the clustering algorithm
 - Hyperparameters of environment / language games
- Clustering benchmarks
- Missing attribute prediction [2]:
 - Artificially remove one of the features
 - Predict its value based on all other features

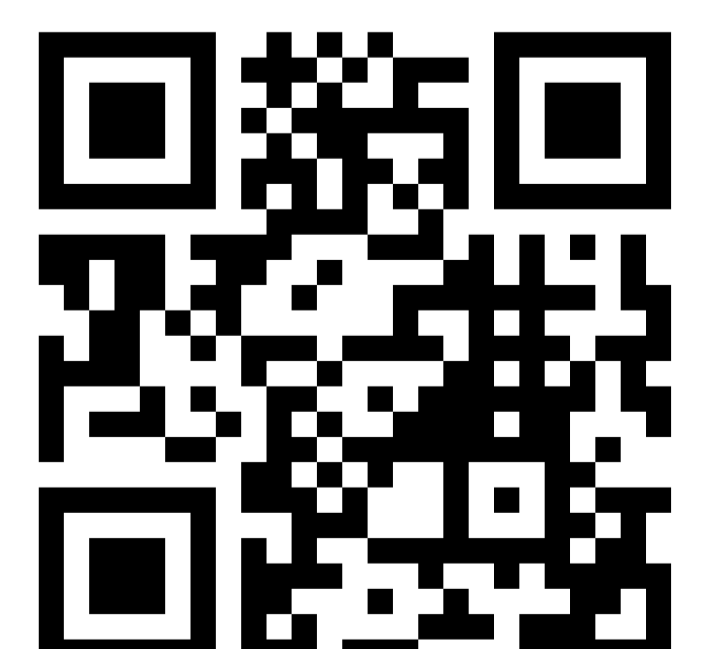
5. Research Contributions

- Thorough mathematical formalization of the conceptual spaces framework
- Combine language games with cognitive framework
- New type of clustering algorithm
- Learning in conceptual spaces
- Publicly available implementation of formalized conceptual spaces and concept formation system

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Literature

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