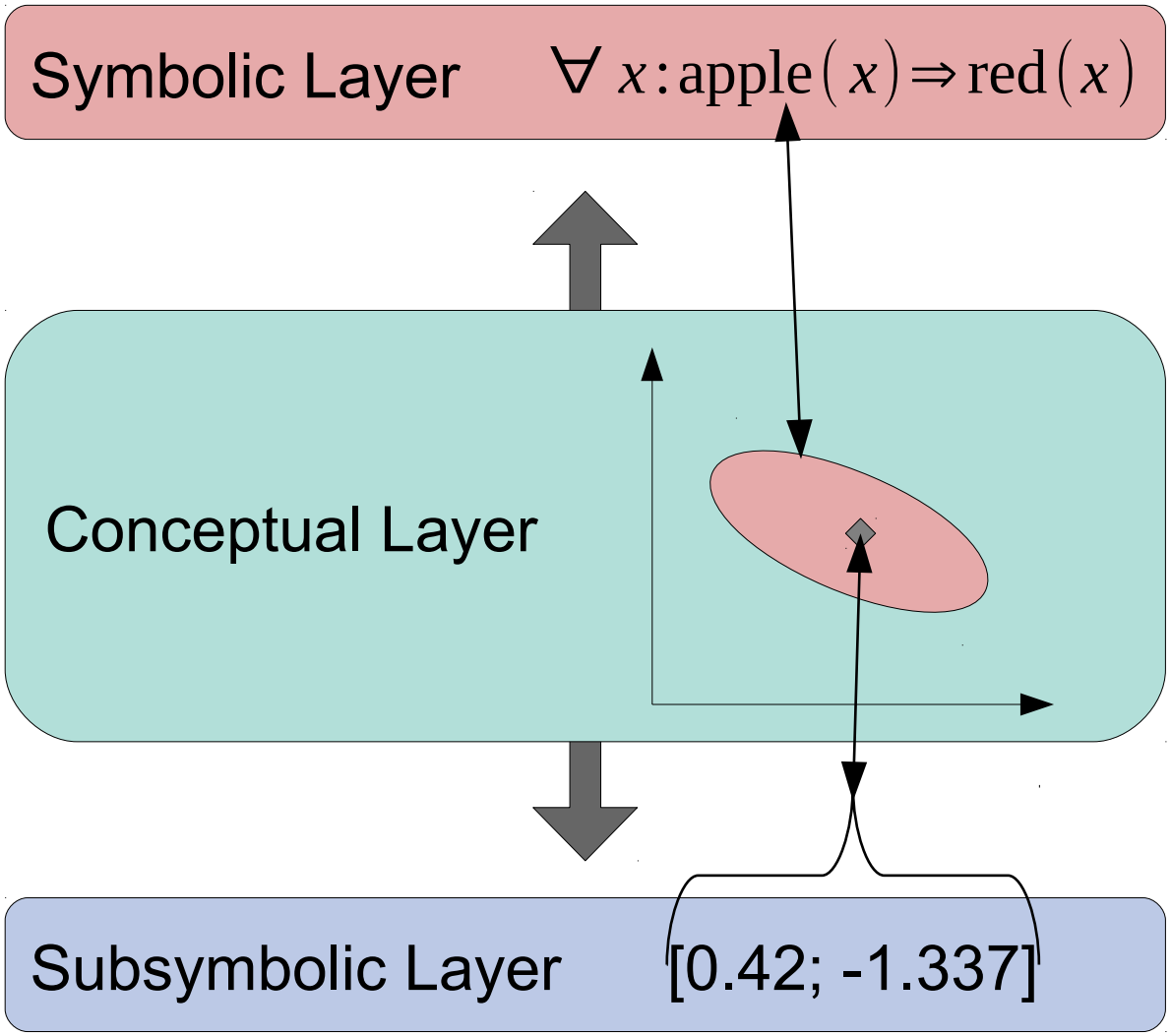
Conceptual Spaces

A Bridge Between Neural and Symbolic Representations?

Lucas Bechberger

Peter Gärdenfors, “Conceptual Spaces: The Geometry of Thought”, MIT press, 2000

The Different Layers of Representation



Formal Logics

Geometric Representation

Sensor Values, Machine Learning

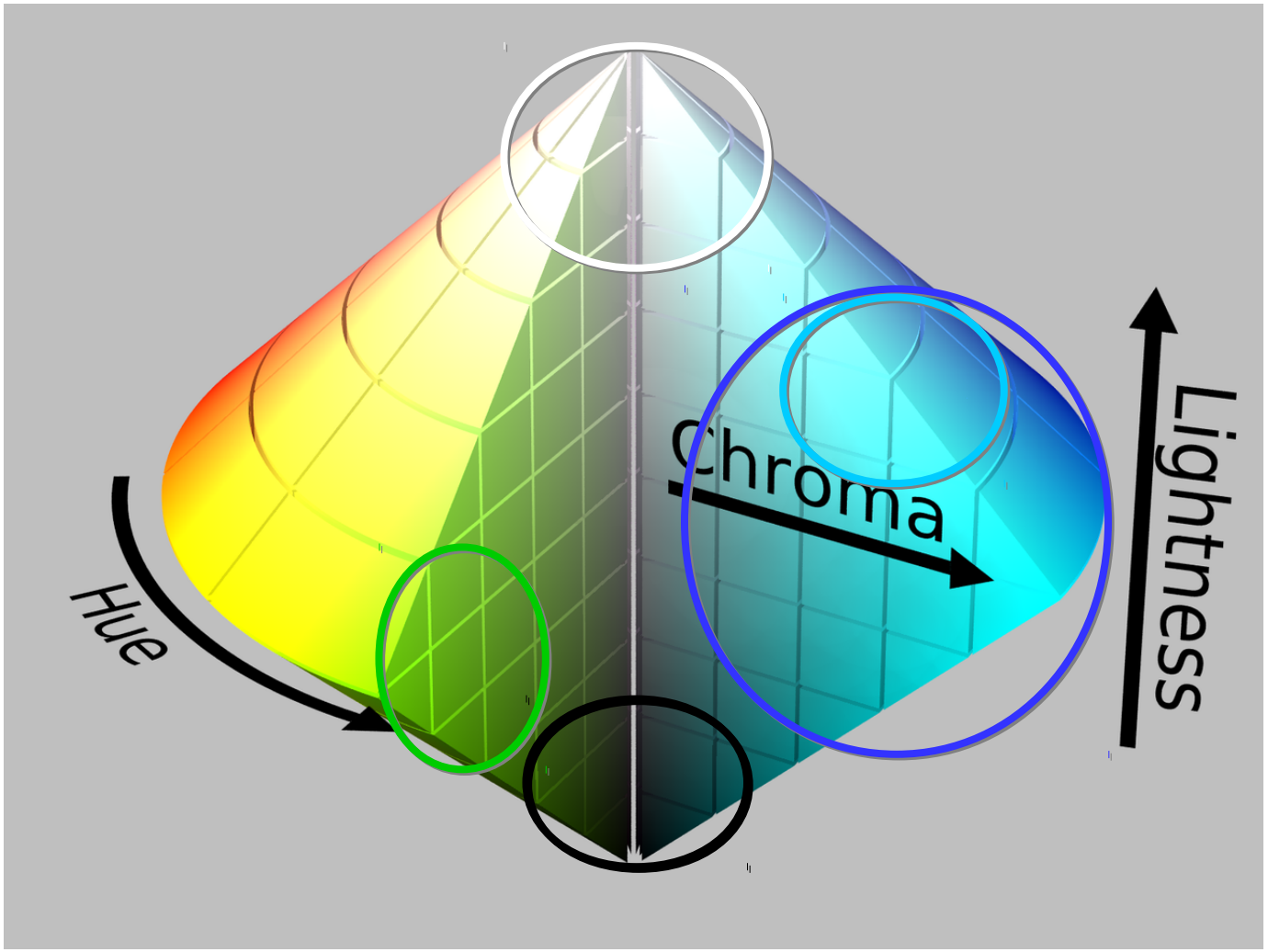
Dimensions & Domains

- Quality dimensions
  - Different ways stimuli are judged to be similar or different
  - Interpretable by a human
  - E.g., temperature, weight, brightness, pitch
- Domain
  - Set of dimensions that inherently belong together
  - Color: hue, saturation, and brightness
- Distance in this space is inversely related to similarity
  - Within a domain: Euclidean distance
  - Between domains: Manhattan distance

Properties

- A natural property is a convex region within a domain.

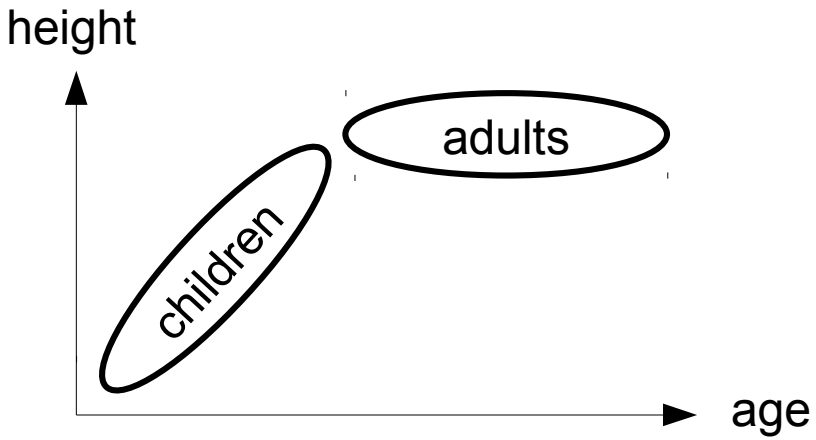
Example: The Color Domain



https://en.wikipedia.org/wiki/HSL_and_HSV#/media/File:HSL_color_solid_dblcone_chroma_gray.png

Concepts

- Example: „apple“
  - Color: red
  - Shape: spherical
  - Texture: smooth
  - Taste: sweet

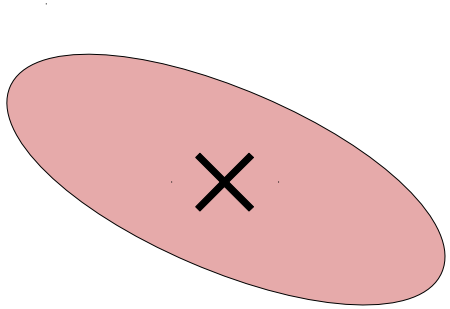


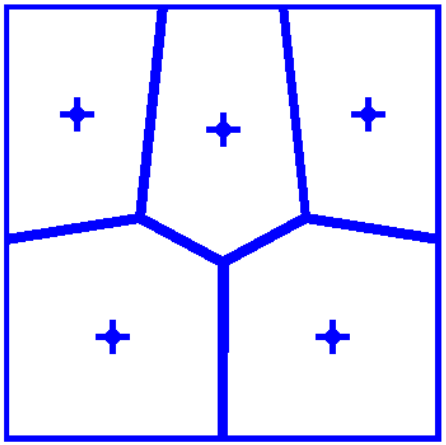
- Defined across multiple domains: combination of properties
  - Different „importance“ to the concept (influenced by context)
  - Potentially correlated

Connection to Psychology

- Prototype theory of concepts
  - Each concept is mentally represented by a prototype
  - e.g., the most typical instance

- Conceptual spaces
  - Central point of convex region can be interpreted as prototype
  - Voronoi-tesselation based on prototypes results in convex sets





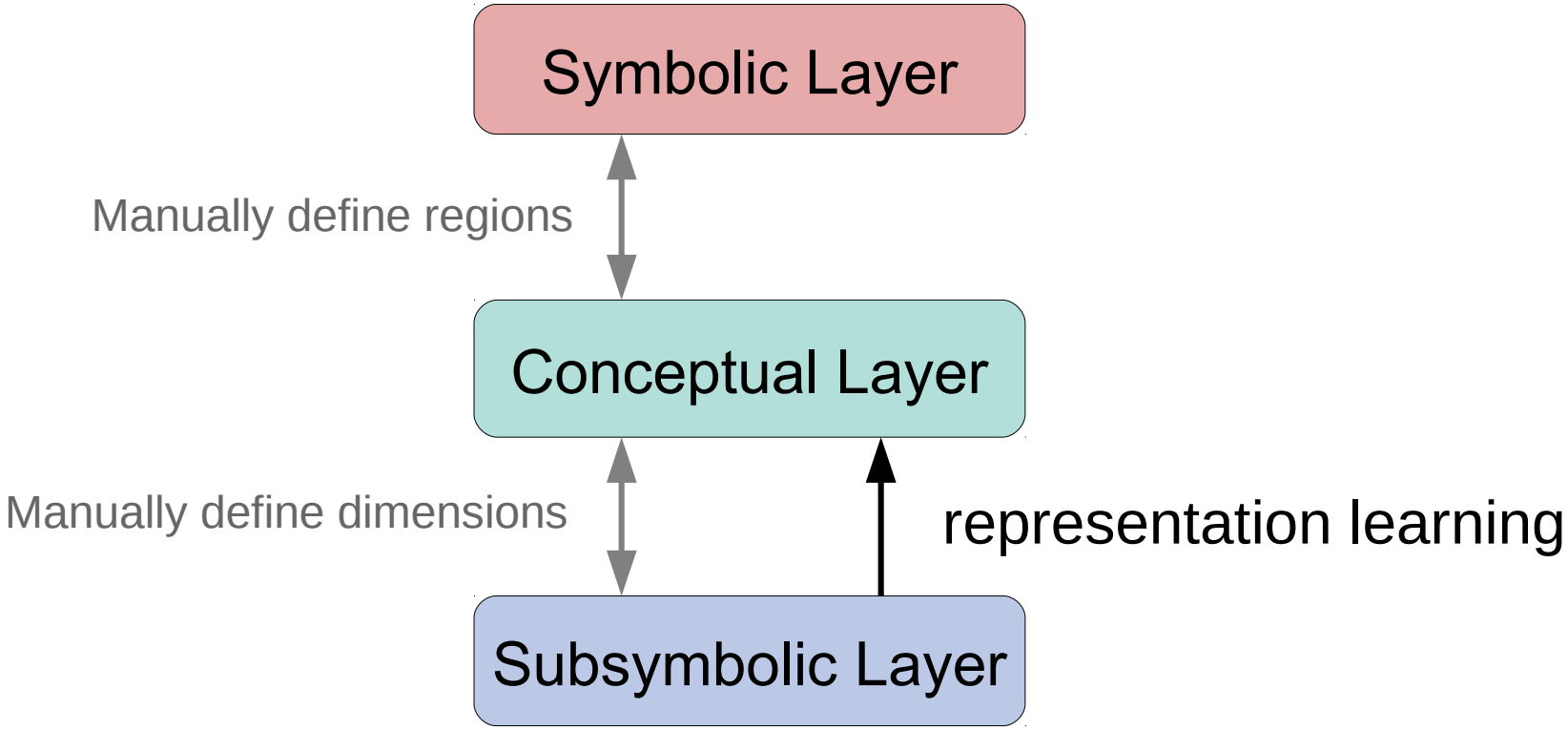
https://commons.wikimedia.org/wiki/File:CentroidalVoronoiTessellation2.png

Reasoning in Conceptual Spaces

- Geometric relationships between regions
  - ***Sky blue*** is a subset of ***blue***
  - Projecting ***apple*** onto the color domain results in ***red*** region
- Concept combination: “green banana”
  - Narrow down the color region of ***banana*** to ***green*** region
  - Correlations between domains yield further updates:
    - Consistency is ***solid***, taste is ***bitter***
- Use betweenness and similarity for plausible reasoning
  - Both bachelor and PhD students have to pay a certain fee
  - What about Master students?

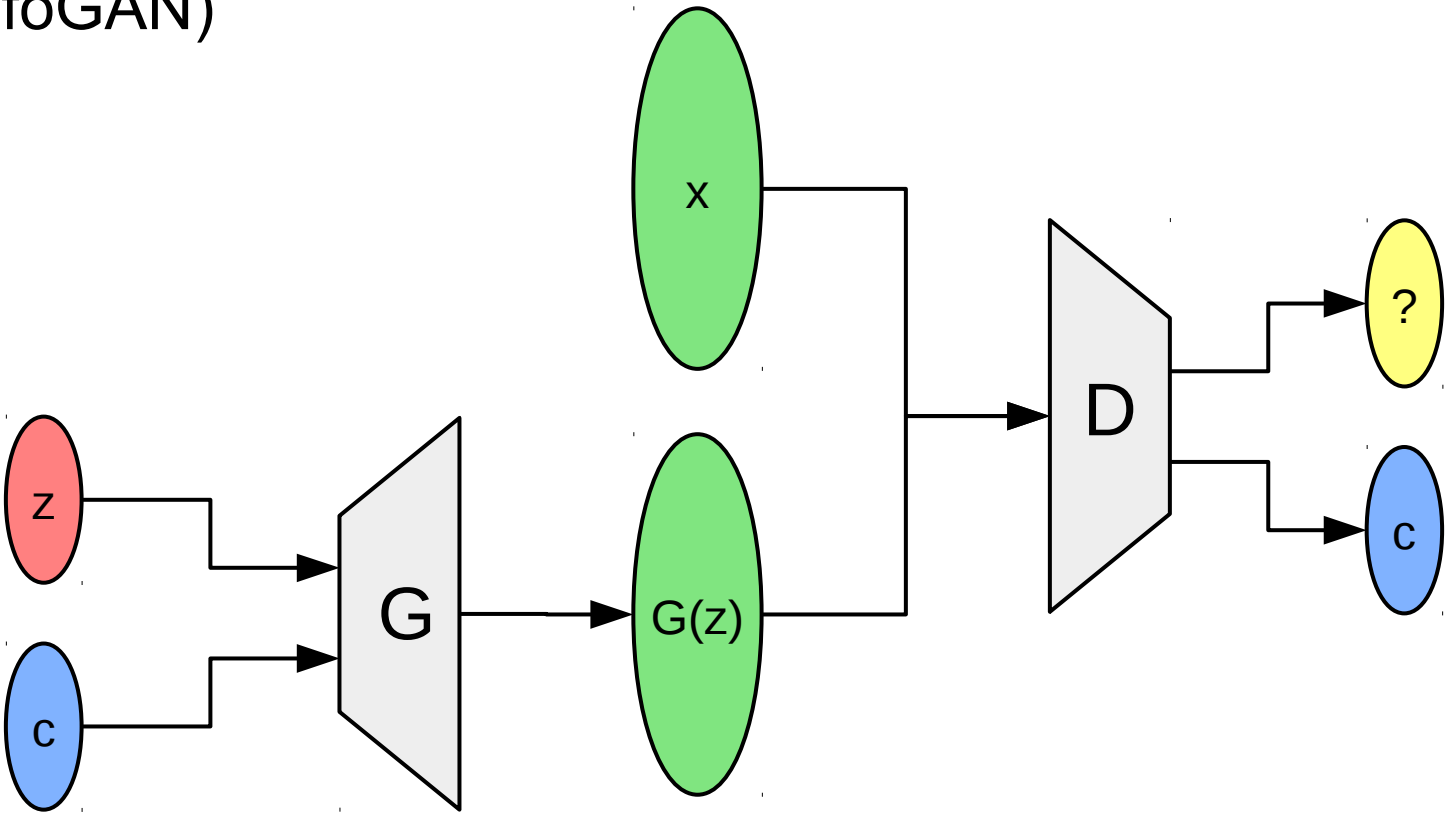
J. Derrac and S. Schockaert, “Inducing Semantic Relations from Conceptual Spaces: A Data-Driven Approach to Plausible Reasoning”, Artificial Intelligence, 2015

My Research


Symbolic Layer
Manually define regions
Conceptual Layer
Manually define dimensions
representation learning
Subsymbolic Layer

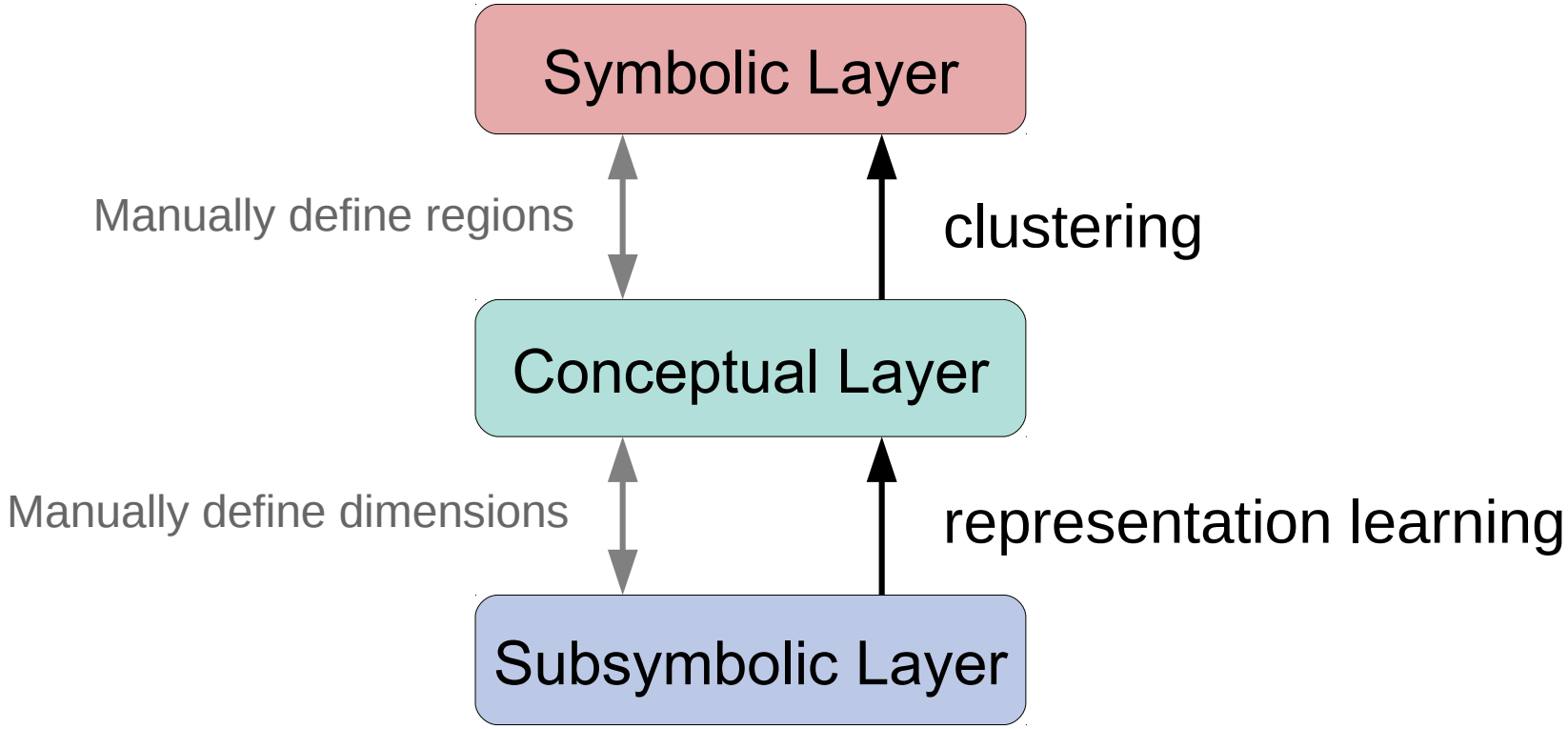
Learning Dimensions with ANNs

- Information Maximizing Generative Adversarial Networks (InfoGAN)



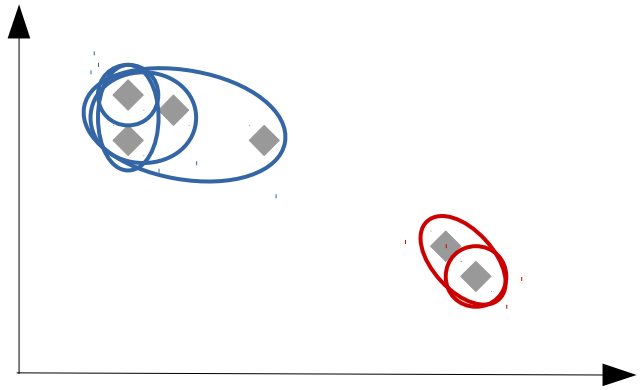
X. Chen et al., “InfoGAN: Interpretable Representation Learning by Information Maximizing Generative Adversarial Nets”, Advances in Neural Information Processing Systems, 2016

My Research

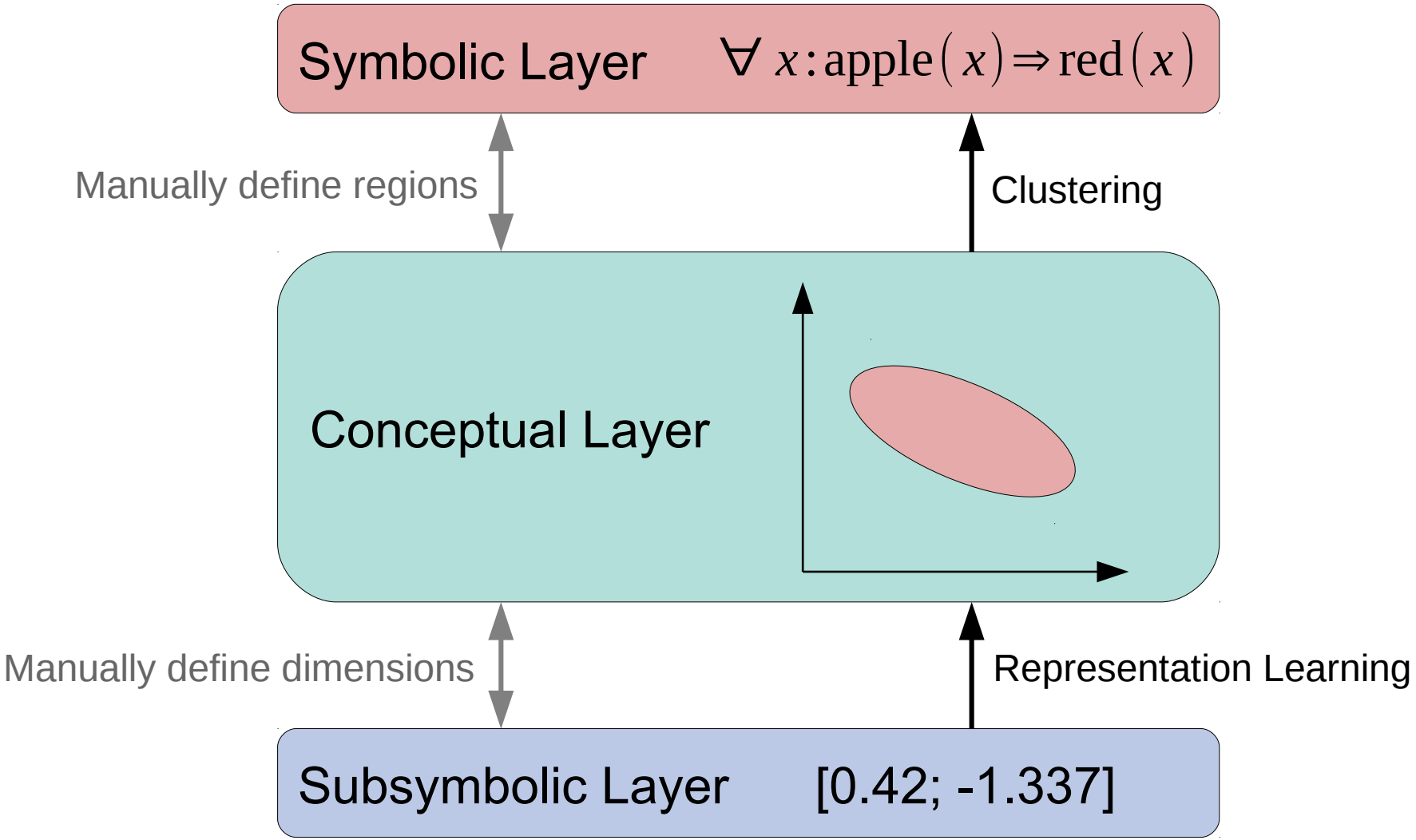

Symbolic Layer
Manually define regions
clustering
Conceptual Layer
Manually define dimensions
representation learning
Subsymbolic Layer

Learning Concepts Through Clustering

- We look for meaningful regions in the conceptual space
  - Concepts = clusters of data points
- Observed objects usually come without class information
  - unsupervised
- Observing one object at a time, limited memory
  - Stream of data points, incremental processing



Summary


Symbolic Layer
$\forall x : \text{apple}(x) \Rightarrow \text{red}(x)$
Manually define regions
Clustering
Conceptual Layer
Manually define dimensions
Representation Learning
Subsymbolic Layer
[0.42; -1.337]

Thank you for your attention!

Questions? Comments? Discussions?

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