

Using Conceptual Spaces for Cognitive AI

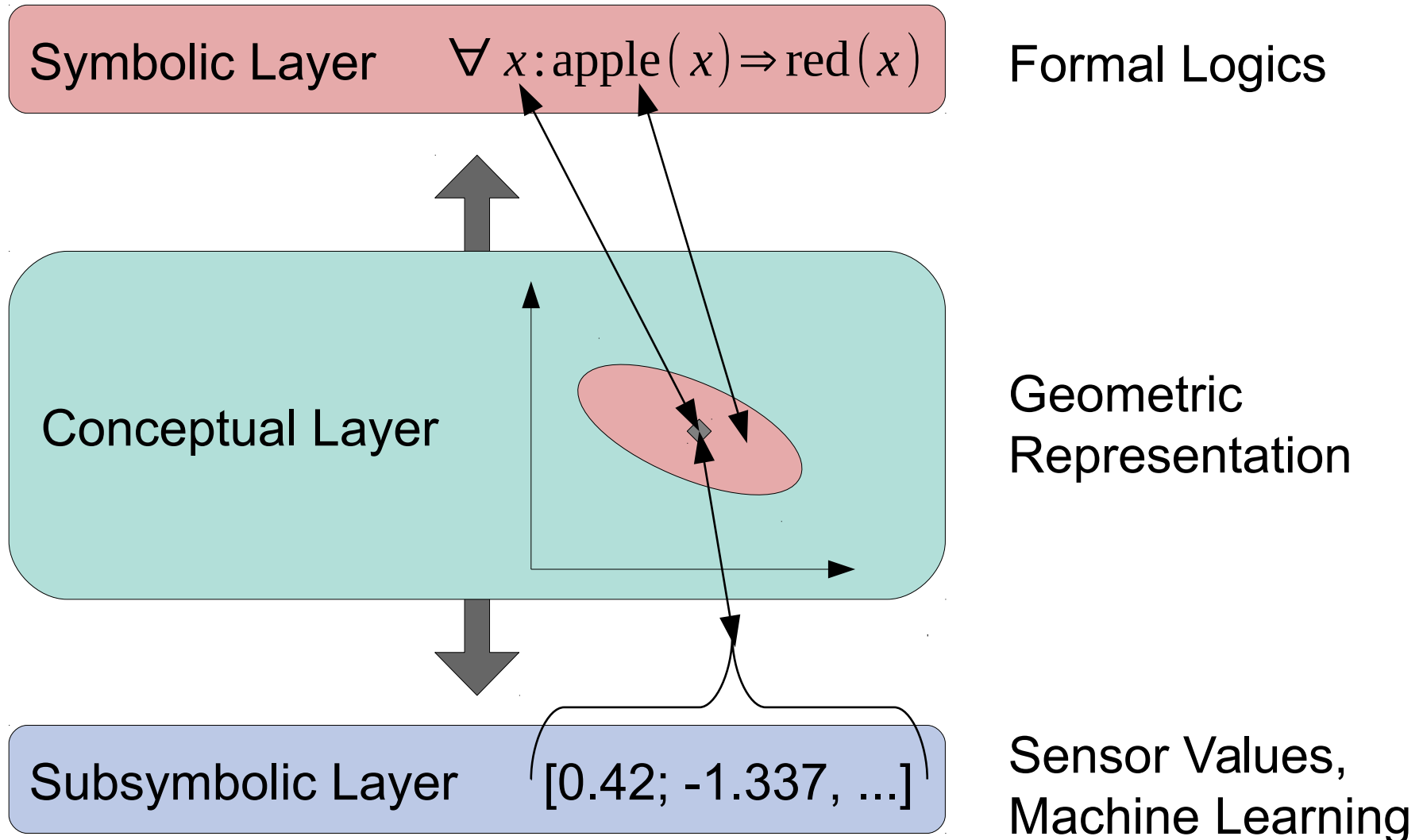
Lucas Bechberger

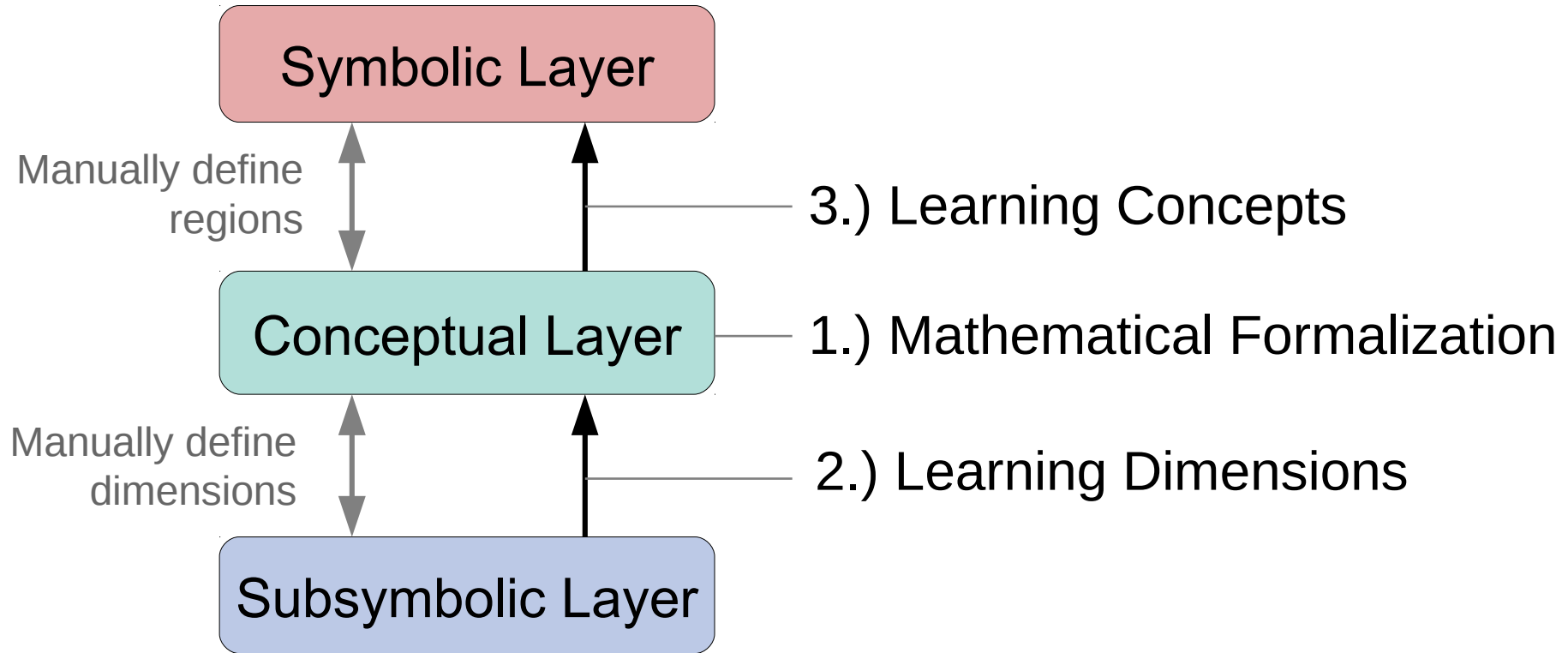
Institute of Cognitive Science

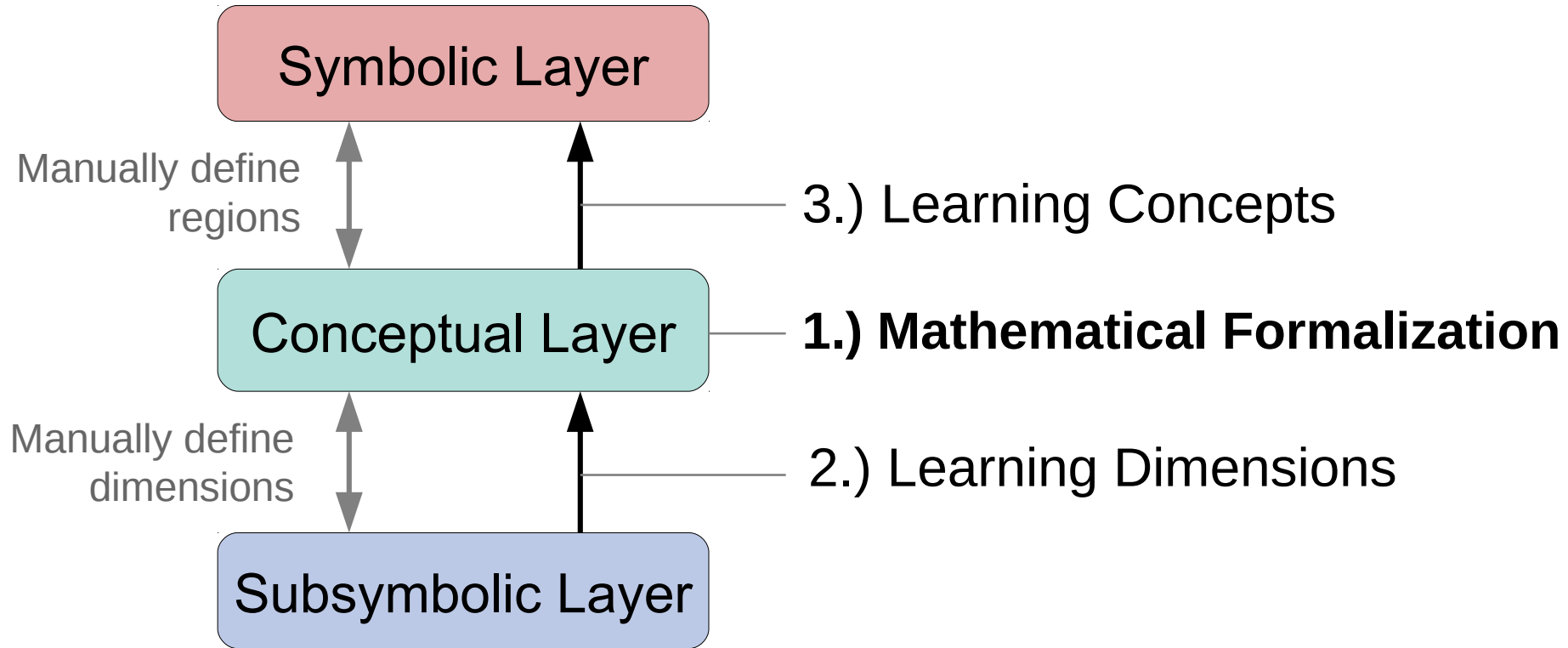
Osnabrück University

<https://www.lucas-bechberger.de>







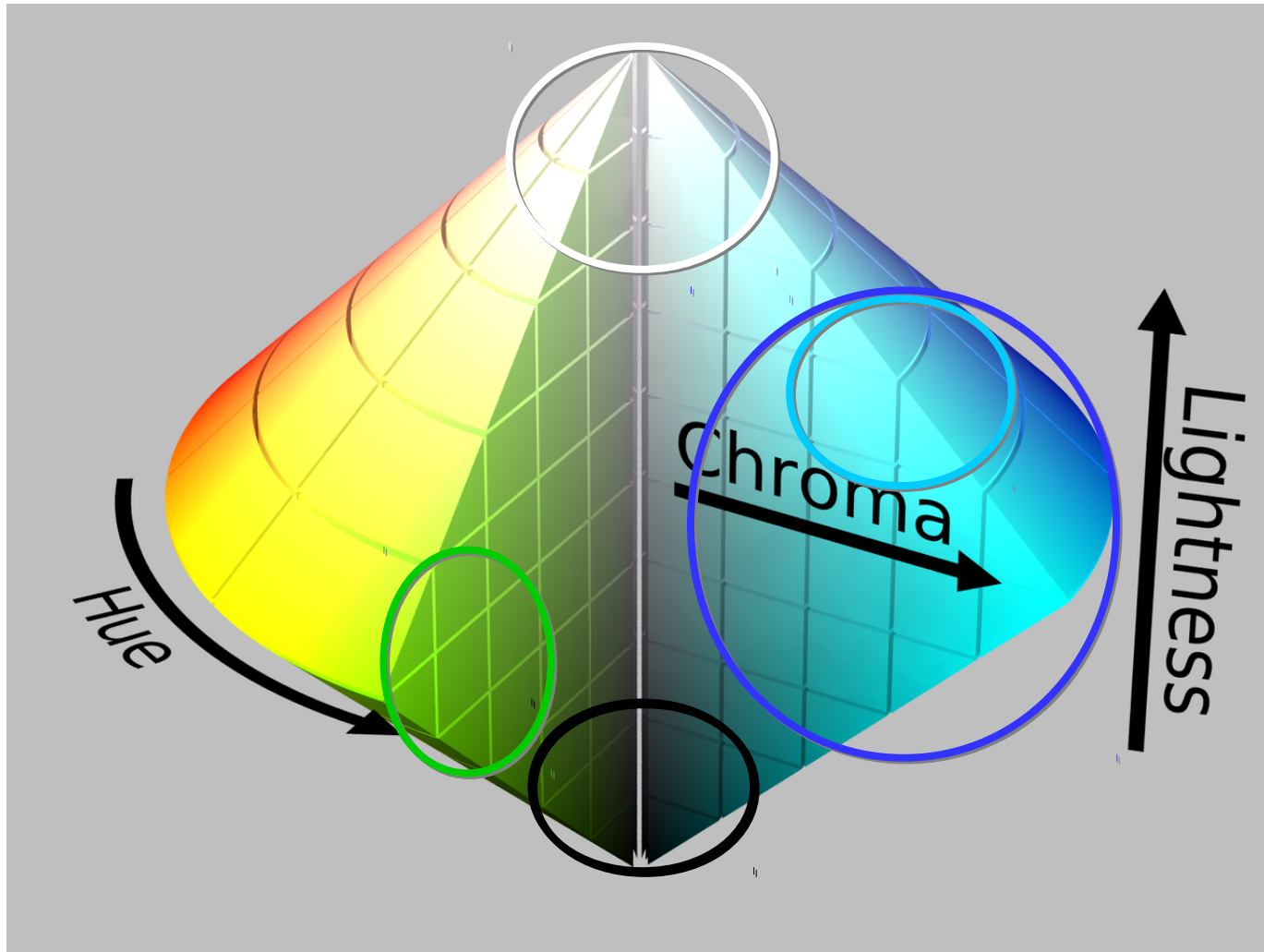


- Quality dimensions
 - Interpretable ways of judging the similarity of two instances
 - E.g., temperature, weight, brightness, pitch

- Domain
 - Set of dimensions that inherently belong together
 - Color: hue, saturation, and brightness

Gärdenfors, P. Conceptual Spaces: The Geometry of Thought. MIT press, 2000

The Color Domain



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

- Property
 - Region within a single domain
 - Examples: “white”, “baby blue”, “hot”, “sour”, “round”

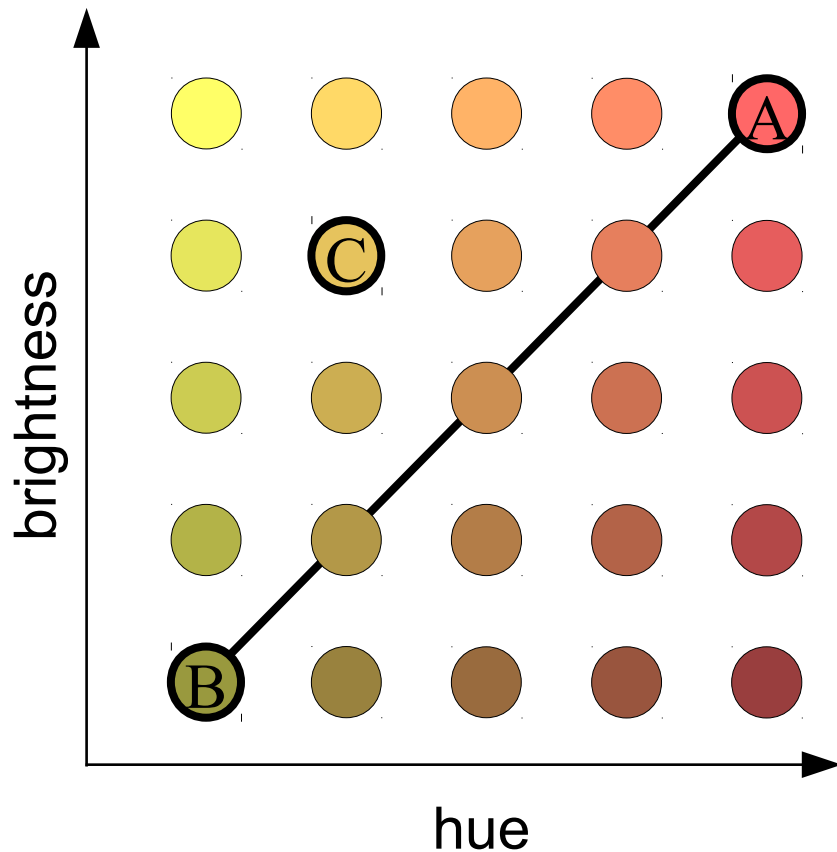
- Concept
 - Spans multiple domains
 - Examples: “apple”, “dog”, “chair”

- Components of a concept
 - One region per domain
 - Salience weights for the domains
 - **Correlations between the domains**

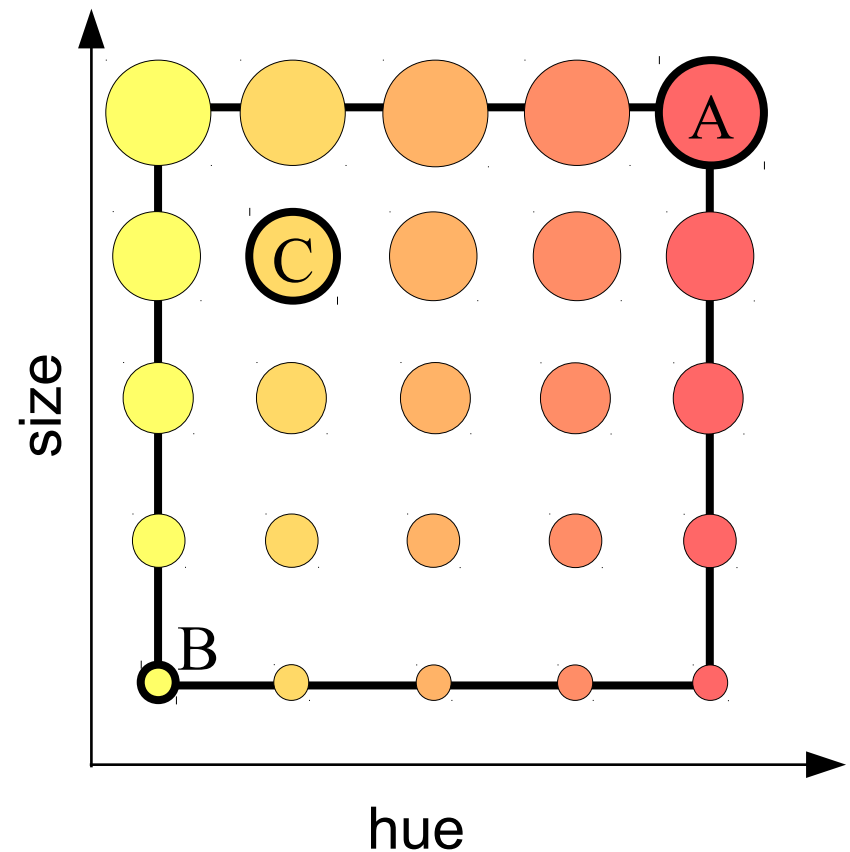
Betweenness and Distance

$$B(x,y,z) :\leftrightarrow d(x,y) + d(y,z) = d(x,z)$$

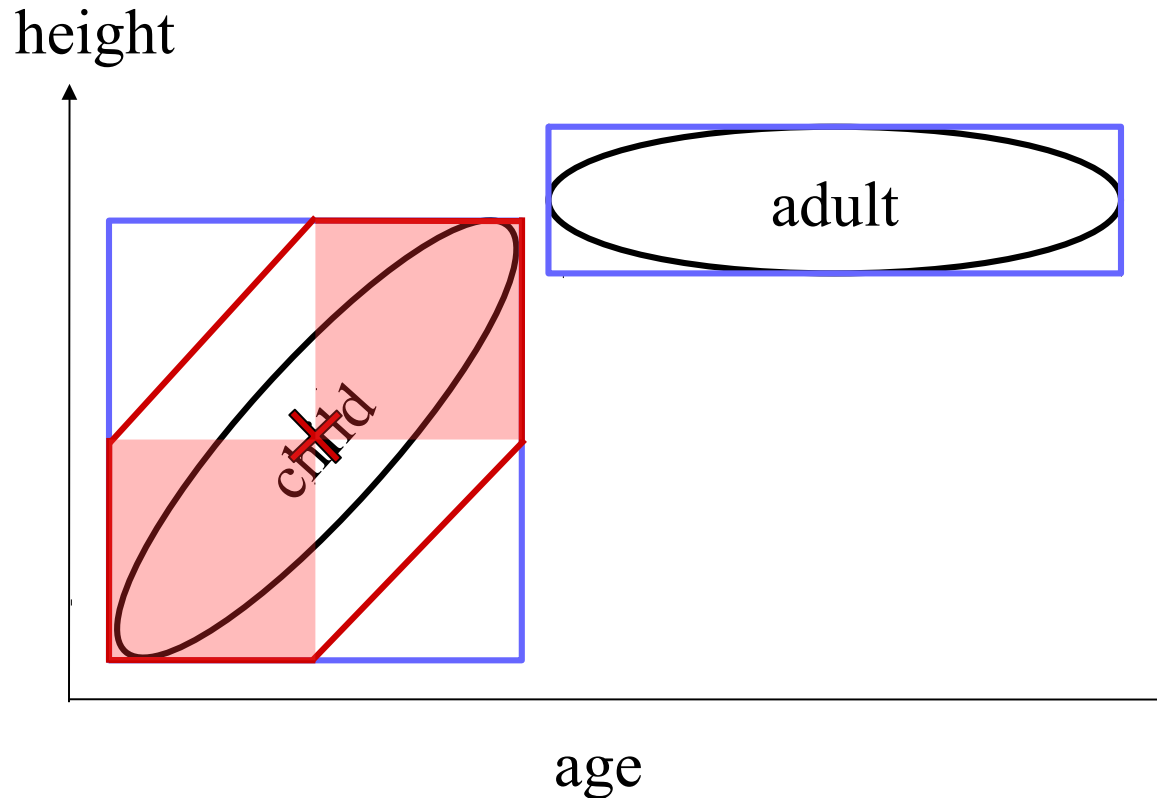
Euclidean distance



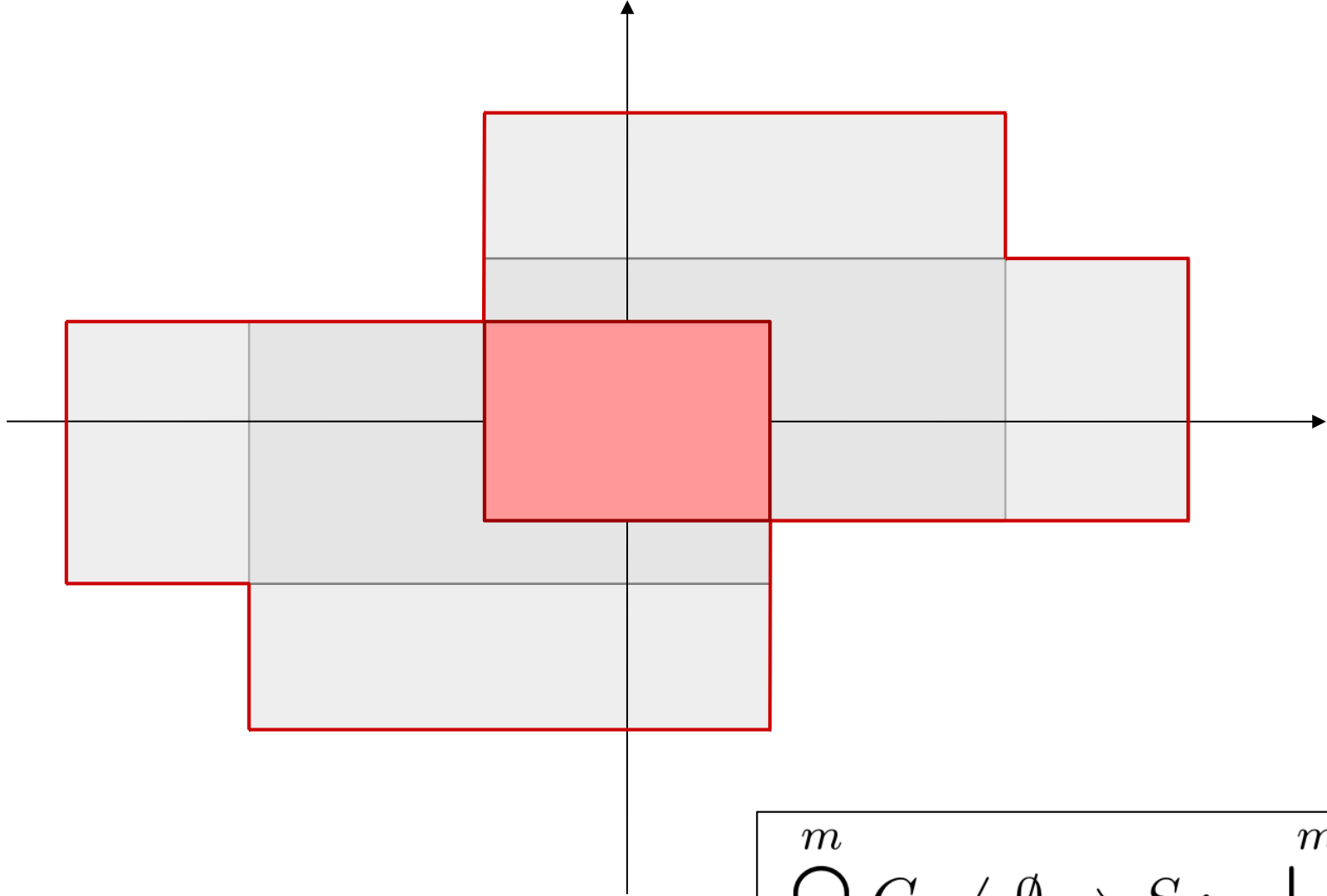
Manhattan distance



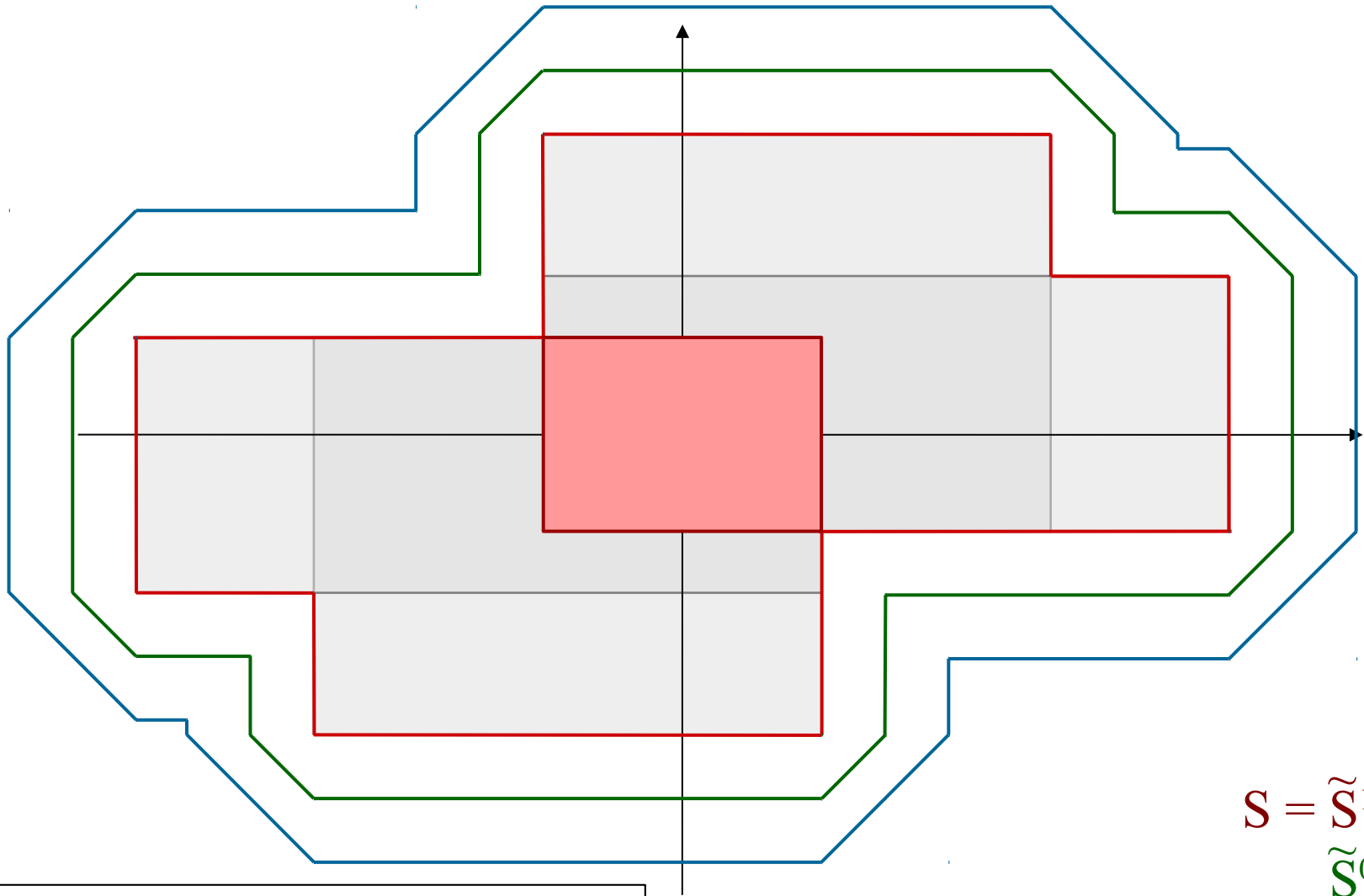
- Convex region C : $\forall x, z \in C : \forall y : B(x, y, z) \Rightarrow y \in C$
- Star-shaped region S : $\exists p \in S : \forall z \in S : \forall y : B(p, y, z) \Rightarrow y \in S$



Bechberger, L. & Kühnberger, K.-U. Formalized Conceptual Spaces with a Geometric Representation of Correlations. In: Kaipainen, M.; Zenker, F.; Hautamäki, A. & Gärdenfors, P. (Ed.). Conceptual Spaces: Elaborations and Applications, Springer International Publishing, 2019, 29-58



$$\bigcap_{i=1}^m C_i \neq \emptyset \Rightarrow S := \bigcup_{i=1}^m C_i$$



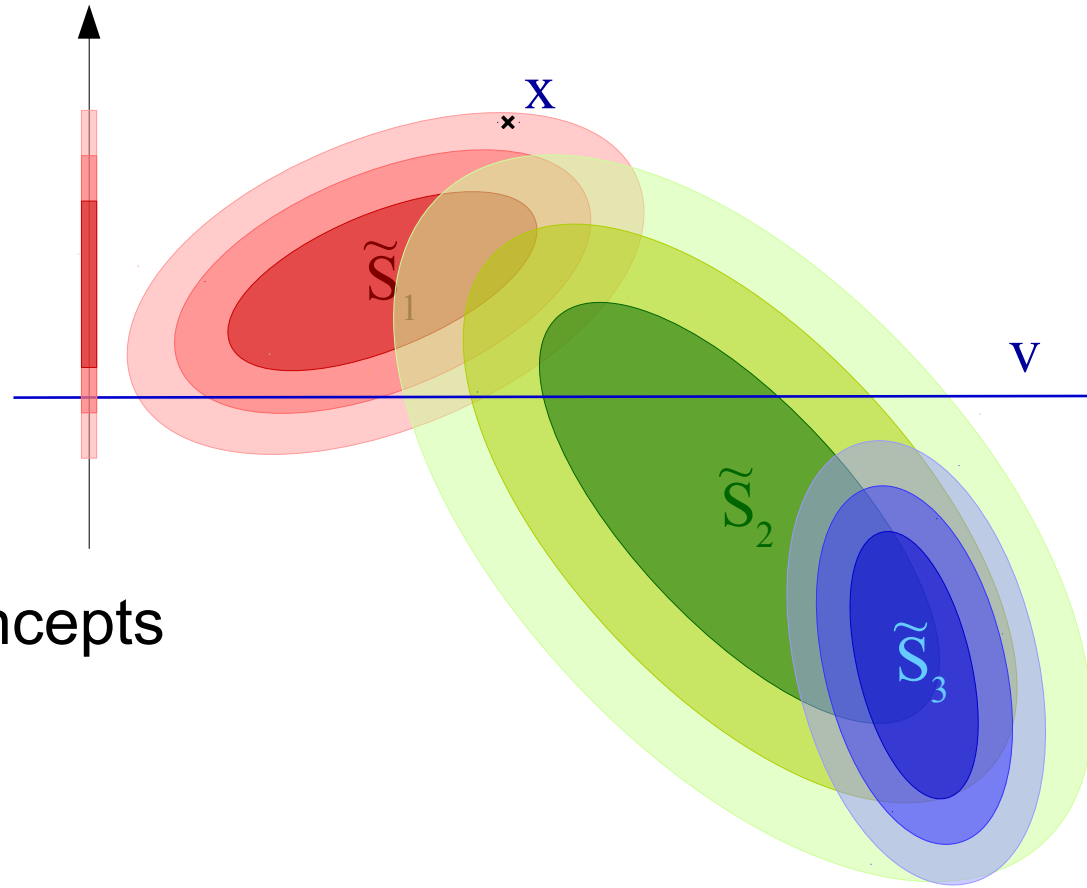
$$S = \tilde{S}^{1.0}$$

$$\tilde{S}^{0.5}$$

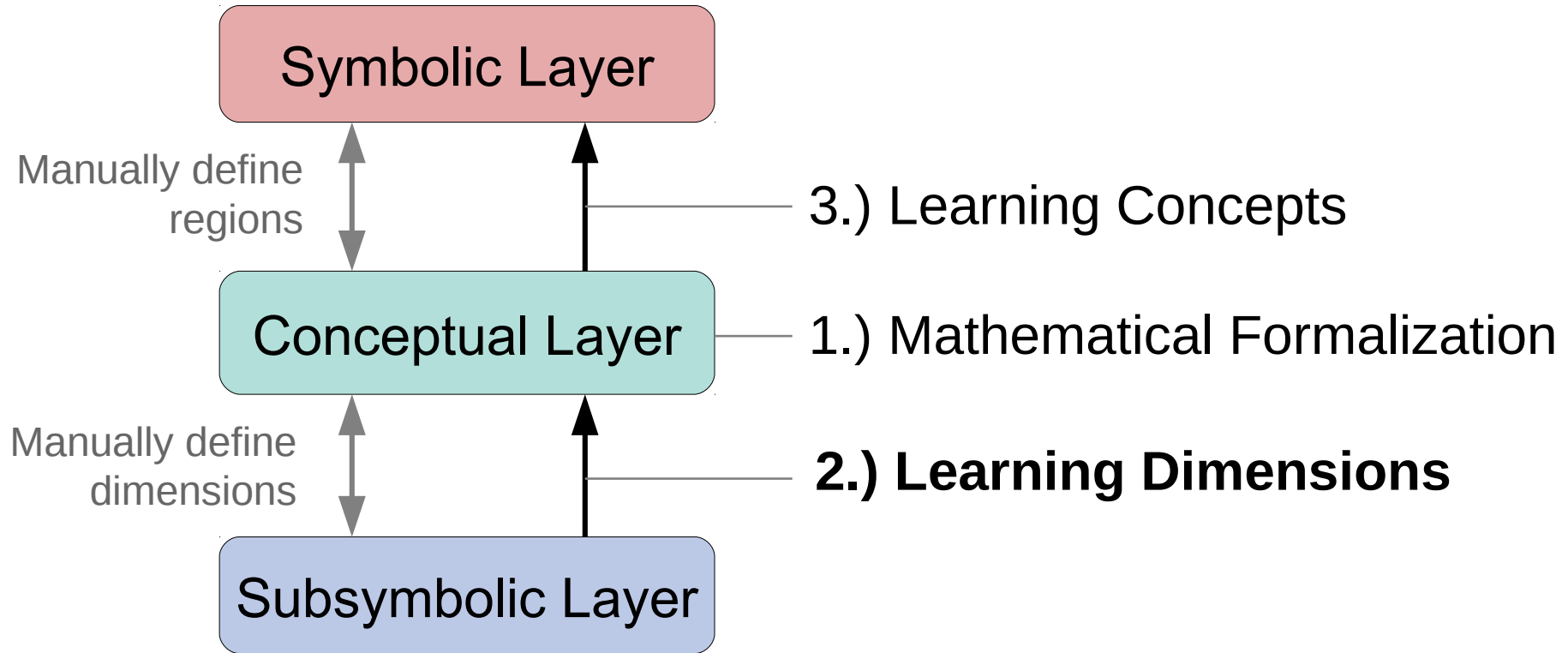
$$\tilde{S}^{0.25}$$

$$\mu_{\tilde{S}}(x) = \mu_0 \cdot \max_{y \in S} (e^{-c \cdot d_C^{\Delta S}(x, y, W)})$$

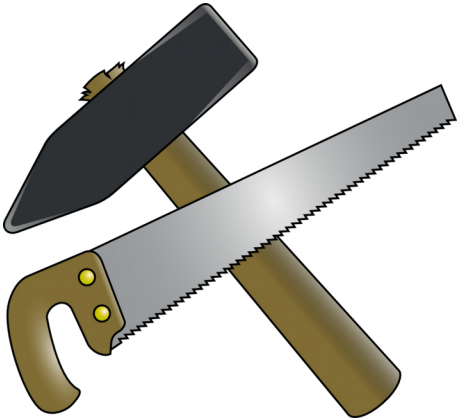
- Basic
 - Membership
- Concept Creation
 - Intersection
 - Unification
 - Projection
 - Cut
- Relations Between Concepts
 - Size
 - Subsethood
 - Implication
 - Similarity
 - Betweenness



<https://github.com/lbechberger/ConceptualSpaces>



Handcrafting



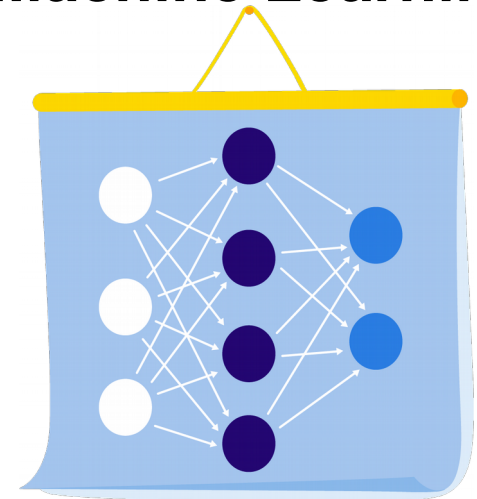
https://www.pinclipart.com/downloadpings/hmJhoT_hammer-saw-clipart-hammer-and-saw-png-transparent/

Psychology

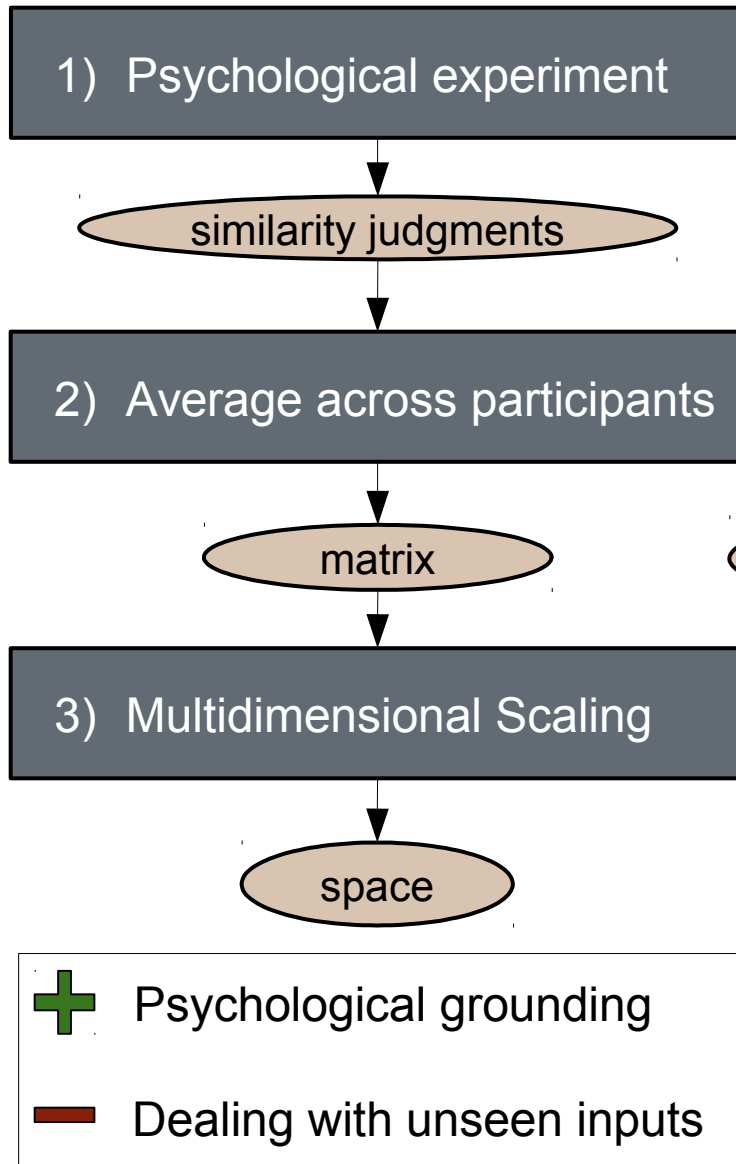


https://www.pinclipart.com/downloadpings/TJoTxi_brain-symbol-of-psychology-clipart/

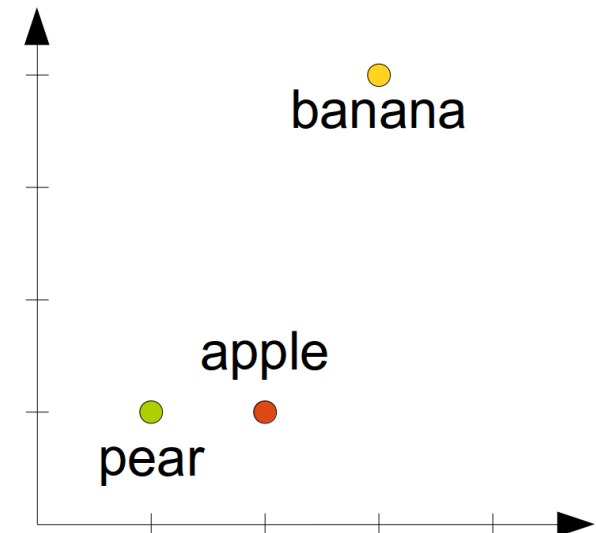
Machine Learning



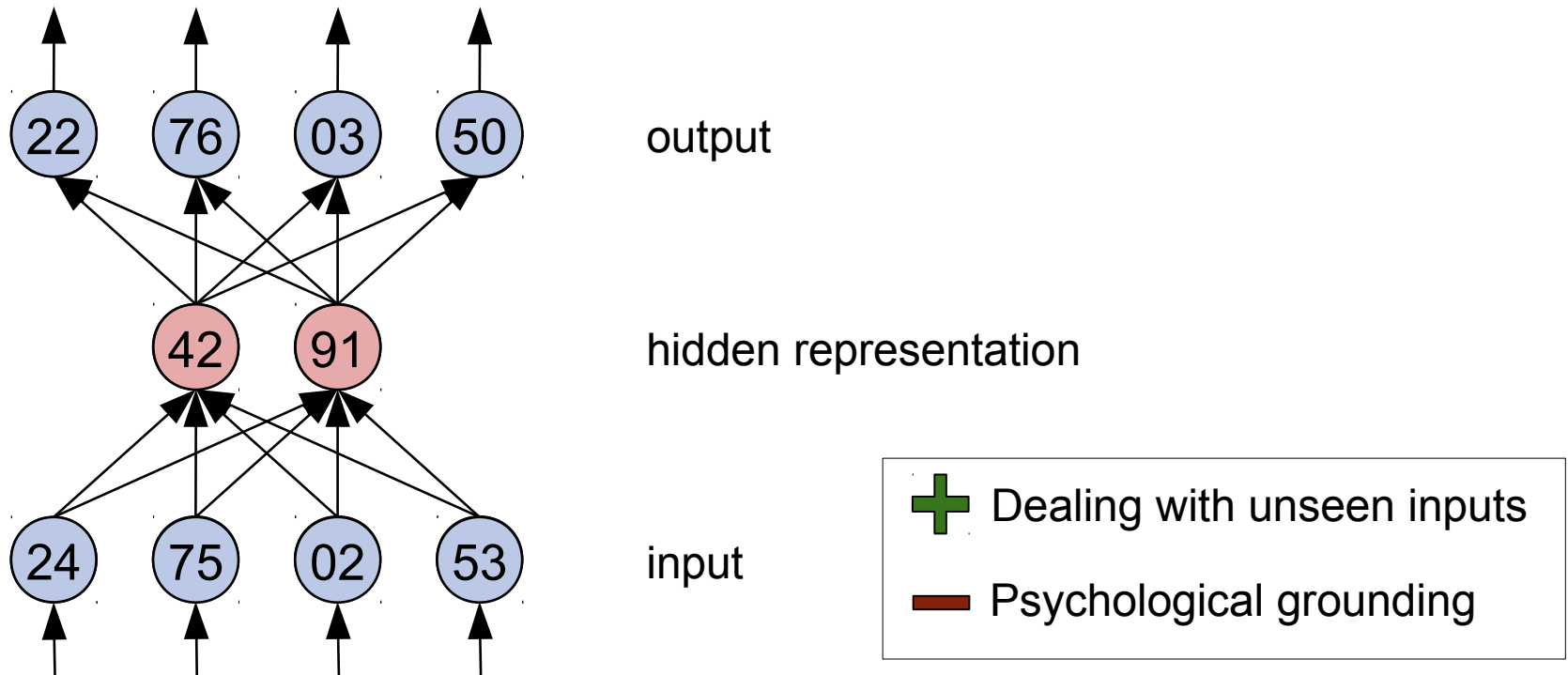
https://www.pinclipart.com/downloadpings/hboiwb_neural-networks-set-out-to-replicate-the-brains/



distance	apple	pear	banana
apple	0.0	1.0	3.2
pear	1.0	0.0	3.6
banana	3.2	3.6	0.0



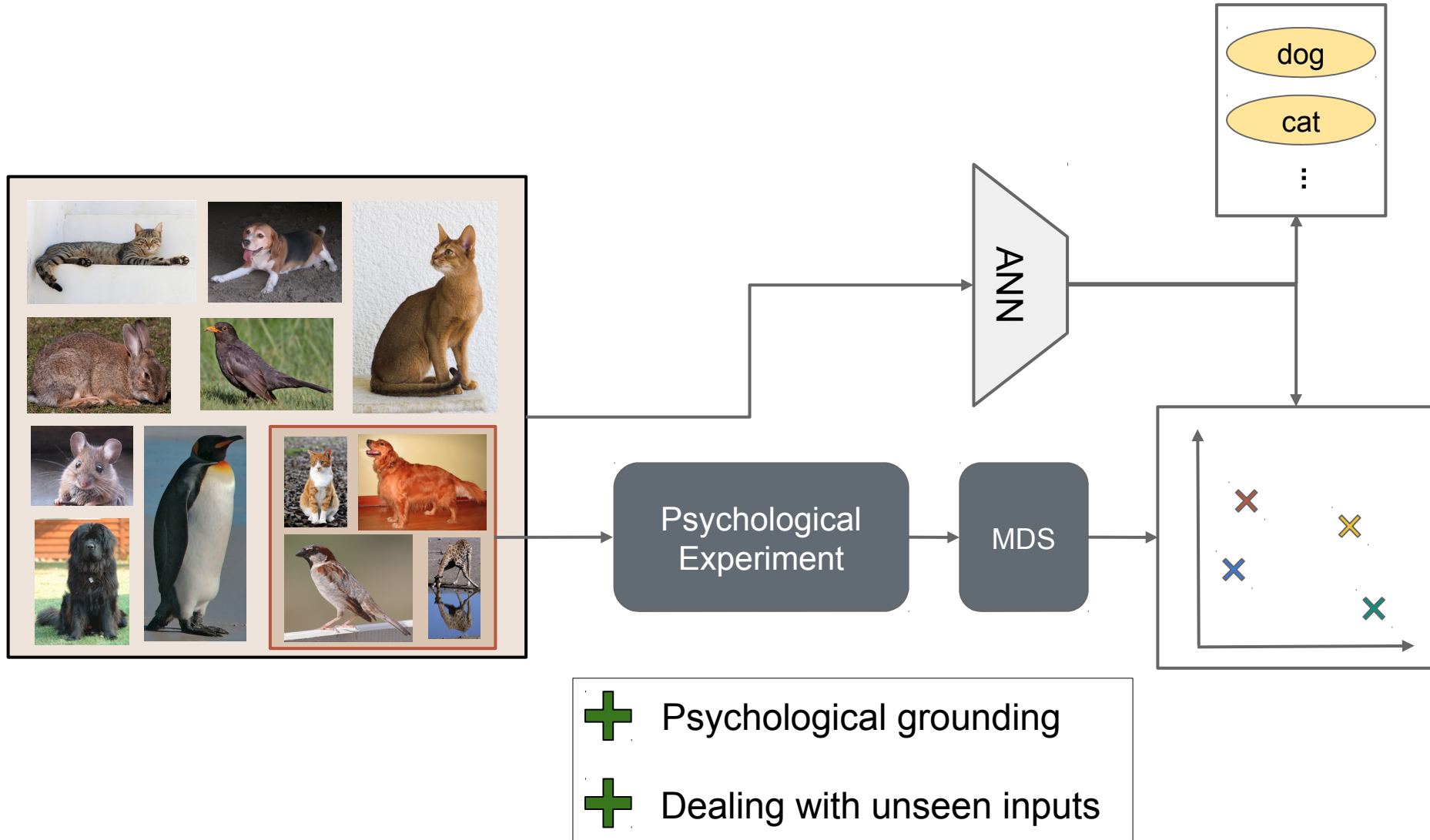
- Autoencoder (e.g., β -VAE): compress and reconstruct input



- Hidden neurons = dimensions in our conceptual space

Higgins, I.; Matthey, L.; Pal, A.; Burgess, C.; Glorot, X.; Botvinick, M.; Mohamed, S. & Lerchner, A. β -VAE: Learning Basic Visual Concepts with a Constrained Variational Framework, ICLR 2017

Learning Dimensions: Hybrid



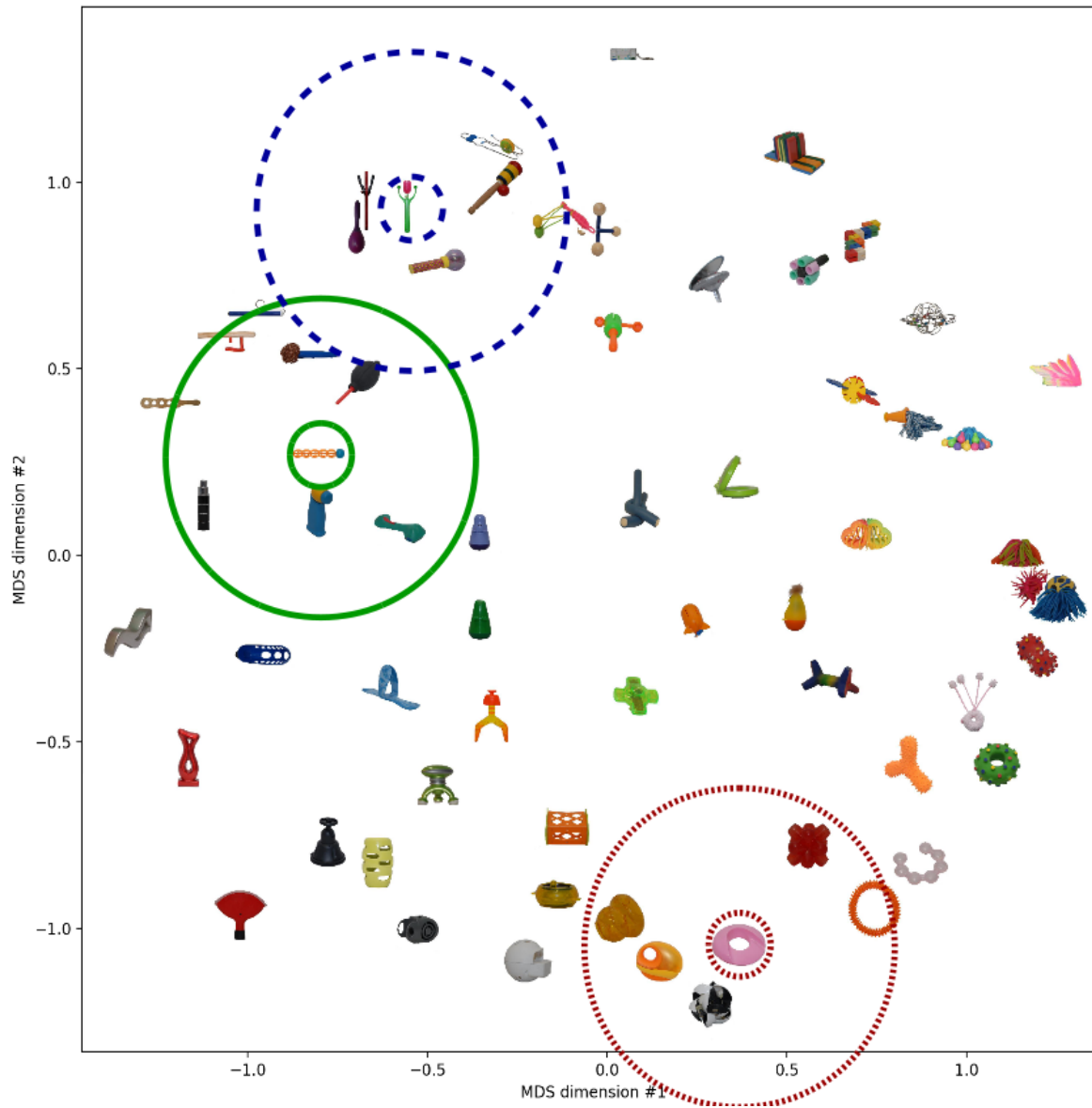
Bechberger, L. & Kypridemou, E. Mapping Images to Psychological Similarity Spaces Using Neural Networks. AIC 2018
 Bechberger, L. & Kühnberger, K.-U. Generalizing Psychological Similarity Spaces to Unseen Stimuli. Preprint 2019

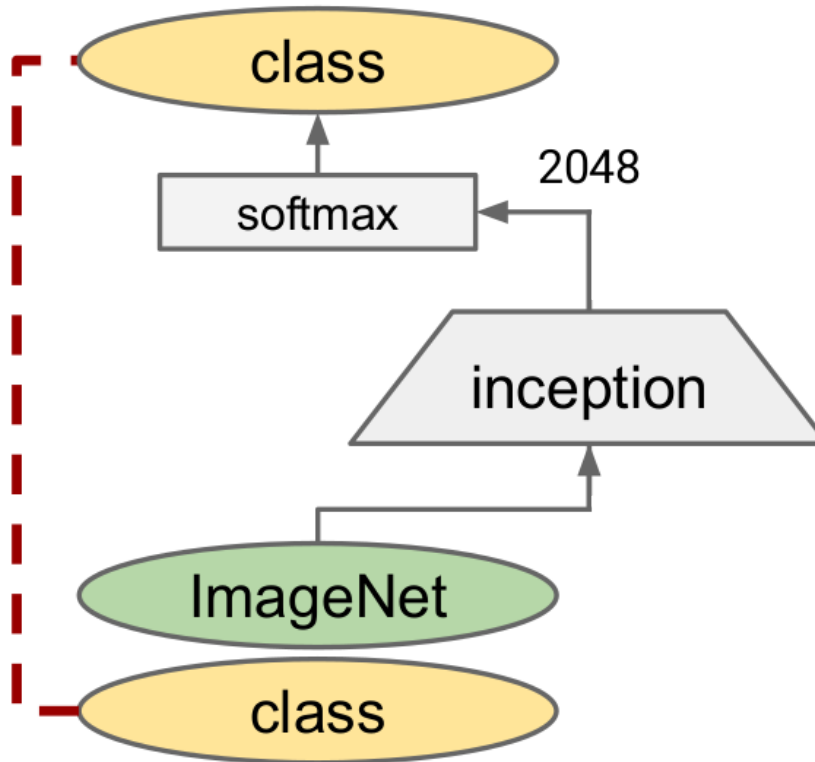
- NOUN data set
 - 64 images of novel objects
 - Pairwise similarity ratings



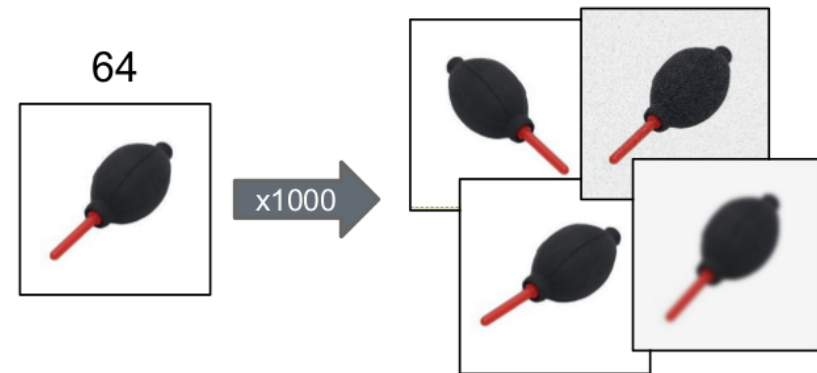
Horst, J. S. & Hout, M. C. The Novel Object and Unusual Name (NOUN) Database: A Collection of Novel Images for Use in Experimental Research. *Behavior Research Methods*, 2016, 48, 1393-1409

Feasibility Study: MDS

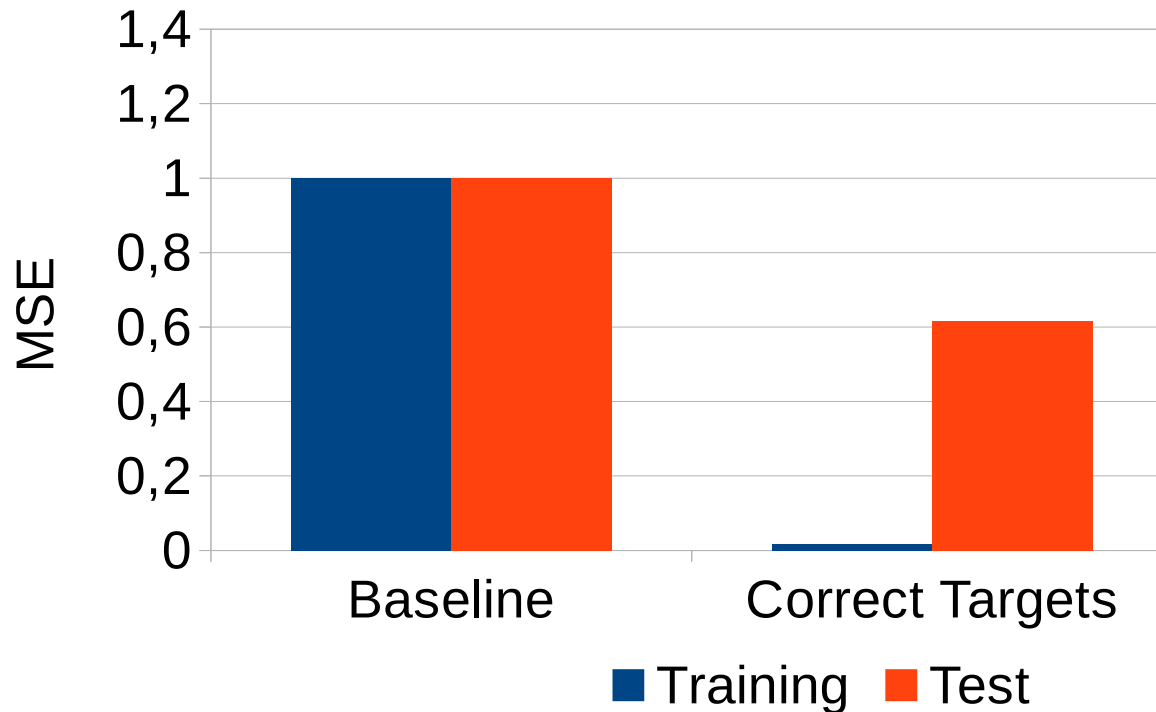


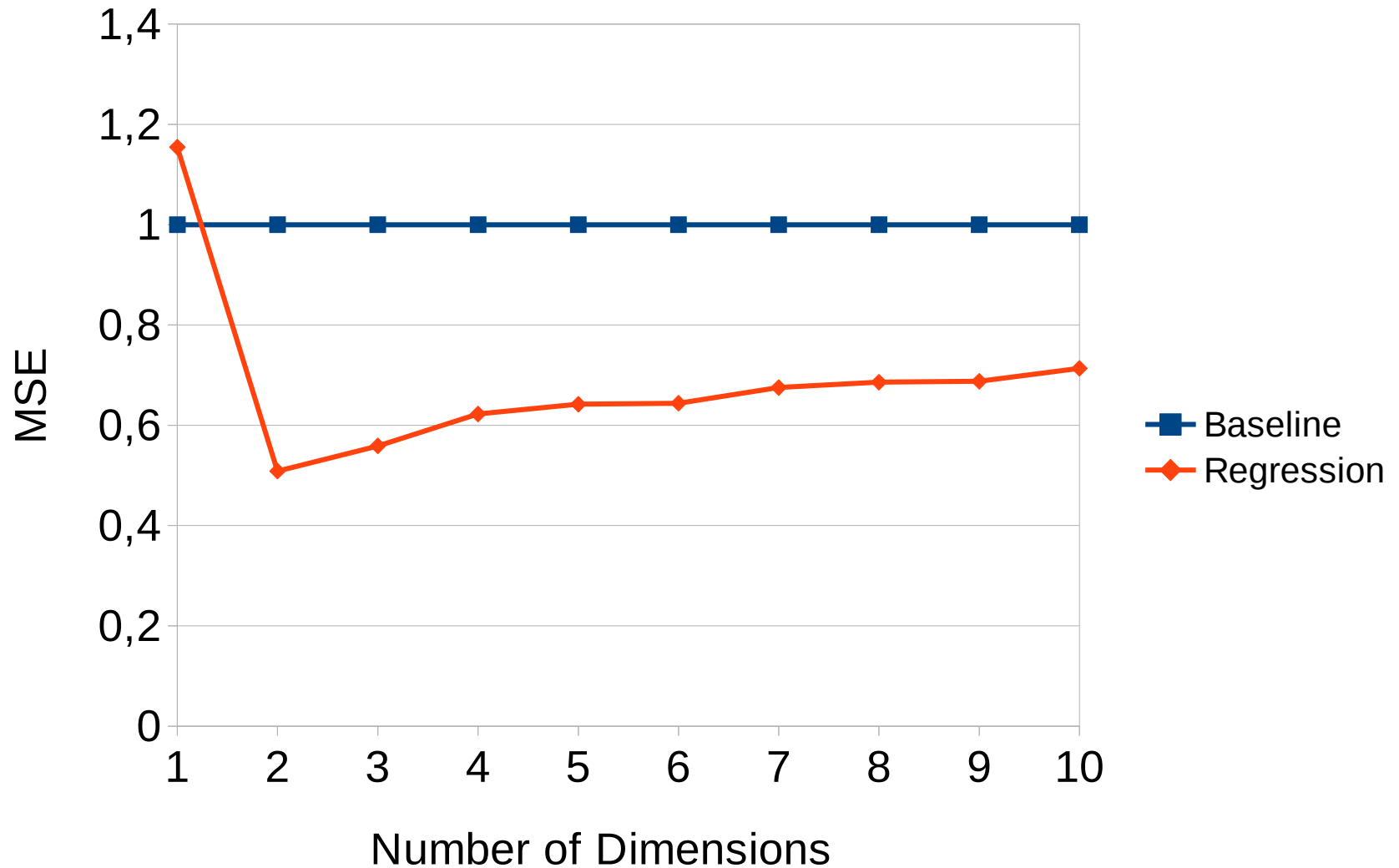


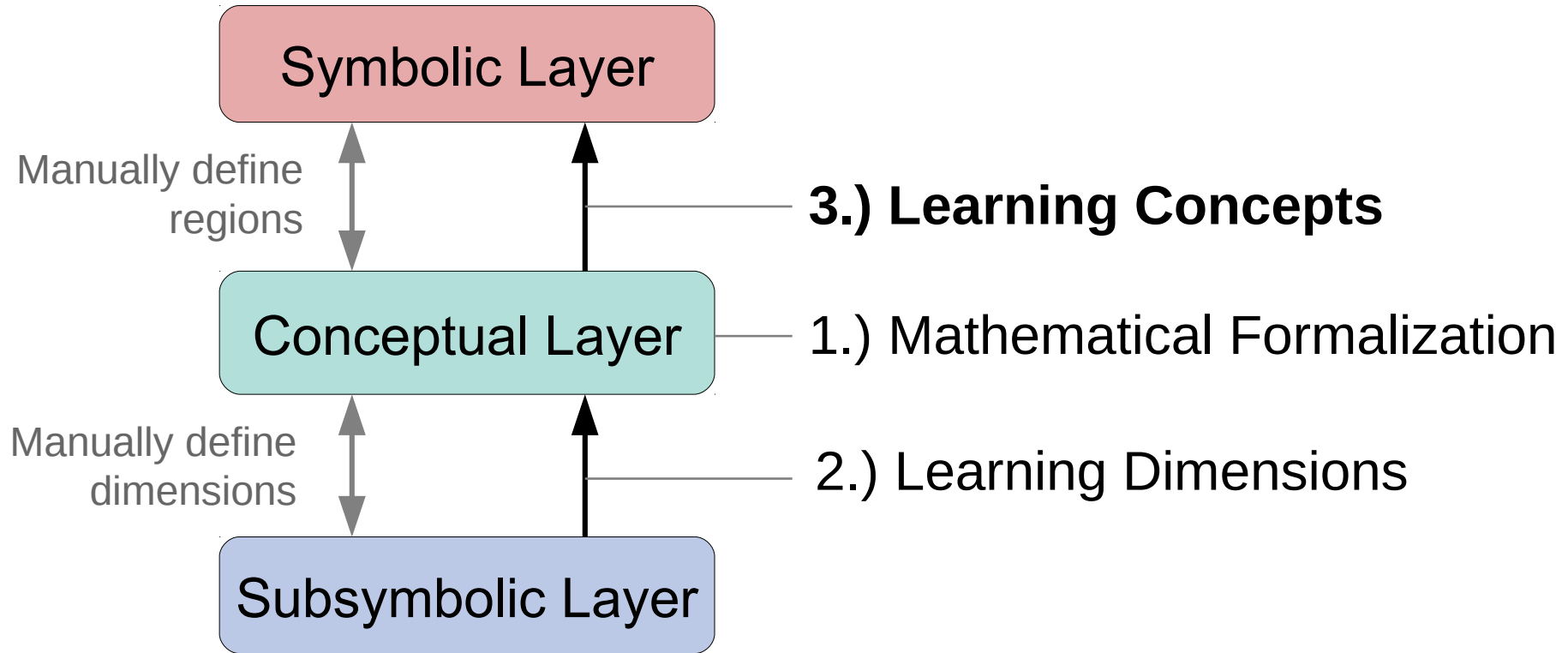
Szegedy, C.; Vanhoucke, V.; Ioffe, S.; Shlens, J. & Wojna, Z.
Rethinking the Inception Architecture for Computer Vision.
Proceedings of the IEEE Conference on Computer Vision and
Pattern Recognition, 2016, 2818-2826



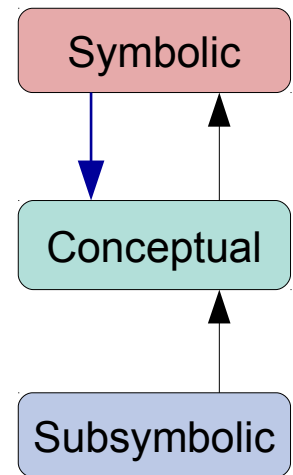
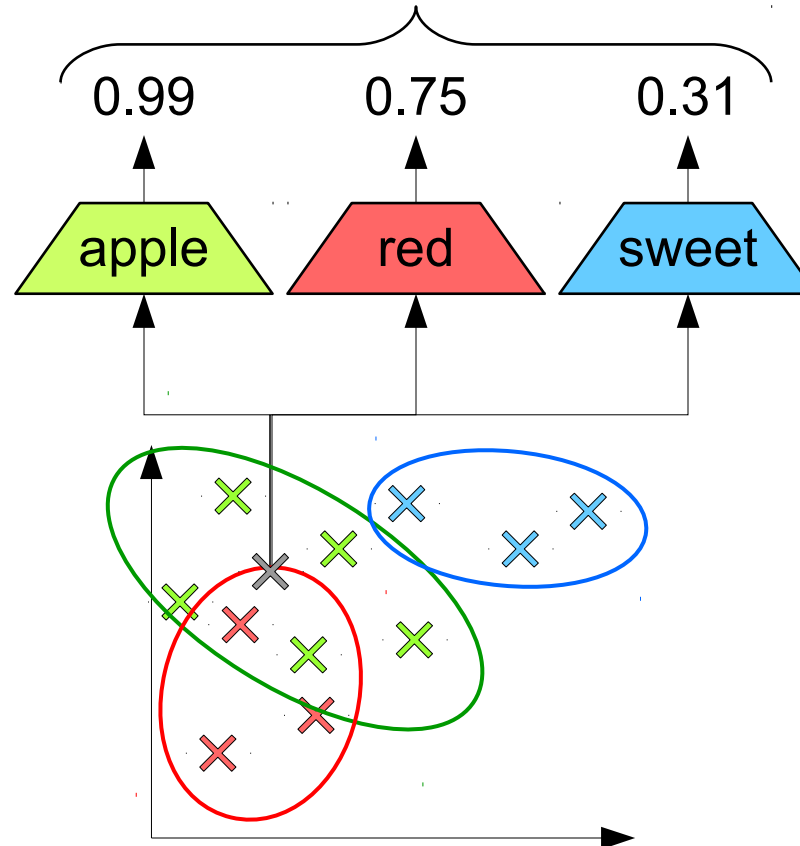
	(0.5, 0.7)
	(-0.2, 0.8)
	(0.1, -0.3)







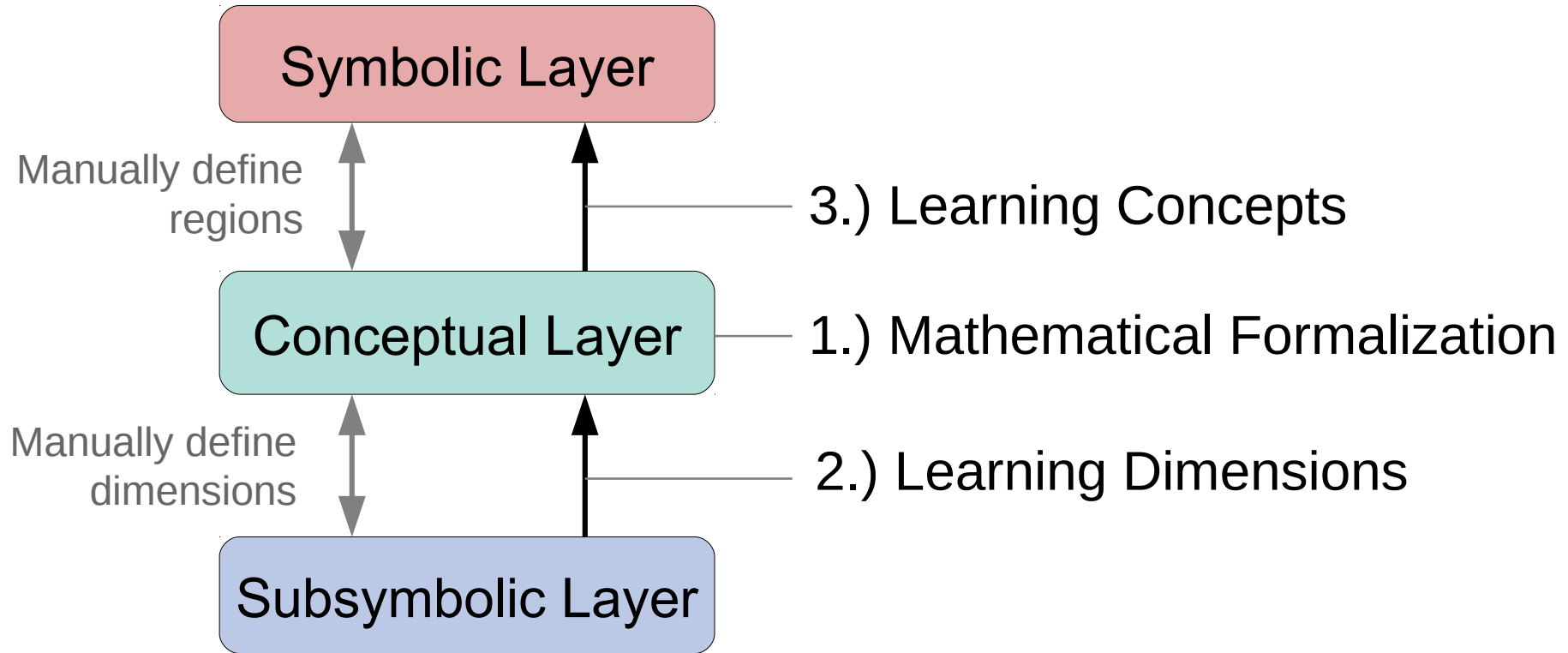
Apple AND red IMPLIES sweet: 0.31



Serafini, L. & d'Avila Garcez, A. Logic Tensor Networks: Deep Learning and Logical Reasoning from Data and Knowledge. NeSy 2016

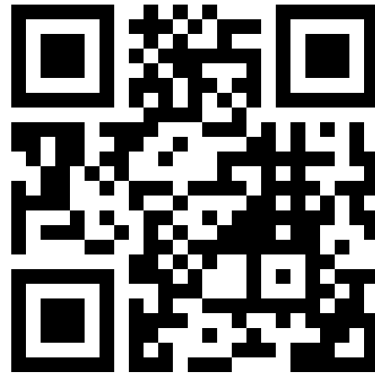
- Conceptual space of movies from Derrac and Schockaert
 - Extracted conceptual space from movie reviews
 - 15.000 data points
 - Multi-label problem: genres, plot keywords, age restriction
- Use LTN to learn concepts in that space
 - Extract rules with apriori algorithm
 - Vary size of training set and compare to other classifiers
- Long run: align LTN with conceptual spaces theory
 - Convexity, domain structure, ...

Joaquín Derrac and Steven Schockaert. Inducing semantic relations from conceptual spaces: a data-driven approach to commonsense reasoning, Artificial Intelligence, vol. 228, pages 66-94, 2015



Thank you for your attention!

Questions? Comments? Discussions?



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