UNIVERSITÄT OSNABRÜCK

# Machine Learning in Conceptual Spaces

Two Learning Processes

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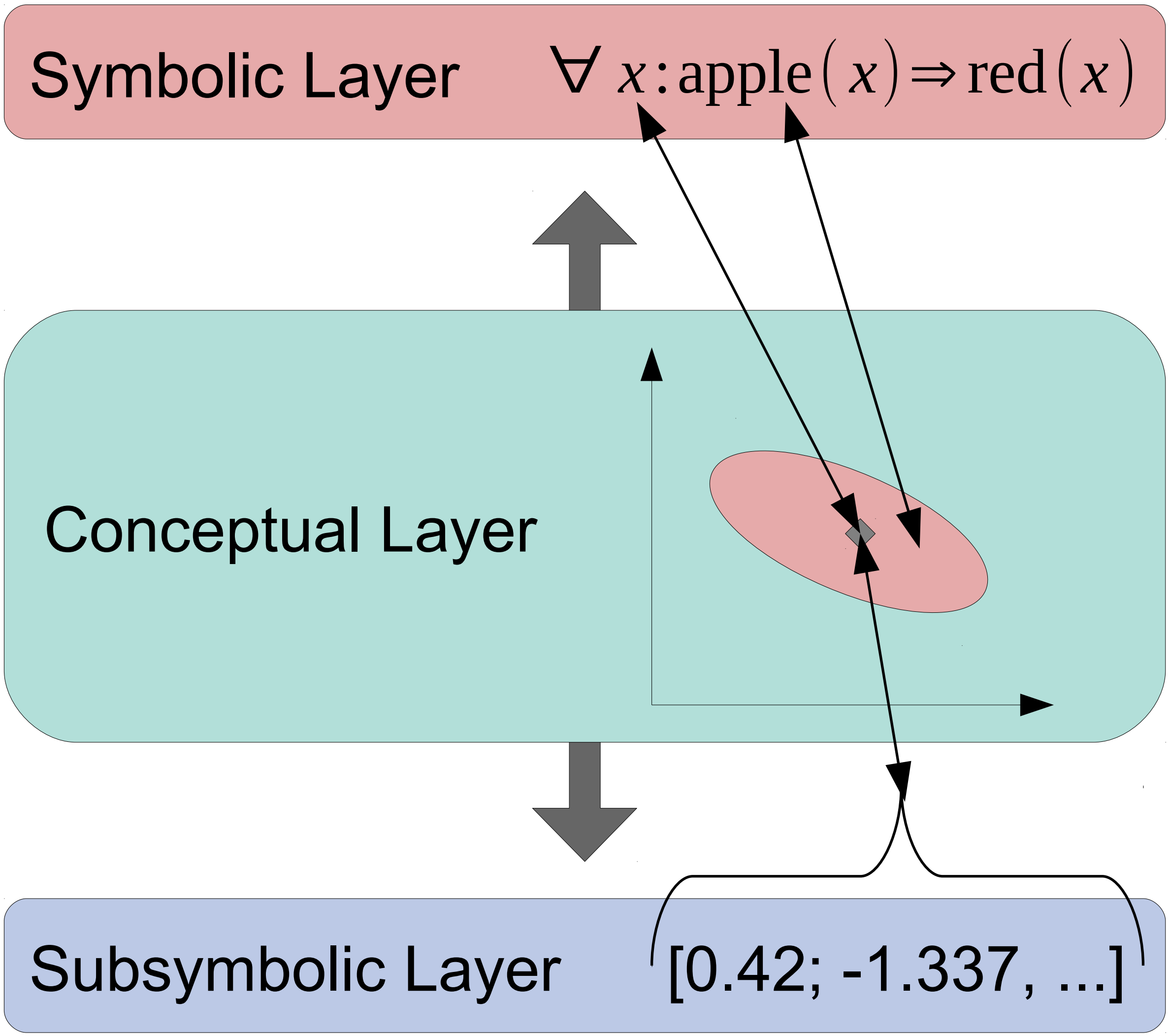
# Conceptual Spaces

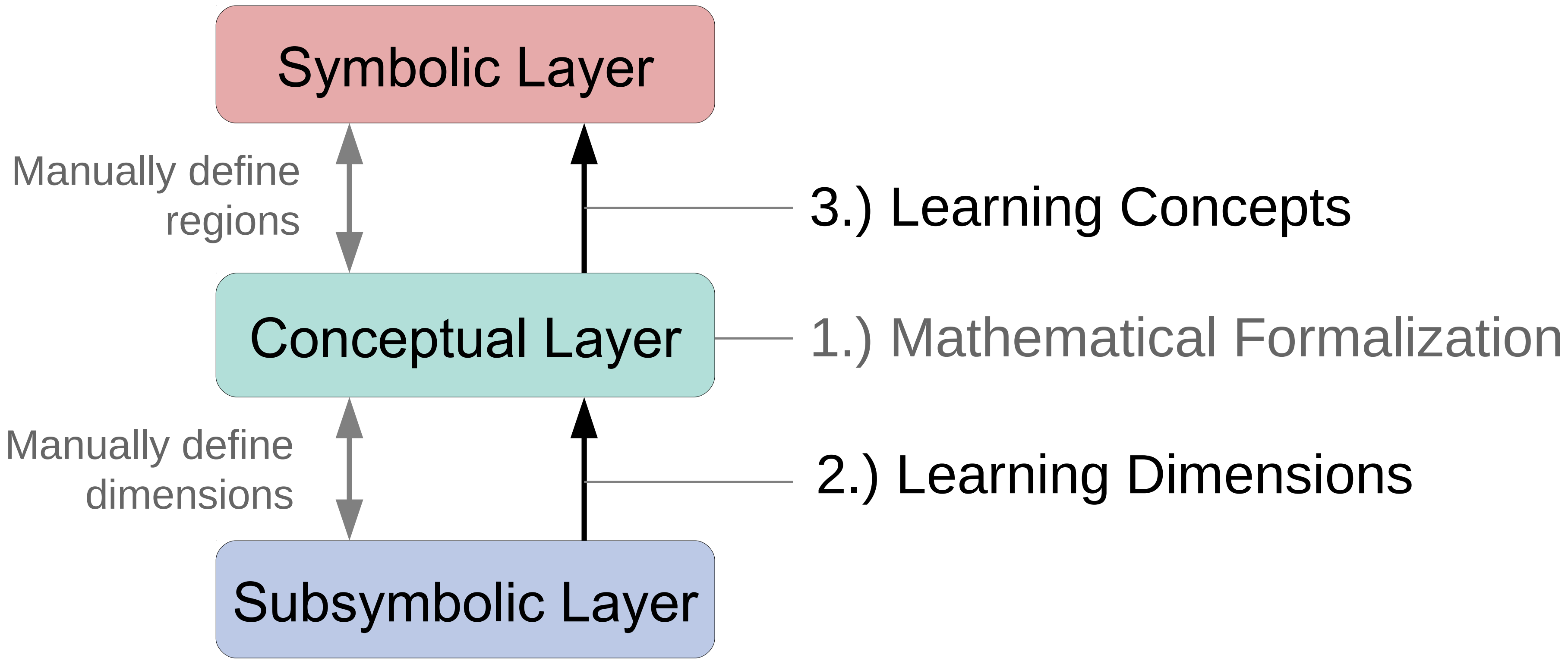



Formal Logics

Geometric Representation

Sensor Values, Machine Learning

# My PhD Project / Outline



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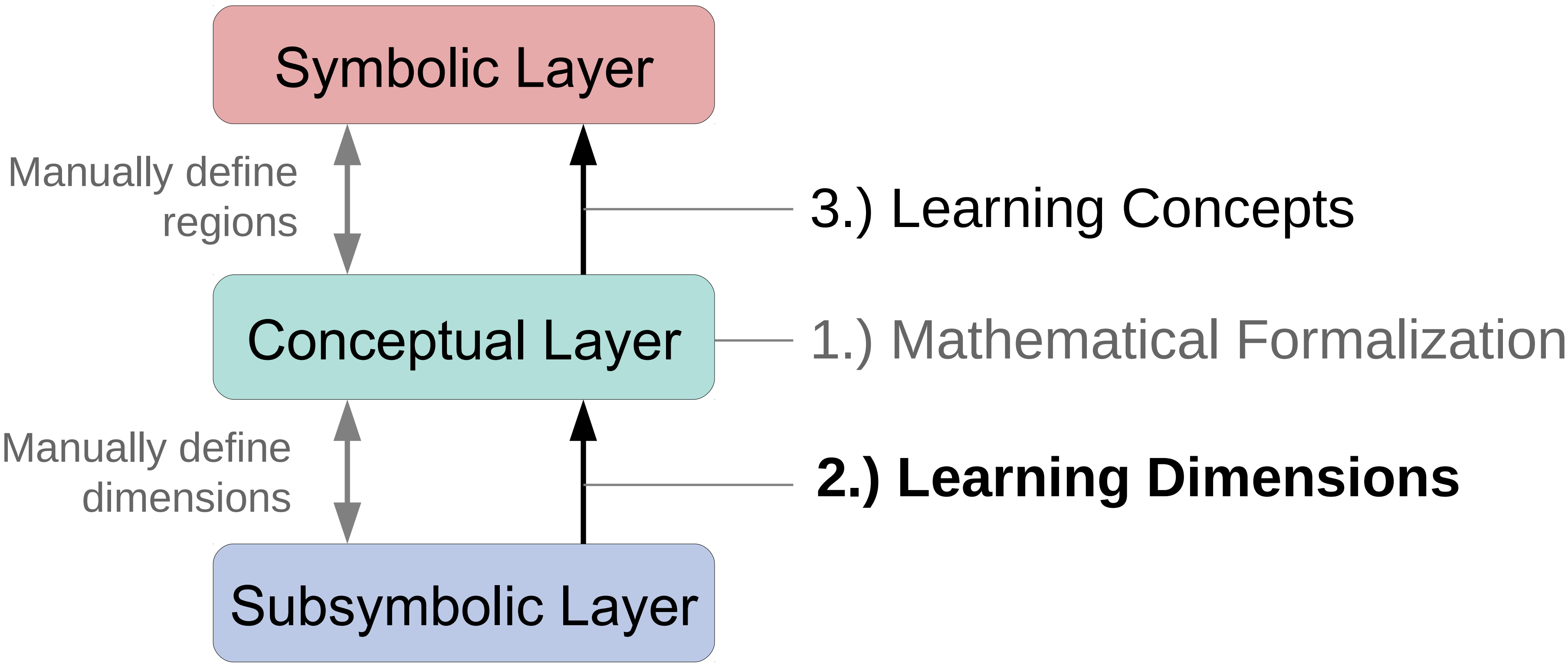

# Learning Dimensions

- There are (at least) three approaches:
  - Handcrafting
  - Multidimensional Scaling
  - Artificial Neural Networks

- Bonus: A Hybrid Approach

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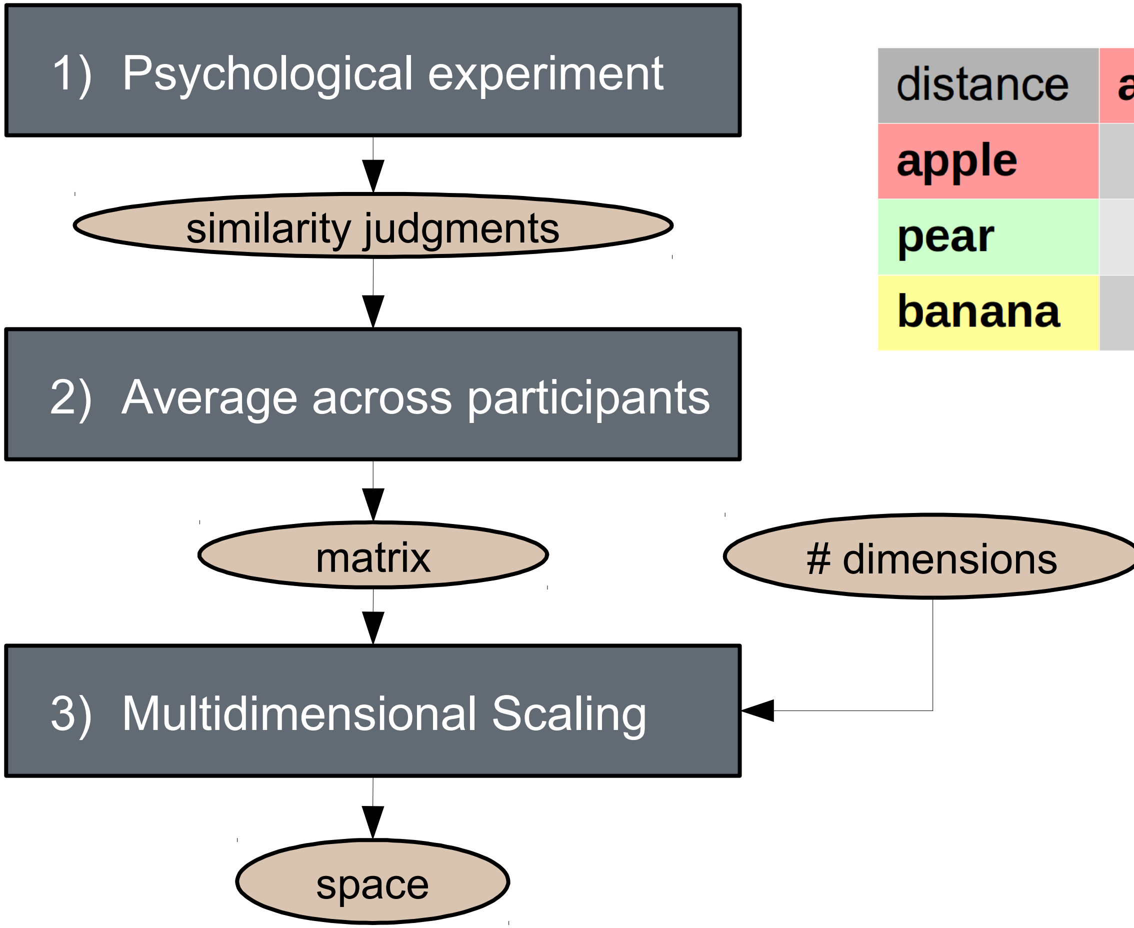
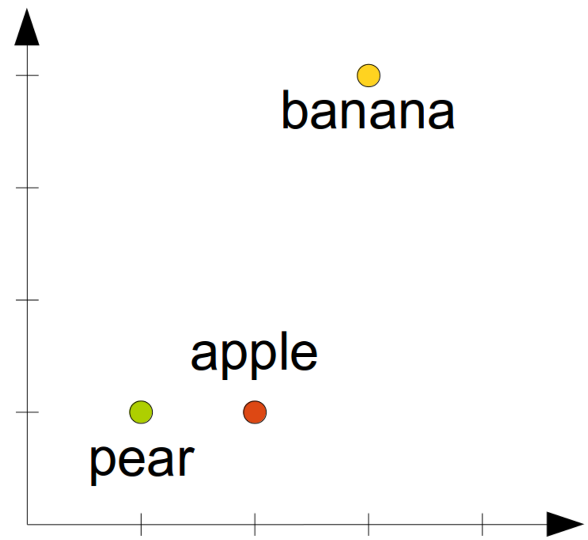
# Learning Dimensions: MDS




| 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* |




+ Psychological grounding

– Dealing with unseen inputs

# Learning Dimensions

- There are (at least) three approaches:
  - Handcrafting
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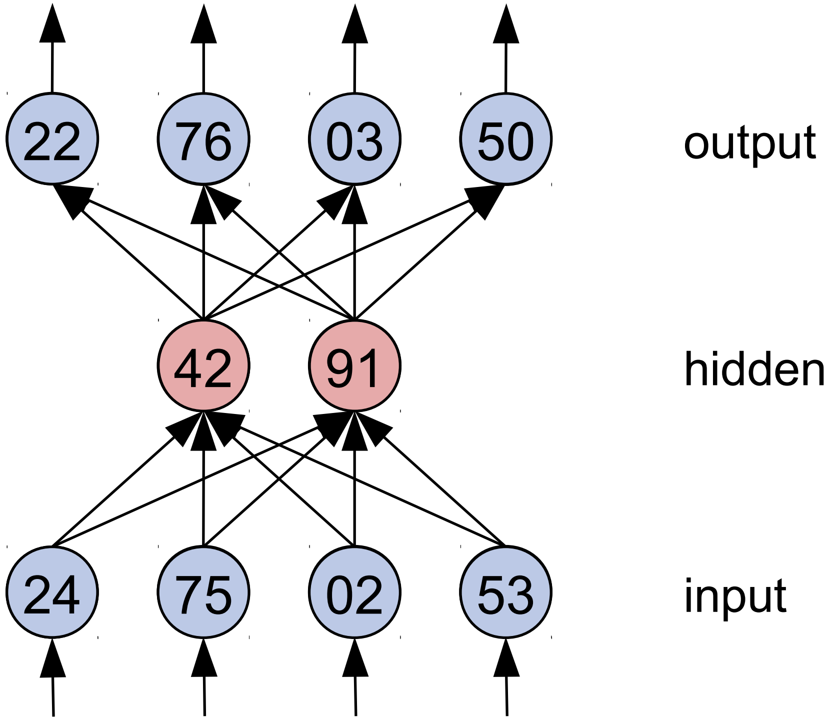
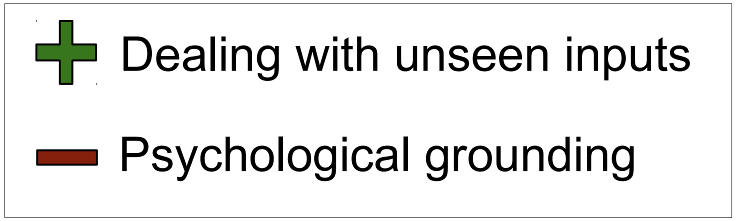
  - **Artificial Neural Networks**

- Bonus: A Hybrid Approach

# Learning Dimensions: ANNs

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



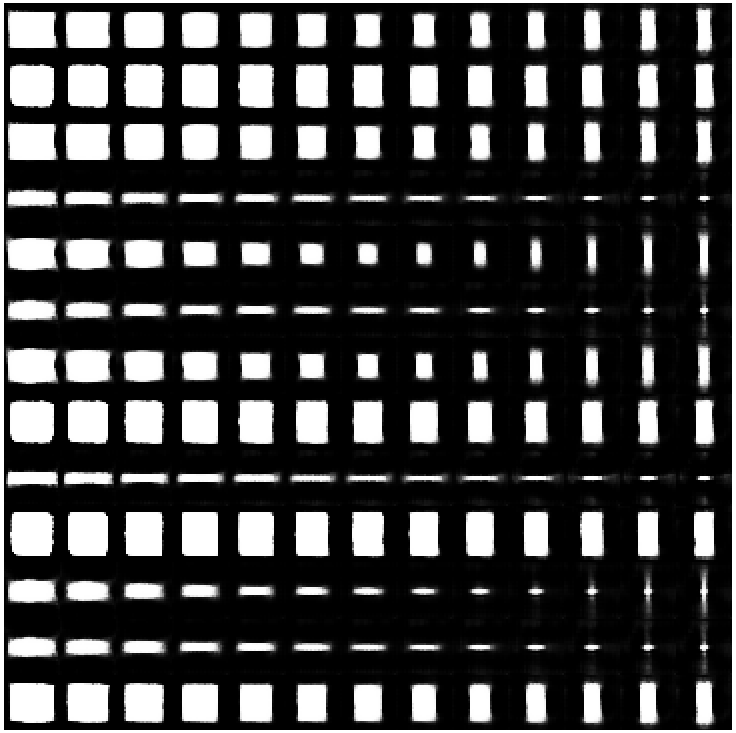
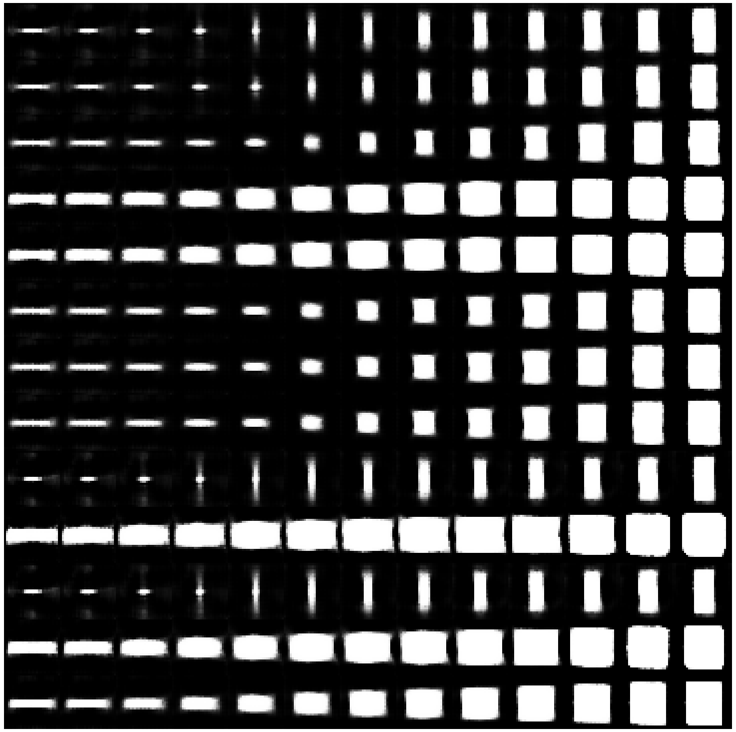




- Hidden neurons = dimensions in our conceptual space

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: ANNs

- Centered, unrotated rectangles
  - Differing only with respect to width and height
- Use InfoGAN to learn interpretable dimensions

Chen, X.; Duan, Y.; Houthooft, R.; Schulman, J.; Sutskever, I. & Abbeel, P. InfoGAN: Interpretable Representation Learning by Information Maximizing Generative Adversarial Nets Advances in Neural Information Processing Systems, 2016

# Learning Dimensions

- There are (at least) three approaches:
  - Handcrafting
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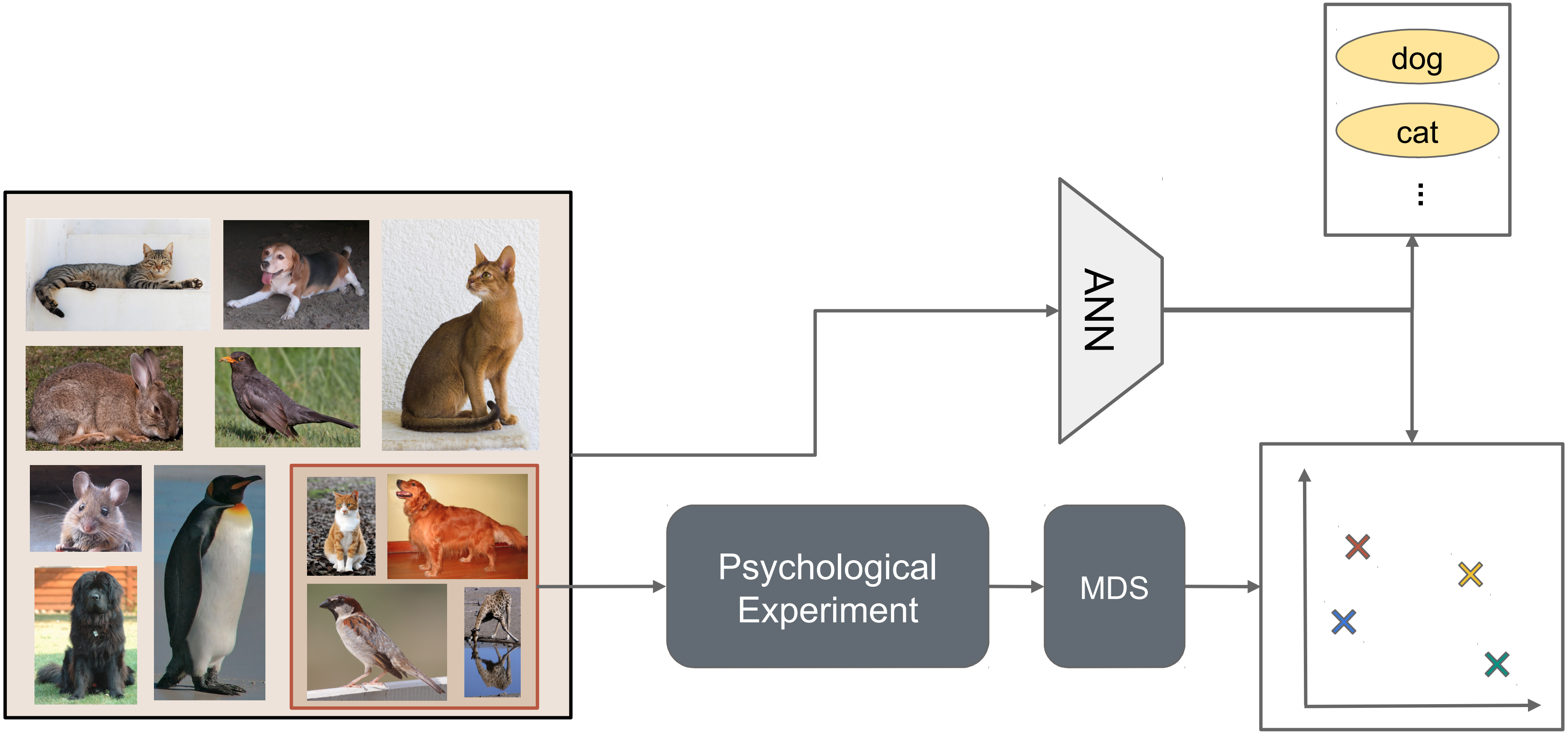
- **Bonus: A Hybrid Approach**

# Learning Dimensions: Hybrid




- ✚ Psychological grounding
- ✚ Dealing with unseen inputs

Bechberger, L. & Kypridemou, E. Mapping Images to Psychological Similarity Spaces Using Neural Networks. AIC 2018

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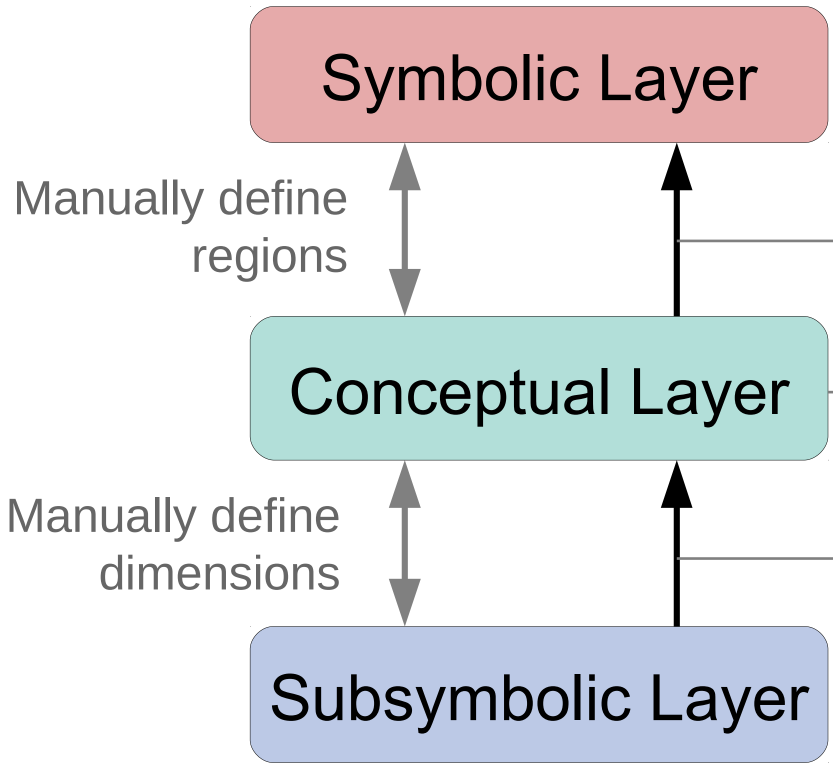



**3.) Learning Concepts**

1.) Mathematical Formalization

2.) Learning Dimensions

# Learning Concepts

Give me a big data set of labeled examples!

I'll train a neural network for a bunch of epochs to find a nice decision boundary.

It's just a standard ML problem!

That's too complicated for now.

Machine Learning Engineer

Wait a second, that's cognitively implausible!

In real life, we have more unlabeled than labeled examples.

Plus: Humans don't learn via batch processing.

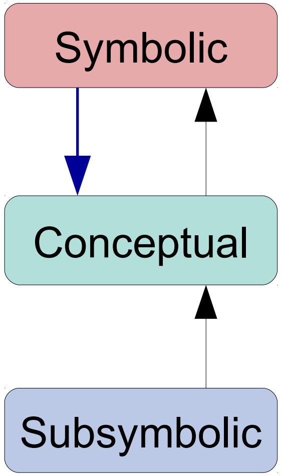
Cognitive Science Researcher

# Learning Concepts: LTN

- Fuzzy Logic
  - Degree of membership between 0 and 1

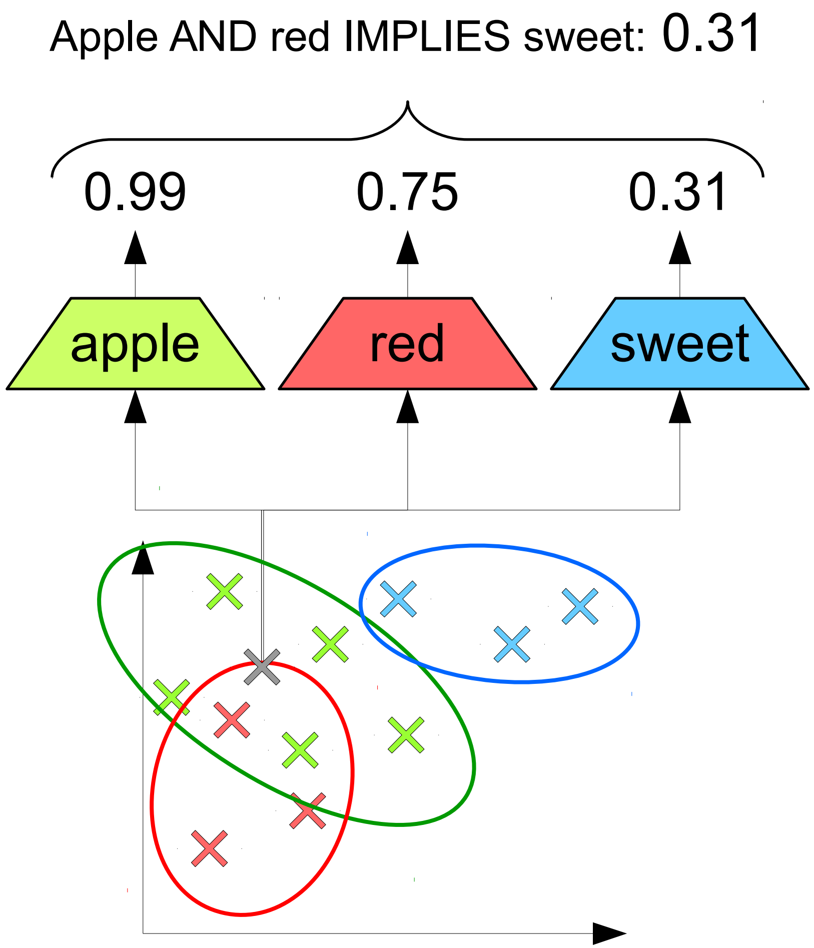
apple: 1.0
red: 0.9
round: 0.7
banana: 0.0

  - One can generalize logical operators:
    - apple AND red = min(apple, red)
  - We can express **rules** over these fuzzy sets



# Learning Concepts: LTN

- Use neural networks to learn membership functions
- Constraints:
  - Labels
  - Rules
- Tune NN weights such that all constraints are fulfilled



# Learning Concepts: LTN

- Conceptual space of movies from Derrac and Schockaert
  - Extracted conceptual space from movie reviews
  - 15.000 data points, labeled with one or more of 23 genres
- Use LTN to learn genres in that space
  - Compare to kNN with respect to classification performance
  - Compare to simple counting with respect to rule extraction
- 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

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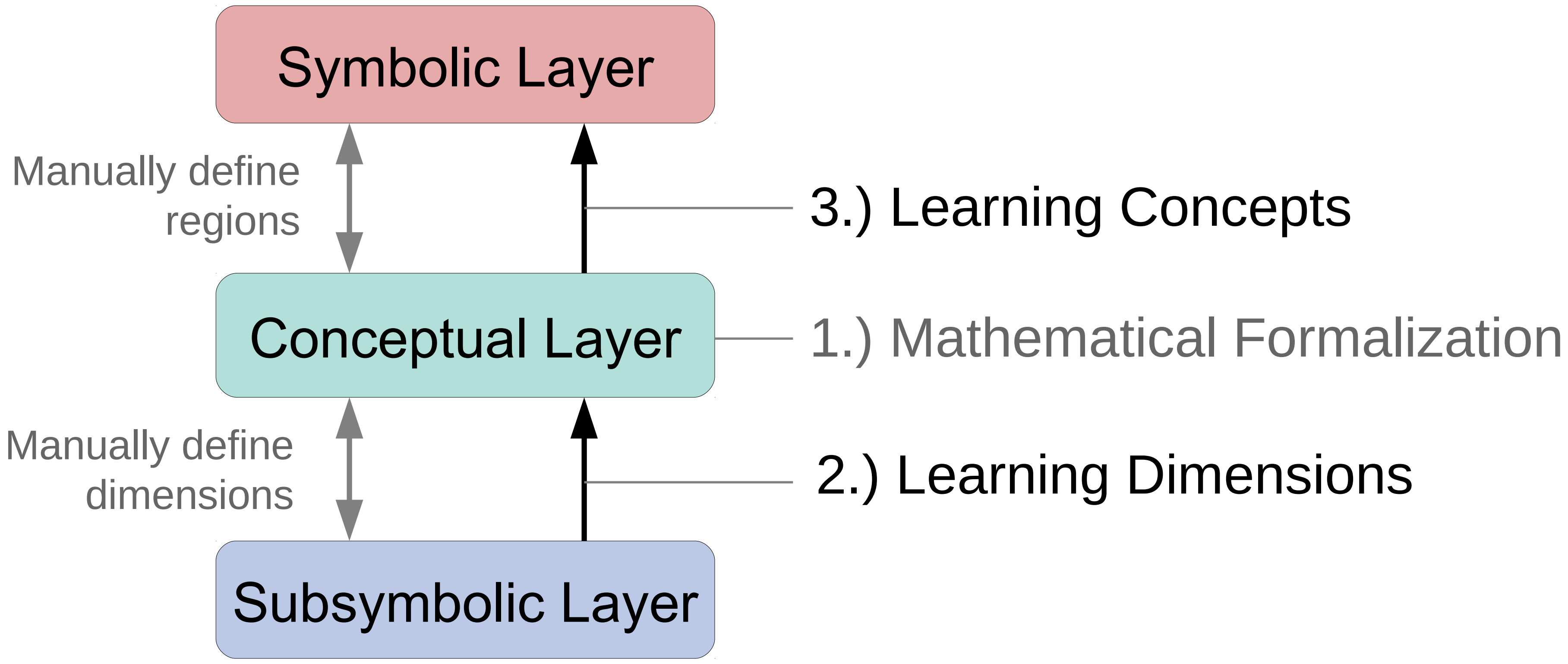

# Thank you for your attention!

Questions? Comments? Discussions?

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