MAX-PLANCK-GESELLSCHAFT

Structure learning and abstractions in motor control

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BIOLOGISCHE KYBERNETIK

Sensorimotor Learning and Decision-Making

- Independent research group: *Sensorimotor Learning and Decision-Making*, headed by **Daniel A. Braun**.
- Learning and adaptation of movements is a hallmark of intelligence, yet state-of-the-art artificial systems perform quite poorly on motor control problems. We study how the human motor system exploits the structure in its environment to enhance adaptation and to integrate information for action.
- Each movement can be regarded as a decision that is selected from a vast set of alternatives. We study neuro-economical principles that can explain human motor control and learning.
- Experiments are backed up by theoretical work on principles of adaptation and control that take into account bounded (computational) resources.

Bounded rationality

Any physical system is bounded in its information processing capacity which can lead to the emergence of seemingly suboptimal decisions in biological agents, because the optimal solution can not be computed or is too costly to compute. An optimality principle that takes into account bounded computational resources:

$$\underset{p(x|y)}{\operatorname{argmax}}\ \mathbf{E}_{p(x|y)}[U(x,y)] - \beta D_{\mathrm{KL}}(p(x|y)||p_0(x)).$$

Leads to a trade-off between expected gain and **cost of computation** to change initial behavior $p_0(x)$ to posterior policy $p(x|y)$.
Close connection to *Free energy minimization* in thermodynamics.

Experimental studies (psychophysics)

- How do humans select among learned structures? Do humans prefer the simpler option in case two models fit the data equally well? (Genewein and Braun, 2012, 2014)
- Structure learning in a reaching task with visuomotor shift. Is human behavior in line with Bayesian integration? (current work)
- Choice task with limited reaction time to force boundedness, modeling with the thermodynamic framework for decision making. Potential generalization of Hick's law? (current work)

Published work

Genewein, T. and Braun, D. A. (2012). A sensorimotor paradigm for bayesian model selection. *Frontiers in human neuroscience*, 6.

Genewein, T. and Braun, D. A. (2013). Abstraction in decision-makers with limited information processing capabilities. *NIPS 2013 Workshop on Planning with Information Constraints arXiv:1312.4353*.

Genewein, T. and Braun, D. A. (2014). Occam's razor in sensorimotor learning. *Proceedings of the Royal Society B: Biological Sciences*, 281(1783):20132952.

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Information theory and abstractions

Extension of the free energy model by averaging over observations and seeking for the *optimal* prior:

$$\underset{p(x|y),p_0(x)}{\operatorname{argmax}}\ \mathbf{E}_{p(x,y)}[U(x,y)] - \beta \sum_{x,y} p(x,y) \log \frac{p(x|y)}{p_0(x)},$$

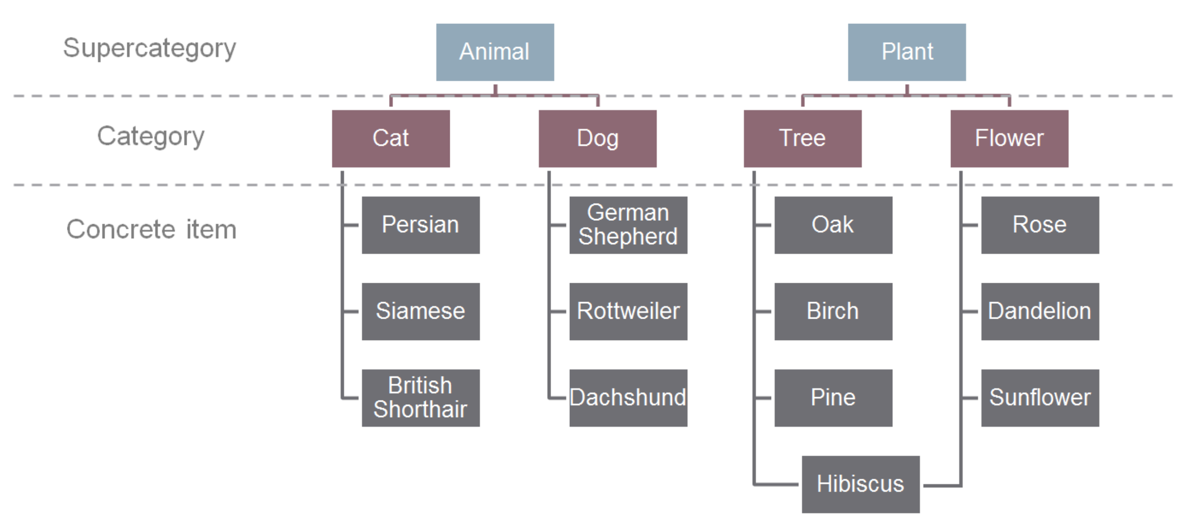
can be rewritten as a trade-off between expected gain and average cost of computation:

$$\underset{p(x|y)}{\operatorname{argmax}}\ \mathbf{E}_{p(x,y)}[U(x,y)] - \beta I(x;y)$$

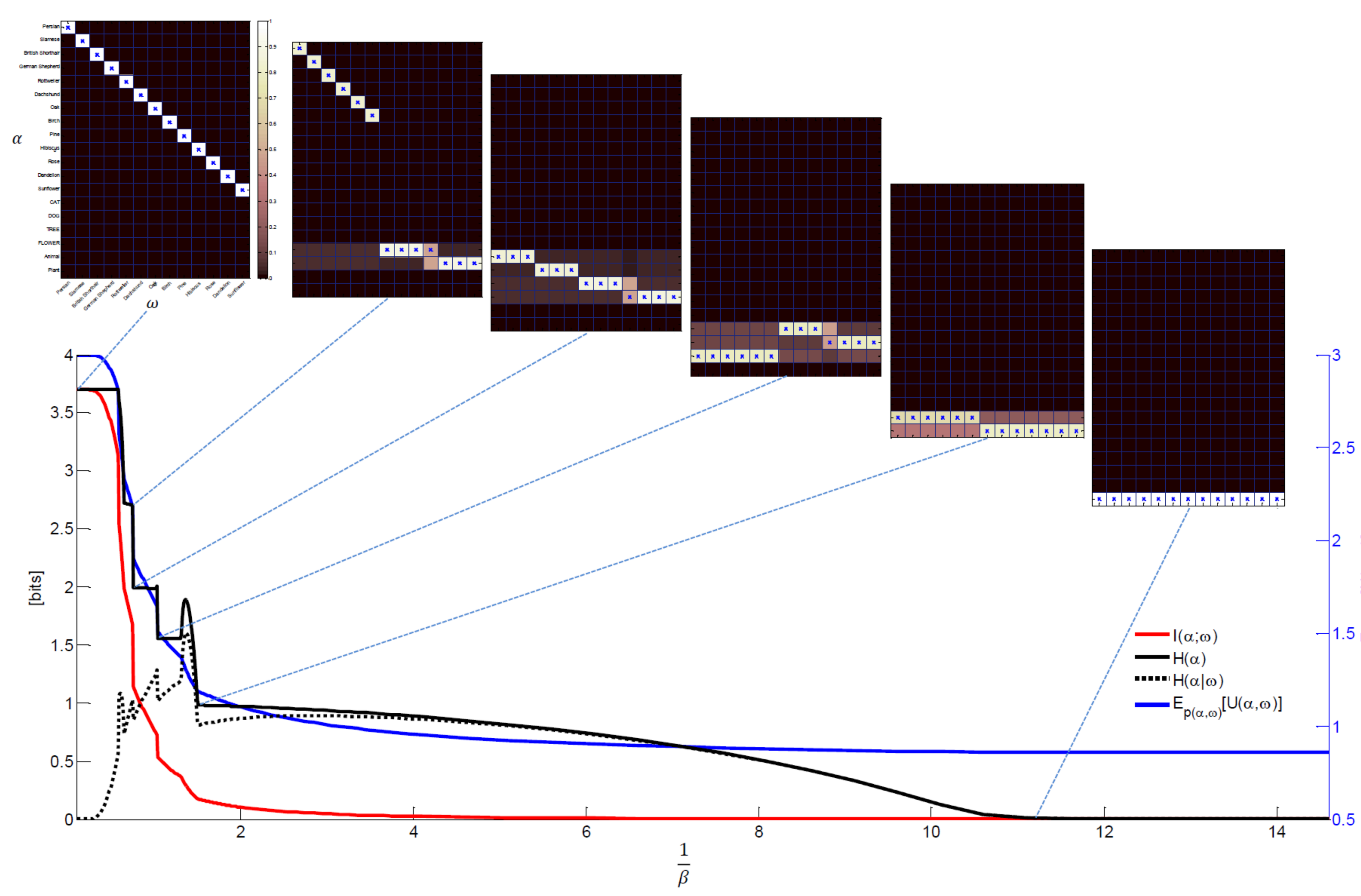
Same form as the **rate distortion** problem. Both, in lossy compression and when forming abstractions the fundamental problem is the separation of structure and noise ((Genewein and Braun, 2013)).
β governs the boundedness and thus the granularity of the abstraction.
Current work: Extension to model hierarchies of abstraction.

Simulation

Simple taxonomy with three levels of abstraction.



Observation $\omega \in \{\text{concrete items}\}$.
Action $\alpha \in \{\text{concrete items, categories, supercategories}\}$.
Utility $U(\alpha,\omega)$: \$3 if item correct, \$2.2 if category correct, \$1.6 if supercategory correct.
Goal: design an agent with limited information processing capabilities that achieves maximum utility given its computational constraints.



Qualitatively, there are only a hand full of different levels of representation with phase-transitions in between. The solutions above are theoretical upper bounds, given the particular constraints on the mutual information - no system can operate beyond these limits.