# Slowness in Hierarchical Networks for Visual Processing

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## Abstract

Primates are very good at recognizing objects and at the same time assessing their viewing angle and relative position. In such tasks they outperform existing computer vision systems. We present a model for the unsupervised learning of object identities and codes for position and viewing angle. The model is based on a hierarchy of Slow Feature Analysis (SFA) modules. Based on this we have also build a biologically plausible model that uses reinforcement learning on complex visual stimuli to direct an agent towards a target.

## Hierarchical Visual Model

### Slow Feature Analysis (SFA)

Behaviorally relevant features of our environment generally change on a much slower timescale than the raw visual data. This inspired the slowness learning principle which has been turned into a well defined optimization problem [2] (fig 1.a):
Given a function space $\mathcal{F}$ and a multi-dimensional input signal $\mathbf{x}(t)$ find a set of instantaneous functions $g_j(\mathbf{x}) \in \mathcal{F}$ such that the output signals $y_j(t) := g_j(\mathbf{x}(t))$

$$\text{minimize } \Delta(y_j) := \langle \dot{y}_j^2 \rangle_t$$

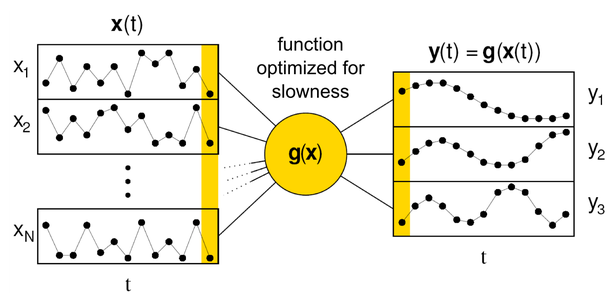
under the constraints

$$\begin{aligned} \langle y_j \rangle_t &= 0 \quad \text{(zero mean)}, \\ \langle y_j^2 \rangle_t &= 1 \quad \text{(unit variance)}, \\ \forall i < j : \langle y_i y_j \rangle_t &= 0 \quad \text{(decorrelation and order)}. \end{aligned}$$

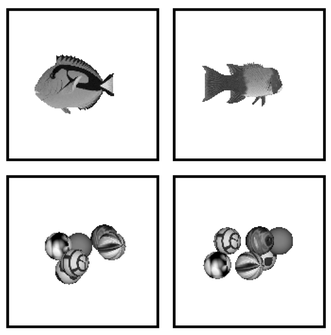
### Invariant Object Recognition

We train a hierarchical feed-forward model for invariant object recognition [1] (fig 1.c). Each network layer is based on the SFA algorithm.

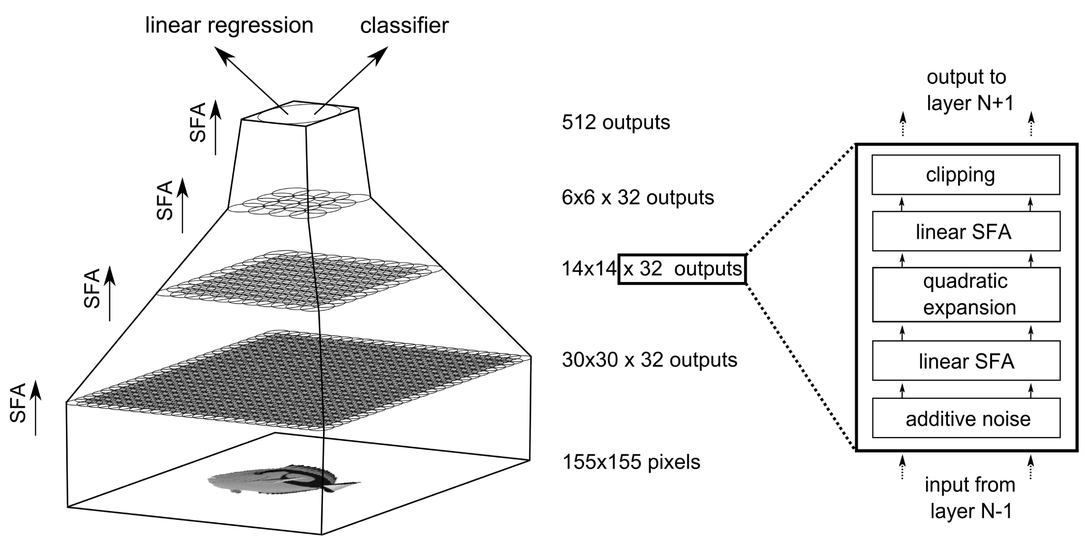
**1.a** Slow Feature Analysis




**1.b** Model Input Examples



**1.c** Architecture of the Hierarchical Model based on SFA




Most of the model software is now part of the “Modular Toolkit for Data Processing” (MDP) open source project [3].

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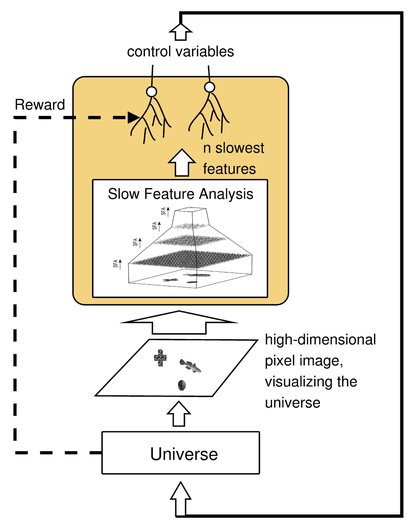
This model is able to extract both the identity and pose of 3D-objects from rendered images. We used detailed 3D-models of different fish with translation, in-depth rotation and scale transformations (fig 1.b). The model achieved a classification hit-rate of 96% for 25 different fish, of which only 15 were shown during training. Continuous parameters like position and angle were simultaneously extracted with good precision as well (e.g. with a standard deviation of 17° for the angle).

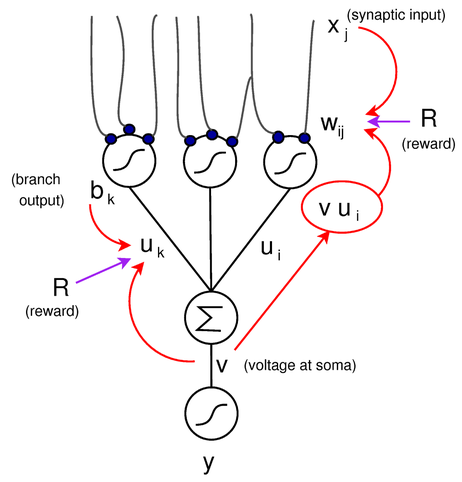
## Combination with Reinforcement Learning

The already trained hierarchical network is combined with a reinforcement learning stage to form a system that can control an agent based on raw visual input (fig 2.a). There are two control variables, one to control the speed of the agent and one for its angular velocity. The reward signal is given by the change of the distance to the target, which is the only supervision signal in the whole model.

**2.a** Simulation Setup

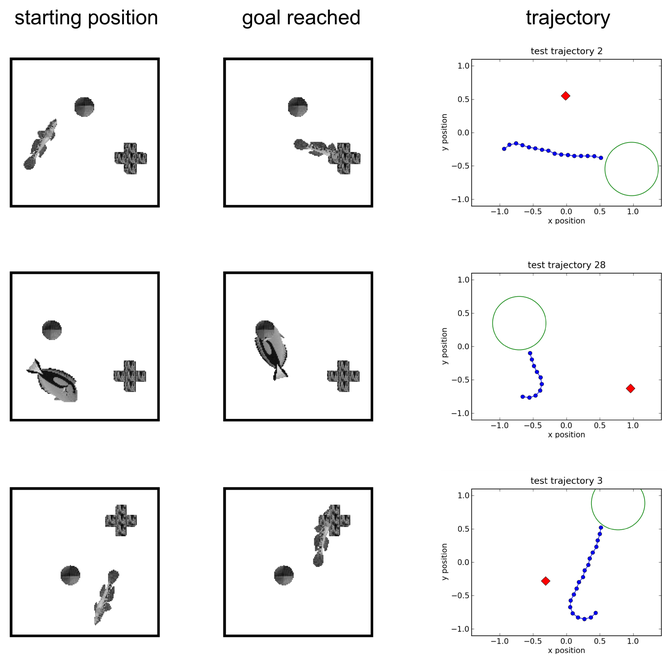



**2.b** Learning Model




The values of the two control variables are directly given by the outputs of two neural networks (fig 2.b) which receive as input the state representation from the hierarchical network. These control outputs are then used to update the scene, so the whole model runs in closed loop. The parameters $w_{ij}$ and $u_k$ of the networks are adapted in the direction of the gradient of the reward signal $R$ (a policy gradient method).

**3.a** Trajectories after training




**3.b** Rewards during training


[1] M. Franzius, N. Wilbert, and L. Wiskott. Invariant Object Recognition with Slow Feature Analysis. In *Proceedings of the 18th international conference on Artificial Neural Networks, Part I*, pages 961–970. Springer, 2008.

[2] L. Wiskott and T. Sejnowski. Slow feature analysis: Unsupervised learning of invariances. *Neural Computation*, 14(4):715–770, 2002.

[3] T. Zito, N. Wilbert, L. Wiskott, and P. Berkes. Modular toolkit for data processing (mdp): a python data processing framework. *Front. Neuroinform.*, 2:8, 2008.