Distributed model for sensorimotor control: anticipatory coordination and lateral competition

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Distributed Model for Sensorimotor Control

Anticipatory Coordination & Lateral Competition

Introduction & Framework

We propose a two layer **modular infrastructure** and evaluate various **distributed algorithms** for competition and spatiotemporal coordination in order to control artificial sensorimotor systems. Both layers are **topologically organized**, providing to the system generalization and interpolation capabilities. Since the proposed models are massively distributed, software and hardware optimization techniques are presented to allow **real-time interactions**.
The (upper) **coordination layer** is composed of anticipatory spatiotemporal representations that, once acquired through interaction, determine goal-oriented actions through local coordination and remove ambiguities from the noisy sensorimotor flow. The resulting future-oriented activity is projected on the (lower) **competition layer**, that unifies bottom-up and top-down signals. This layer not only produces an interpretation of the sensory flow but also dynamically selects the most adequate actions by merging activity from past knowledge and immediate context.

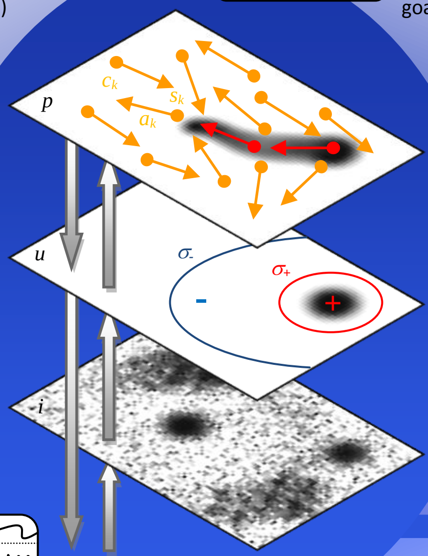
Learning of Anticipations

s_k	c_k	a_k
1	1	+1
1	0	-1
0	?	0

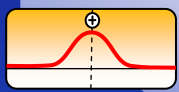
In the coordination layer, predictions can be learned locally and independently of the current goals of the agent:
- **Imitation** of the observed and unexpected dynamics
- **Statistical rules** (LWR, or bio-plausible rules like STDP, BCM)
- **Variation/selection** mechanisms (constructivist approach)

The learning rule must account for:
- **Feature selection** (spaces might be high dimensional)
- **Redundancy** (context-specific/general predictions)
- **Delays** (complex dynamics of the other structures)

The anticipations activity can be modulated by a normative confidence level, which can also be used to select useful predictions (see table).

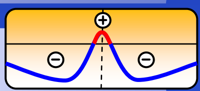


Coordination & Planning



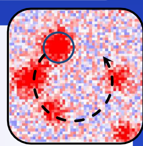
Local anticipations can coordinate by **back-propagating** their activity (distance based on common dimensions). **Chains of predictions** can then be formed to link distant goals to the current situation.
Interpolation between anticipations also occurs as all their activities are projected to the lower layer.
Activity spreads from local sensations to large scale potentialities about future interactions.

Competition



Through lateral **large scale inhibition and local excitation**, bottom-up stimuli and top-down predictions (expected sensations and proposed actions) can dynamically compete. They are merged into a single **perception and decision** (actions to perform). The **CNFT model** is adapted to sparse high dimensional inputs.

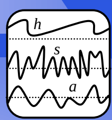
Robustness



The input flow is ambiguous:
- **Distracters, noise, occlusions**

A stable interpretation of the sensorimotor flow is however needed to interact in a coherent manner, and made possible by:
- **Generalization** capability of the topology
- **Attentional properties** of the competition layer (temporal integration of new stimuli)
- Top-down **projections of expectations** (matched against the stimuli)

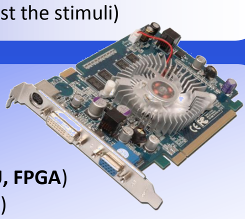
Evolution & Development



Embodied approach even for artificial agents (focus on the coupling):
- **Bootstrap and constrain** the exploration/exploitation (reflexes)
- **Scaffolding** through the body/environment (constraints from others)
- Provide **implicit goals** to the agent (slow and stable body dynamics)

Evolutionary approach to tune the parameters (propagation, lateral connectivity schemes) in order to **guarantee the agent viability**.

Optimization



Hardware implementations:
- Symmetric & low complexity on parallel devices (**GPU, FPGA**)
- Asymmetric computations (**DSP, Cell-BE, cluster, grid**)

Algorithmic optimization (to reduce the complexity or number of components):
- **Matrix based** optimization (truncated SVD, FFT, sparse matrices)
- **Gaussian mixture** models (function/field approximation, high dimensional CNFT)
- **Tree structures** (kd-trees extended to sparse spaces and sensorimotor systems)

Layers Comparison & Complementarity

Common characteristics
distributed
continuous update
population coding
lateral connectivity
input/output projections

Coordination layer	Competition layer
flexibility	robustness
dynamic propagation	differential equation
asymmetry (predictions)	symmetry (kernel)
future-oriented activity	reduced temporal window
local → global	global → local
spread out (trajectory)	localized activity (focus)
excitatory connections	inhibitory connections
planning/navigation	action selection/decision
memory/learning	perception

Inspirations & Interpretations

Piagetian & **interactivist framework** (anticipation, normativity)
Dynamic neural fields (CNFT, place/goal cells, cortex organization)
Artificial intelligence (D* optimal planning, anticipatory inferences)
Markov processes (FPDPOMDP), Classifiers (XCS with interpolation)
Function approximation (LWPR), Bayesian framework (fields as probability distributions, anticipation as prior)

Limitations & Perspectives

Conceptual complexity (**sparse spaces**), computational complexity (**parallelism**), abstraction (HTM like construction of **hierarchies**)

CORTEX PROJECT

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