

# 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

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)

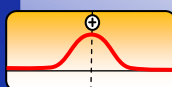
The learning rule must account for:

- **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).

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

### Coordination & Planning

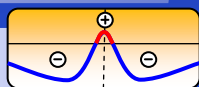


Local anticipations can coordinate by **back-propagating** their activity (distance based on common dimensions). **Chains of predictions** can then be formed to link distant goals to the current situation.

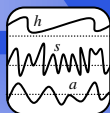
**Interpolation between anticipations** also occurs as all their activities are projected to the lower layer.

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.



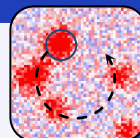
### Evolution & Development

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**.

### Robustness



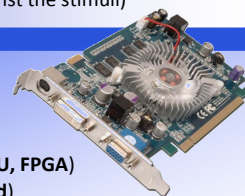
The input flow is ambiguous:

- **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)

### 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	Coordination layer	Competition layer
distributed	flexibility	robustness
continuous update	dynamic propagation	differential equation
population coding	asymmetry (predictions)	symmetry (kernel)
lateral connectivity	future-oriented activity	reduced temporal window
input/output projections	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**)



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