Ontogeny of Mappings for Invariant Recognition

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The Invariance Problem

Schematic illustration of the invariance problem
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Note
- blue and black Ys appear similar
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Schematic illustration of the invariance problem

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- blue and black Ys appear similar
- but they are orthogonal!
- → recognition must be based on a different representation
Correspondence-based recognition

Visualization of a normalizing transformation

Memory (IT)

Input (V1)
Correspondence-based recognition

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- active unit transforms the input in the normalized window
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- topogographic memories proved to be a viable basis for face recognition \([Wiskott96, Wolfrum2008]\)
Correspondence-based recognition

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- → similar to retinotopy
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Correspondence-based selection of control, e.g. [Wolfrum2008]:

$$k^* = \arg \max_k \left( \sum_o \sum_i w_{koi} O_o l_i \right)$$
Bilinear Models

Bilinear Model

\[ O_o = \sum_k \sum_i w_{koi} c_k I_i \]

- information is actively routed \( \rightarrow \) transformations are explicitly accessible \([Grimes2005, Olshausen2007]\)
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→ Prenatal organization of object-independent transformations is advantageous
Modulation Hypothesis

A tripartite synapse

Implementation of Modulation

- astrocytes modulate synaptic transmission [Haydon2001]
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Implementation of Modulation

- astrocytes modulate synaptic transmission \[Haydon2001\]
- specific locust neurons perform a multiplication \[Gabbiani2002\]
the retino-cortical pathway is organized prenatally

Figure: Retina-Cortex Wiring
[Hubel88]
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mapping: topology of the retina is preserved in primary visual cortex

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two classes of proposed mechanisms:
1. chemoaffinity based [Sperry63]
2. activity based [Willshaw76]
the retina-cortical pathway is organized prenatally
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two classes of proposed mechanisms:
1. chemoaffinity based [Sperry63]
2. activity based [Willshaw76]
evidence for both! [Huberman2008]
Review of a Map Formation Mechanism

Weight Interaction Matrix

Emerging Weight Matrix

- Competition enforces 1-1 mapping
Review of a Map Formation Mechanism

Weight Interaction Matrix

- Competition enforces 1-1 mapping
- Cooperation encourages neighbors
Review of a Map Formation Mechanism

### Weight Interaction Matrix

\[ \dot{w}_{oi} = \alpha + F_{oi} w_{oi} - w_{oi} B_{oi}(\alpha + FW) \]

\[ B_{oi}(X) = \left( \sum_{o'} x_{o'i} + \sum_{i'} x_{oi'} \right) / 2N \]

- Competition enforces 1-1 mapping
- Cooperation encourages neighbors
Multimap Formation

Necessary ingredients for multimap formation

1. Competition within a map
2. Cooperation in the proximity of each point within the map
Necessary ingredients for multimap formation

1. Competition within a map
2. Cooperation in the proximity of each point within the map
3. Competition between several maps
The effect of prenatal waves on correspondence finding

Retinal waves [Feller96]

Unstructured Memories

- assume unstructured memories:

\[ O_o = \text{const. } \forall o \]
The effect of prenatal waves on correspondence finding

**Retinal waves** [Feller96]

Unstructured Memories

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- then

\[ c_k = \sum_{o,i} w_{koi} l_i O_o \propto \sum_{o,i} w_{koi} l_i \]
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- together with WTA mechanism → input-based competition
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    \[ c_k = \sum_{o,i} w_{koi} I_i O_o \propto \sum_{o,i} w_{koi} I_i \]
  - together with WTA mechanism → input-based competition
  - size variance [Warland2006] of retinal wave active regions imposes various transformation parameters
The model

Algorithmic Description

- generate input at a random position
- determine best fitting control unit $k = \arg \max_{k'} \left( \sum_{o,i} w_{k'oi} l_i \right)$
- change weight matrix:

$$\dot{w}_{koi} = \alpha + F_{oi}w_{koi} - w_{koi}B_{oi}(\alpha + FW_k)$$

$$B_{oi}(X) = \left( \sum_{\tau'} x_{o'i'} + \sum_{i'} x_{oi'} \right) / 2N$$

- where the input cooperation matrix is modulated by the input activity:

$$F = C^0 W(C^I \ast I)^2$$
Wave-driven Model

Inputs

Initial Conditions
Wave-driven Model

Inputs

$t = 150$
Wave-driven Model

**Inputs**

![Graphs of input functions at different times](image)

**Output at t = 24000**

![Graphs of output functions at time t = 24000](image)
Quantification of the Results

**Definitions**

- Input-Control Specificity is the (highest) winning probability a control unit has given an input:

$$\left\langle \max_c p_{\text{win}}(c|\text{input}) \right\rangle_{\{\text{input}\}}$$
Quantification of the Results

**Definitions**

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  \[
  \langle \max_c p_{\text{win}}(c|\text{input}) \rangle_{\{\text{input}\}}
  \]

- Synaptic Standard Deviation is the width from which an output gets input:

  \[
  \text{ssd} = \langle w_{koi} \left( r_i - \sum_{i'} w_{koi'} r_{i'} \right)^2 \rangle_{\{k,o,i\}}
  \]
Quantification of the Results

**Specificity**

![Specificity Graph](image1)

**Synaptic Standard Deviation**

![Synaptic Standard Deviation Graph](image2)
Wave-driven 2D Results

Weight projection

Projection of Control Unit 1
Projection of Control Unit 2
Projection of Control Unit 3
Projection of Control Unit 4

Synaptic Standard Deviation

Mean Standard Deviation
Invariance transformations can be organized prenatally
Can be understood as learning before eye-opening
Necessary competitions between maps emerge from wave inputs
Model generalizes to higher dimensions
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