Modeling the Visual Cortex Area 1(V1) for Pattern Recognition

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Order of Presentation

- Introduction
- Development of Corticocortical Lateral Connections
- Simulation Results
- Role of Lateral Connections
- Axon Growth Model
- Conclusion and Future Works
- Pattern Recognition
Neuro Vision: Introduction

- Bhagabhan Buddha
Neuro Vision: Introduction

■ The Visual System
Neuro Vision: Introduction

- A Simplified Model of the Visual Pathway
Neuro Vision: Introduction

- Receptive Fields
Neuro Vision: Introduction

- Visual Information Processing

V5: Movement, Contrast
V4: Colour, Contrast
V3: Form
V2: Orientation, Form etc
V1: Orientation Selectivity
Neuro Vision: Introduction

- Cell organizations
Neuro Vision: Introduction

Characteristics of Cortical Cells of V1

1. Orientation Specificity

2. Orientation Tuning
The Orientation Map (Bosking et. al, 1997)
Neuro Vision: Introduction

- Characteristics of Horizontal Connections

1. Orientation Specificity

2. Axial Specificity
Neuro Vision: Introduction

- Importance of Horizontal Connections

1. Elongated Receptive Fields of Layer 6 Simple Cells
2. Integration of Information by a Neuronal Cell
3. Receptive Field Surround Effects
4. Cortical Plasticity
Neuro Vision: Introduction

- **Our Objective:**

  1. Development of Orientations Maps
  2. Development of Horizontal Connections
  3. Study of Horizontal Connections in the Development Orientation Tuning
Neuro Vision

- Developed Orientation Map:

(200 – 700)
The Model

(Development of Horizontal Connections)
Modeling the Horizontal Connections

- The Three Layer Model of the Visual System

Cortex: 50x50
RF: 13x13
LGN: 42x42
VS: 195x195
• The Model

- Initial Response Generation: Three Layer Model

- Cortical Weight development: One Layer Model

- Cortical Response Generation: Three Layer Model
Modeling the Horizontal Connections

- The Model

- Initial Response Generation:

\[
u_i(t) = \sum_{t_i^{(f)} \in F_i} \eta_i(t - t_i^{(f)}) + \sum_{j \in \Gamma_i} \sum_{t_j^{(f)} \in F_i} W_{ij} \varepsilon_{ij}(t - t_j^{(f)}) + R_P
\]  

(1)

where

\[
\varepsilon_{ij}(s) = \left[ \exp\left(-\frac{s - \Delta^{ax}}{\tau_m}\right) - \exp\left(-\frac{s - \Delta^{ax}}{\tau_s}\right) \right]
\]  

(2)

\[
\eta_i(s) = -\varrho \exp\left(-\frac{s}{\tau}\right)
\]  

(3)
Modeling the Horizontal Connections

• The Models

- Cortical Weight Development: Model1

\[ W'_{ij} = \left( \gamma_1 - WW^T \right) \left( \gamma_2 - YY^T \right) W_{ij} \exp \left( -\left( \frac{\phi_i - \phi_j}{1 - R_j} \right)^2 f_{dist}(i, j) \right) \] (3)

- Cortical Weight Development: Model2

\[ W'_{ij} = \left( \gamma_1 - W^TW \right) \left( \gamma_2 - YY^T \right) W_{ij} f_{dist}(i, j) O_i O_j \] (4)

Modeling the Horizontal Connections

• The Model

- Cortical Response Generation:

\[ u_i(t) = \sum_{t_i^{(f)} \in F_i} \eta_i(t-t_i^{(f)}) + \beta_i^l \sum_{j \in \Gamma_i, t_j^{(f)} \in F_j} W_{ij}^l \varepsilon_{ij}(t-t_j^{(f)}) + \beta_2^e \sum_{j \in \Gamma_i} W_{ij}^e \varepsilon_{ij}(t-t_j^{(f)}) + \beta_2^c \sum_{j \in \Gamma_i, t_j^{(f)} \in F_j} W_{ij}^c \varepsilon_{ij}(t-t_j^{(f)}) + R_p \] (7)

where

\[ \eta_i(t) : refractory \ function \]

\[ R_p : resting \ potential \]
Simulation Results

1. Development of Horizontal Connections:

2. An Individual Cell: (20, 25)

3. Lateral Connections

4. Role of Lateral Connections
   - Scatter Plot: hwhh
   - Tuning Plots
     • Improvement: Inhibition Excitation LGN
     • Deterioration: Inhibition
   - Locations: Inh Exc LGN
   - Contextual Effects

5. Result Discussions
Simulation Results

Movie
Effect of Receptive Field Overlap on Lateral Connections

Reference Cell

Target Cell

Target Cell

Target Cell

Cell (30,17), $\Phi_i = 21.37^\circ$

Cell (9,41), $\Phi_j = 21.24^\circ$
Edist=31.9, $w_{ij} =0.471$

Cell (18,36), $\Phi_j = 20.7^\circ$
Edist=22.5, $w_{ij} =0.132$

Cell (45,19), $\Phi_j = 109.3^\circ$
Edist=15.1, $w_{ij} =0.124$
Scatter Plots: Tuning Half Widths

(a) LGN Contribution only

(b) LGN + Lateral Contributions
Role of Lateral Connections

• Simulation Results
  - Improvement due to Inhibition
Role of Lateral Connections

- Simulation Results
  - Improvement due to Excitation
Role of Lateral Connections

• Simulation Results

- Improvement due to LGN
• Simulation Results
  - Deterioration due to Inhibition
• Simulation Results

- Locations: Improvement due to Inhibition

Spike < 150

Spike > 150
Role of Lateral Connections

- Simulation Results
  - Locations: Improvement due to Excitation
• Simulation Results

- Locations: Improvement due to LGN
Role of Lateral Connections

- Lesion Experiment

Cortex: 50x50

RF: 13x13

LGN: 42x42

RF-VS: 79x79

Visual Space: 195x195
Role of Lateral Connections

- Lesion Experiment Result
Role of Lateral Connections

- Determination of RF by Reverse Correlation Technique
  (Jones and Pakmer, 1978a)

RF of a cortical cell shown (a) as a set of LGN weights
(b) as obtained through reverse correlation technique
Role of Lateral Connections

- **Contextual Effects Experiment Results**

  ![Graph](image-url)

  **Cell:** (31,13)
  **Location:** Boundary between two zones

  ![Diagram](image-url)

  **Cell:** (40,25)
  **Location:** Pinwheel
Development of Lateral Connections: Result Discussions

- Characteristics of the Developed Horizontal Connections are Similar to the Experimental Findings

- Improvement in Tuning of Cortical Cells are due to Various Mechanisms rather than one single mechanism

- Various Mechanisms Correspond to Various Locations in the Orientation Map

- Context Dependent Modulation of Cortical Cell Response is dependent upon the Location of the cell in the Orientation Map
Axon Growth Model

- The Model
  - Axon Growth
  - Cell Connectivity to the Axonal Branches
  - Modeling the Optimization Process
- Results
- Force Directed Partitioning

Modeling the Axon Growth

• The Model – Axon Growth

Location of the Growth Cone at Time $t$:

$$A(t) = A(t - 1) + \Delta A \quad \cdots \quad (1)$$

where

$$\Delta A = a_i \ast U(M_{\text{dist}} - M_{\text{dist}_a_i})$$

$$U(k) = \begin{cases} 
1 & : \text{if } k > 0 \\
0 & : \text{otherwise}
\end{cases}$$
Modeling the Axon Growth

**The Model – Cell Connectivity to the Axonal Branches**

Number of Cells Connected at Time $t$:

$$N(t) = N(t - 1) + \Delta N$$

where

$$\Delta N = \sum_{i=1}^{N(r)M(t)} \sum_{j=1}^{M(t)} U(p_i) \times U(l_{max} - d_{ij}) \times h(d_{ij}) \times U(M_{dist} - M_{dist-p_i})$$

$$U(p_i) = \begin{cases} 1 & : \text{if } \Phi(p_i) = \Phi \\ 0 & : \text{otherwise} \end{cases}$$
Modeling the Axon Growth

• The Model – Cell Connectivity to the Axonal Branches

\[ h(d_{ij}) = \begin{cases} 
1 & : \text{for } \min d_{ij} \\
0 & : \text{otherwise}
\end{cases} \]

\[ l_{\max} = \begin{cases} 
 l_{\max} & : M_{\text{dist}-p_i} \leq l_{\max} \\
 l_{\max} \exp \left( - \frac{M_{\text{dist}-p_i} - l_{\max}}{M_{\text{dist}}} \right) & : \text{otherwise}
\end{cases} \]
Modeling the Axon Growth

• The Model – Optimization Process (Jaydeva & Bhaumik, 1994)

\[
E = \sum_{i=1}^{M} \text{dist}(2, x_{i+1}, x_i) \sum_{j=1}^{M} d_{ij} h(d_{ij})
\]

where

\[
\text{dist}(2, x_{i+1}, x_i) = \|x_{i+1} - x_i\|_2, \quad d_{ij} = \text{dist}(2, p_i, x_j)
\]

\[
h(d_{ij}) = \frac{\exp\left(-\frac{d_{ij}^2}{\beta^2(t)}\right)}{\sum_{i=1}^{M} \exp\left(-\frac{d_{ij}^2}{\beta^2(t)}\right)}\]

Dynamic Equation

\[
x'_i = -\frac{\partial E}{\partial x_i} = \frac{(x_{i+1} - x_i)}{\text{dist}(2, x_{i+1}, x_i)} + \frac{(x_{i-1} - x_i)}{\text{dist}(2, x_i, x_{i-1})} + \sum_{k=1}^{N} h(d_{ki}) \frac{(p_{kj} - x_{ij})}{d_{ki}}
\]

\[
+ \sum_{k=1}^{N} (x_{ij} - p_{kj}) \frac{1}{\beta^2(t)} h(d_{ki}) (h(d_{ki})-1)
\]
Modeling the axon Growth

• Results: Neural Optimization: Features Incorporated

1. Curves of Various Shapes
2. Importance of Merging Partitions
3. Number of Curve Points Added
4. Direction of Curve Opening
5. Algorithm Used for Partition

Modeling the Axon Growth

• Simulation Result

Axon Growth: Movie

Optimization Process: Movie
Results: Axon Growth

Modeling the Axon Growth
Modeling the Axon Growth

• Results: Axon Growth
Results: Axon Growth
Modeling the Axon Growth

- **Results**: Axon Growth
• **Results**: Axon Growth
• Results: Axon Growth
Modeling the Axon Growth

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Modeling the Axon Growth

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Modeling the Axon Growth

• Results: Axon Growth
Modeling the Axon Growth

- **Results**: Axon Growth
Modeling the Axon Growth

• Results: Axon Growth

• Optimization Process: Movie
• Results: Optimization
Modeling the Axon Growth

• **Results**: Optimization
Modeling the Axon Growth

• **Results**: Optimization
Modeling the Axon Growth

• **Result**: Optimization
Modeling the Axon Growth

• **Result**: Optimization
Modeling the Axon Growth

• **Result**: Optimization
• Result: Optimization
Force Directed Partitioning

\[ F_i = \sum_{j=1}^{n(r)} \frac{1}{r_{ij}^2} \times U(p_j) \]

where

\[ U(p_j) = \begin{cases} 
1 & : \text{if } \Phi(p_j) = \Phi \\
0 & : \text{otherwise} 
\end{cases} \]
Modeling the Axon Growth

• Result: Force Directed Axon Growth: [Movie]
Modeling the Axon Growth

• Result: Force Directed Axon Growth
Modeling the Axon Growth

- **Result**: Force Directed Axon Growth
Modeling the Axon Growth

• Result: Force Directed Axon Growth
• Result: Force Directed Axon Growth
Modeling the Axon Growth

- **Result**: Force Directed Axon Growth
Modeling the Axon Growth

- **Result**: Force Directed Axon Growth
Modeling the Axon Growth

- **Result**: Force Directed Axon Growth
• Force directed partitioning of a displaced point set.
Axon Growth on Ferret Orientation Map

IC-Design Group, CEERI, Pilani
Principal contributions

- Tuning improvements of cortical cells are due to multiple mechanisms.
- Cortical Excitation is also one of the mechanisms.
- Effects of lateral connections on orientation tuning of cortical cells are location dependent.
- Contextual Effects are also location dependent.
- Force directed mechanism can be a natural mechanism for the movement of growth-cones.
- An optimization based neural network approach with force directed mechanism is used to model the growth of long-range horizontal connections.
Future and Present Activities

- Integration of Short-Range and Long-Range Model
- Development of an Event Driven Simulator
- Use of the Model as a Pattern Recognition System
- VLSI Implementation
Some of the Important References


- **Kisvárday ZF, Toth E, Rausch M, and Eysel UT (1997)**, Orientation-Specific Relationship Between Populations of Excitatory and Inhibitory Lateral Connections in the Visual Cortex of the Cat. *Cerebral Cortex*, 7(7):605-618


Neuro Vision: Pattern Recognition
Rupasi Bangla of Jivananda Das
Neuro Vision: Pattern Recognition

CONTROLLER

INPUT

Pre Processing

Post Processing

0° 45° 90° 135° 180°
Neuro Vision: Future Work

- VLSI Implementation of a Neuro Chip
- Colour Perception
- Depth Perception
- Motion Perception
- Feature Perception
- Texture Perception
- Learning
- Memory
Thank You!