

# Hierarchies in Visual Pathway: Functions and Inspired Artificial Vision

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The development of artificial intelligence has posed a challenge to machine vision based on conventional complementary metal-oxide semiconductor (CMOS) circuits owing to its high latency and inefficient power consumption originating from the data shuffling between memory and computation units. Gaining more insights into the function of every part of the visual pathway for visual perception can bring the capabilities of machine vision in terms of robustness and generality. Hardware acceleration of more energy-efficient and bio-realistic artificial vision highly necessitates neuromorphic devices and circuits that are able to mimic the function of each part of the visual pathway. In this paper, we review the structure and function of the entire class of visual neurons from the retina to the primate visual cortex within reach (Chapter 2) are reviewed. Based on the extraction of biological principles, the recent hardware-implemented visual neurons located in different parts of the visual pathway are discussed in detail in Chapters 3 and 4. Furthermore, valuable applications of inspired artificial vision in different scenarios (Chapter 5) are provided. The functional description of the visual pathway and its inspired neuromorphic devices/circuits are expected to provide valuable insights for the design of next-generation artificial visual perception systems.

## 1. Introduction

Machine vision has been developed for more than several decades that is now developed as an indispensable part of numerous

intelligent systems, such as autonomous robotics and vehicles.<sup>[1–3]</sup> Pathway of classic machine vision systems from the image sensors, analog-to-digital converter (ADC), a memory unit to computation units can be implemented based on conventional CMOS technology where the photo sensors convert the light shined on each pixel into a voltage signal.<sup>[4,5]</sup> ADCs binarize the data after amplification and de-noising, memory store the binary information and computation units perform final recognition and classification.<sup>[6,7]</sup> However, this pathway is in flat processing schemes where redundant sensory data were employed as input to be processed by computation units with machine-learning algorithms.<sup>[8–10]</sup> Owing to its high latency and inefficient power consumption originating from the data shuffling between memory and computation units, the general and robust resolutions to the major problems including vision-based navigation, object recognition, activity recognition, and motion detection, are still beyond the reach of current hardware-implemented machine vision systems.<sup>[11,12]</sup>

Compared with conventional artificial visual systems, natural eyes display the abilities of high-quality image capturing and recognition with a small but delicately optical geometry. Therefore, various bio-inspired artificial vision systems have been developed extensively by mimicking the distinct structure and mechanism of natural eyes, including amphibious (crab-eye-type) artificial vision,<sup>[13]</sup> aquatic (fish-eye-type) artificial vision,<sup>[14]</sup> etc., with outstanding performance. The specific of the visual system of primates is its capability to easily accomplish some advanced functions such as recognition and categorization of large-scale objects, scenes, and activities with the omnidirectional field of view and broadband response.<sup>[15]</sup> By encoding optical signals as nerve spikes through the retina and processing them through the visual cortex (Figure 1a), the biological vision system is capable of high speed and ultra-low energy consumption.<sup>[15,16]</sup> Gaining more insight into the function of every part of the visual pathway for visual perception could bring the capabilities of machine vision in terms of robustness and generality. For example, the ganglion cells and lateral geniculate nucleus (LGN) cells have a concentric receptive field (RF) with the “on” periphery and “off” center or the “off” periphery and “on” center, which are mutually antagonistic.<sup>[17]</sup> Therefore, the circular light spots restricted

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# An Inquiry Driven Vision System Based On Visual And Conceptual Hierarchies

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### **Table of Contents An Inquiry Driven Vision System Based On Visual And Conceptual Hierarchies**

1. Understanding the eBook An Inquiry Driven Vision System Based On Visual And Conceptual Hierarchies
  - The Rise of Digital Reading An Inquiry Driven Vision System Based On Visual And Conceptual Hierarchies
  - Advantages of eBooks Over Traditional Books
2. Identifying An Inquiry Driven Vision System Based On Visual And Conceptual Hierarchies
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an An Inquiry Driven Vision System Based On Visual And Conceptual Hierarchies
  - User-Friendly Interface
4. Exploring eBook Recommendations from An Inquiry Driven Vision System Based On Visual And Conceptual Hierarchies
  - Personalized Recommendations
  - An Inquiry Driven Vision System Based On Visual And Conceptual Hierarchies User Reviews and Ratings

- An Inquiry Driven Vision System Based On Visual And Conceptual Hierarchies and Bestseller Lists
- 5. Accessing An Inquiry Driven Vision System Based On Visual And Conceptual Hierarchies Free and Paid eBooks
  - An Inquiry Driven Vision System Based On Visual And Conceptual Hierarchies Public Domain eBooks
  - An Inquiry Driven Vision System Based On Visual And Conceptual Hierarchies eBook Subscription Services
  - An Inquiry Driven Vision System Based On Visual And Conceptual Hierarchies Budget-Friendly Options
- 6. Navigating An Inquiry Driven Vision System Based On Visual And Conceptual Hierarchies eBook Formats
  - ePub, PDF, MOBI, and More
  - An Inquiry Driven Vision System Based On Visual And Conceptual Hierarchies Compatibility with Devices
  - An Inquiry Driven Vision System Based On Visual And Conceptual Hierarchies Enhanced eBook Features
- 7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of An Inquiry Driven Vision System Based On Visual And Conceptual Hierarchies
  - Highlighting and Note-Taking An Inquiry Driven Vision System Based On Visual And Conceptual Hierarchies
  - Interactive Elements An Inquiry Driven Vision System Based On Visual And Conceptual Hierarchies
- 8. Staying Engaged with An Inquiry Driven Vision System Based On Visual And Conceptual Hierarchies
  - Joining Online Reading Communities
  - Participating in Virtual Book Clubs
  - Following Authors and Publishers An Inquiry Driven Vision System Based On Visual And Conceptual Hierarchies
- 9. Balancing eBooks and Physical Books An Inquiry Driven Vision System Based On Visual And Conceptual Hierarchies
  - Benefits of a Digital Library
  - Creating a Diverse Reading Collection An Inquiry Driven Vision System Based On Visual And Conceptual Hierarchies
- 10. Overcoming Reading Challenges
  - Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
- 11. Cultivating a Reading Routine An Inquiry Driven Vision System Based On Visual And Conceptual Hierarchies
  - Setting Reading Goals An Inquiry Driven Vision System Based On Visual And Conceptual Hierarchies
  - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of An Inquiry Driven Vision System Based On Visual And Conceptual Hierarchies
  - Fact-Checking eBook Content of An Inquiry Driven Vision System Based On Visual And Conceptual Hierarchies

- Distinguishing Credible Sources
13. Promoting Lifelong Learning
- Utilizing eBooks for Skill Development
  - Exploring Educational eBooks
14. Embracing eBook Trends
- Integration of Multimedia Elements
  - Interactive and Gamified eBooks

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