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Visual Information Encoding Modeling From the Perspective of Cell Assemblies

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Abstract. This paper aims to explore the visual information encoding mechanism based on neuronal cell assembly theory, focusing on improving the interpretability and credibility of visual information processing models. By comprehensively applying multidisciplinary theories and methods such as neuroscience, computational neuroscience, and information theory, the effect of neuronal activity in the process of visual information processing is analyzed step by step, and the way visual information is encoded in brain is revealed. It is worth emphasizing that results in this paper is just based on the depth of understanding of neuroscience today. Much unknown remains mysterious so only conjectures and assumptions can be made. It is found that the neurons classify, extract, and reconstruct scenes of complex visual features from the acquired images. And visual modeling idea based on Hebb's theory about cell assemblies is similar to the real physiological processing process of visual information, and has great potential to solve real-life research problems.

Keywords: Encoding Modeling; Visual Information; Cell Assemblies.

1. Introduction

Visual processing has exhibited remarkable specificity and complexity in human evolution and development. The proportion of the visual cortex in the human brain is higher than that of the areas of the cerebral cortex that process other sensory information. From a factual point of view, at least 70% of the information received by humans comes from vision. Humans rely on vision to achieve depth perception, that is, to recognize the distance of objects and perceive the curvature of objects. Visual information helps humans to judge and predict their surroundings. Understanding the functions of the human visual system (HVS) and applying it to machine agents has great application prospects, and researchers have conducted cross-domain research on artificial intelligence and neural mechanisms.

Recent successes stem from the application of deep learning networks, which allow researchers to build models of neural function in mathematical form. And the data fit so that parameters correspond to the details of each neuron's processing [1]. The problem with this is that, models that are able to more accurately reproduce observed neural activity often fail to extract simple and deep rules from huge amounts of data. As a result, statistical modeling will increasingly drive the development of more complex theories, rather than be linked to existing theories of visual processing. Overly complex theories will have difficulties in popularization and application.

This review coincides with the period of rapid expansion of brain-computer interface application technology. Interpretation of electrical signal pulses presents attractive application prospects. Obviously, continuing to improve the modeling ideas of the original signals of visual neurons acquired, so as to model the prominent features of the image, will be of great benefit to the development of technology. A literature shows up to 2023, existing methods that use deep neural networks to emulate the simplified architecture of HVS still often suffer from significant performance degradation [2]. Embedding the neural mechanism of HVS into visual perception modeling, imaging quality enhancement, neural network design, etc. is at the forefront of intelligent vision research.

Therefore, the author began the review by providing relevant information on the encoding of visual information in the human visual system. The review also discusses an architecture for redesigning visual models, inspired by Hebb's theory [3]. This review will focus on exploring the following two aspects: 1) the characteristics of information encoding during visual formation. 2) the discussion of the attempt to construct a model with emergent attributes based on Hebb's theory.

2. Characteristics of visual information processing in nerve cells

An array of studies suggests that understanding visual information processing involves a combination of initial image analysis, attention mechanisms, cognitive function and memory system. The information received from the object is in a preliminary processing of its segmentation, extraction of features and decision making.

2.1. Early processing of images

2.1.1. Description of the grey-level changes

It is suggested that the first consequential stage involves computing a basic yet detailed description of the gray-level variations observed in an image [4]. A variety of intensity shift language (such as EDGE, SHADING-EDGE, EXTENDED-EDGE, LINE, BLOB, etc.) is used to communicate the description. The items in the description, along with their POSITION, ORIENTATION, TERMINATION points, CONTRAST, SIZE, and FUZZINESS, are tied to the modifiable parameters. This description, known as the primal sketch, is derived from the intensity array using established approaches as shown in Figure 1. The primitive drawing shows a lot of unprocessed data, which makes it seem overwhelming.

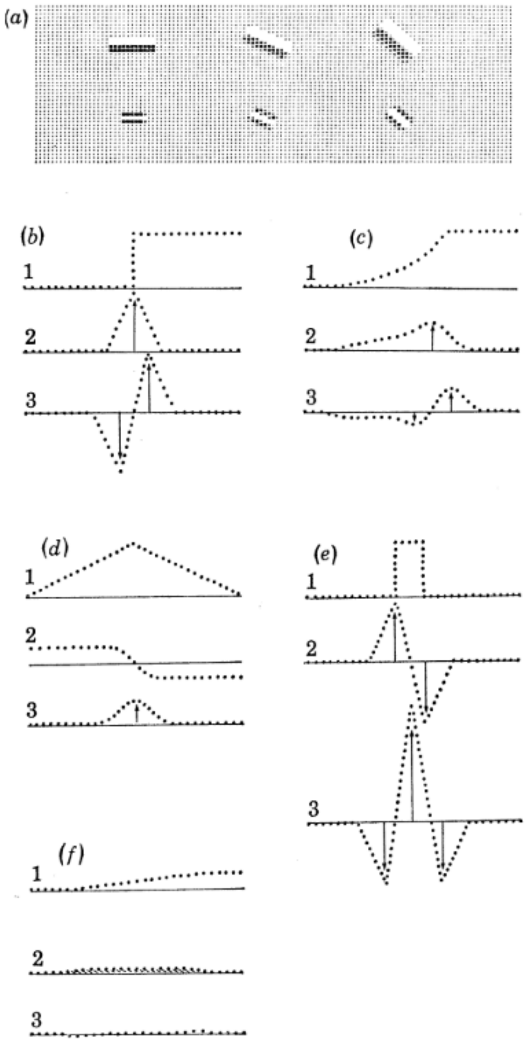

Figure 1. Classifying the grey-level intensity changes present in an image [4]

2.1.2. Symbolic processes

Sorting the elements of a visual image into groups that make sense for later recognition is the second crucial stage in the processing of visual information [4]. Due to human's ability to illustrate simple pencil drawings with extended meaning, it is possible to deduce the existence of symbolic processes in human visual processing system that are able to recognize an object's key characteristics, such as its shape, contour, and general attributes like color, details, shading, and texture, as well as its configure and holistic elements. In other words, the ambient light information of the image is converted into influential meaning in this step. Perceptual constancy, the ability to identify objects even when viewed from obscure or changing angles, is crucial [5]. This might be achieved via a process that can both organize the elements as needed in the primordial sketch and choose items based on first-order discriminations acting on the properties of the elements.

Human perception of images under controlled conditions is not always stable [6]. What is clear, however, is that the way regions are nested creates specific patterns that correspond to the visual perception of the image.

2.2. Attention mechanisms

The previously mentioned techniques utilize downward-flowing information from the specific image under processing, but only to a limited extent. It is argued that these grouping operations and first order discriminations working on the primal sketch are what actually implement "non-attentive" vision in practice [4]. The extra information provided by the first step can then be utilized by the second. Since these segments have some physical significance, it is safe to combine two of them in the second stage even if they don't match on some criteria, as long as there aren't any other plausible candidates nearby. There is a little difference between the class of second order operations on the intensity array and the class of computations so obtained. Using these methods, a form can be extracted from the primitive sketch, separating the figure from the ground. The conclusion is that this paper can accomplish most of the separation using methods that do not depend on the specific image.

The opposite of non-attentive vision is pre-attentive vision and attentive vision. Pre-attentive and attentive mechanisms in vision play crucial roles in perceptual organization and awareness, with attention promoting the entrance of visual stimuli into subjective awareness [7]. Pre-attentive systems split a picture into coherent components by quickly and concurrently transforming the visual input. One of these components could stand out and cause a reaction in behavior. Pre-attentive techniques, however, are frequently insufficient, necessitating the activation of visual attention. Only a portion of the scene can be the focus of attention. Research on neuropsychology and psychophysics supports the idea that pre-attentive and attentive processes differ from one another. Separating processing that results in visual awareness from processing that does not is another difference. While attention facilitates the entry of visual inputs into subjective consciousness, it is still unclear how exactly attentive processing and visual awareness are related. Research about the difference between visual processing that gives rise to awareness and processing that does not is still underway.

2.3. Cognitive function and memory system

Scene understanding and context construction in the visual system begin once a single object is recognized and selectively brought into consciousness. This process also marks the completion of the object segmentation stage, based on the human visual attention model. Because this level of processing is highly dependent on higher-order cognitive functions, including memory, reasoning, and semantic knowledge, this article names this level of cognitive functions as the memory system.

According to the former study, it demonstrated that the next step is scene understanding by analyzing semantics between objects in a scene. This stage finds description of image data with a formatted text [8]. Object semantics play a critical role in guiding attention in real-world scenes, with greater attention being given to semantically related scene regions [9]. The similarity between semantics can be represented by a heat map, as shown in Figure 2.

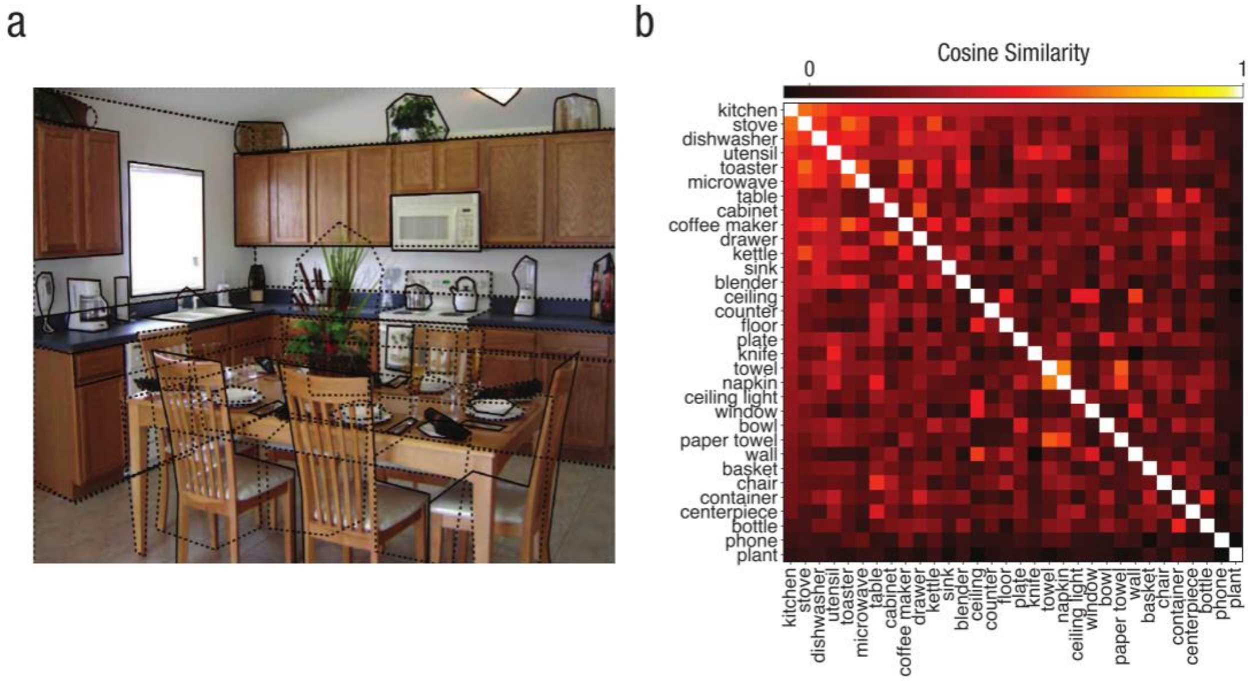

Figure 2. The heat map shows how semantically similar each object is to the scene category and all other scene objects [9]

Scene semantics enhance human memory for objects in naturalistic scenes, even when people don't explicitly try to memorize them [10]. Comprehending space and contextual awareness through multi-view analysis is necessary for the third phase. Time series analysis of scenes and a place is the last step. After this point, a scene, a sequence of scenes, and differences in space can all provide visual information [8].

3. Discussion about the Hebb's theory in model applying

3.1. Proposition of the concept of cell assemblies

Donald Hebb's 1949 book proposed that cortical circuits admit self-sustaining activity, including sensory and motor responses, and suggested that behavior and learning are intimately related to patterns of connections between neurons [11]. The initial guess of Hebb's theory was that under a series of repeated stimuli, the connections between co-active neuron cells will be strengthened, and neuron groups will be formed. In the central nervous system, these groups are called cell assemblies. They become symbols of different stimuli from the environment, and then, using these cell assemblies as units, more complex responses to environmental stimuli can be described.

3.2. Introduce Hebb's theory to model applying

As mentioned earlier, the existing visual information encoding mechanism modeling based on deep learning networks can accurately reflect high-detail neural signal recordings. The drawback of this situation is like the concept of primal sketch during grayscale recognition - rich in detail but overloaded. If salient features and patterns cannot already be modeled, it will be even more difficult to model selective intentions such as metaphor and consciousness [12].

In view of the inefficiency of existing models in the field of artificial intelligence and the lag in the reflection of physiological characteristics of neurons by visual psychology models, the proposal of Hebb's theory is very necessary. Models that are based on Hebb's theory do not ignore the details that can filter out salient features in neuronal activity patterns, which means it is possible to identify finer features. The processing of a logo input by a processor based on Hebb's theory is shown in Figure 3.

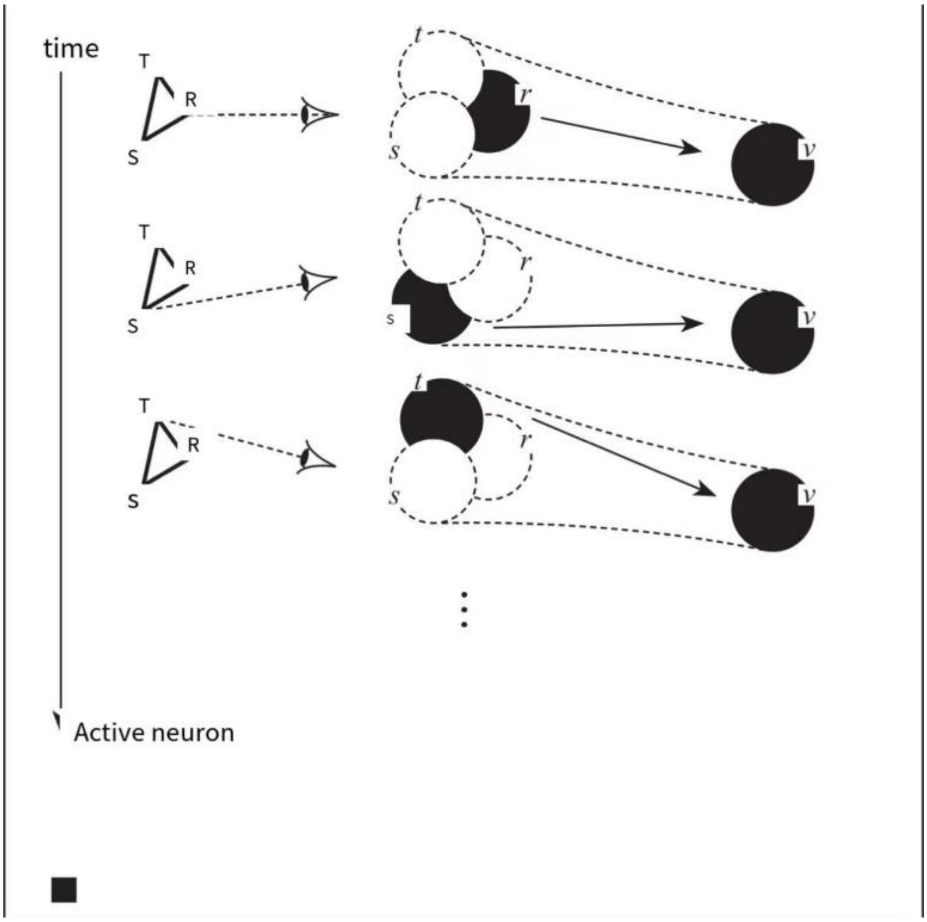

Figure 3. Hierarchical response of cell assemblies simulated by processor based on Hebb’s theory [12]

The modeling mechanism’s imitation of three neuron-based physiological characteristics has greatly promoted the study of behaviors generated by neuronal networks:

Variable excitation threshold. As a neuron’s firing increases, its firing threshold gradually decreases. If the neuron remains stationary for a long period of time, this reduction in its firing threshold causes it to become increasingly sensitive to arriving pulses. Based on this, the model shows predictability.

Fatigue. Neurons that fire at high frequencies for long periods of time will have a continuously increasing firing threshold, and indeed the entire variable firing threshold curve will turn upward. Conversely, neurons that fire at low frequencies for long periods of time will have a continuously decreasing firing threshold. Fatigue will eventually force the firing rate of neurons back to normal levels or set points. Because of this, Computing units forming a loop do not get trapped in a positive feedback loop.

Hebb’s law. If neuron X fires at time t, and neuron Y fires at time t+1, then the connection between X's axon and Y, that is, the synapse, will be enhanced. On the contrary, if Y does not fire at time t+1, then those synapses will weaken. Hebb's law does not apply to firings that are not related to these two neurons. Because of this, the model's adjustment of weights does not require any arbiter or executor.

4. Conclusion

In this paper, the research on the coding mechanism of visual information based on neuronal activity are reviewed. By exploring the basic concepts, characteristics, and roles of processing activity in visual information encoding, possibilities for the development of modeling theory are explored logically. However, there are still many unknowns about the specific mechanism of neuronal group activity, and future research needs to further explore the spatiotemporal pattern and synchronicity of neuronal group activity, in order to understand the mechanism of brain visual information processing more comprehensively. At the same time, as computer computing levels continue to improve and modeling ideas continue to innovate, the complex activity information of visual neurons will be able to be analyzed and interpreted. At that time, the bottleneck in intelligent vision research will be solved.

References

[1] Butts, D. A. Data-Driven Approaches to Understanding Visual Neuron Activity, Annu. Rev. Vis. Sci. 5 (2019) 451-477.

[2] Wu, Q., Ngan, K. N., Lin, W., Bai, L. Editorial: Neuroscience-Inspired Visual Sensing and Understanding, Front. Neurosci. 17 (2023) 1270990.

[3] Kuriscak, E., Marsalek, P., Stroffek, J., Toth, P. G. Biological Context of Hebb Learning in Artificial Neural Networks, a Review, Neurocomputing 152 (2015) 27-35.

[4] Early Processing of Visual Information, Philos. Trans. R. Soc. Lond. B Biol. Sci. 275 (1976) 483-519.

[5] Jonides, J., Yantis, S., Spoehr, K. T., Lehmkuhle, S. W., Visual Information Processing, Am. J. Psychol. 97 (1984) 134.

[6] Gibson, J. J. The Ecological Approach to the Visual Perception of Pictures, Leonardo 11 (1978) 227.

[7] Spekreijse, H. Pre-Attentive and Attentive Mechanisms in Vision, Vision Res. 40 (2000) 1179-1182.

[8] Kang, K., Kwon, Y., Moon, J., Bae, C. Challenging Issues in Visual Information Understanding Researches, MultiMedia Modeling, Lecture Notes in Computer Science, eds. He, X., Luo, S., Tao, D., Xu, C., Yang, J., Hasan, M. A., Springer International Publishing, Cham, 2015, vol. 8936, pp. 458-469.

[9] Hayes, T. R., Henderson, J. M. Looking for Semantic Similarity: What a Vector-Space Model of Semantics Can Tell Us About Attention in Real-World Scenes, Psychol. Sci. 32 (2021) 1262-1270.

[10] Draschkow, D., Wolfe, J. M., Vo, M. L.-H. Seek and You Shall Remember: Scene Semantics Interact with Visual Search to Build Better Memories, J. Vis. 14 (2014) 10.

[11] Sejnowski, T. J. The Book of Hebb, Neuron 24 (1999) 773-776.

[12] Holland, J. H. Emergence: From Chaos to Order, 3rd paperback print., Helix books, Perseus Books, Cambridge, Mass, 2000.