

A Reinforcement Learning Model of Selective Visual Attention^{*}

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ABSTRACT

This paper proposes a model of selective attention for visual search tasks, based on a framework for sequential decision-making. The model is implemented using a fixed pan-tilt-zoom camera in a visually cluttered lab environment, which samples the environment at discrete time steps. The agent has to decide where to fixate next based purely on visual information, in order to reach the region where a target object is most likely to be found. The model consists of two interacting modules. A reinforcement learning module learns a policy on a set of regions in the room for reaching the target object, using as objective function the expected value of the sum of discounted rewards. By selecting an appropriate gaze direction at each step, this module provides top-down control in the selection of the next fixation point. The second module performs "within fixation" processing, based exclusively on visual information. Its purpose is twofold: to provide the agent with a set of locations of interest in the current image, and to perform the detection and identification of the target object. Detailed experimental results show that the number of saccades to a target object significantly decreases with the number of training epochs. The results also show the learned policy to find the target object is invariant to small physical displacements as well as object inversion.

1. MOTIVATION

The problem of visual search is to find a small object in a large usually cluttered environment (e.g. a pen on a desk). In solving such a problem it is preferable to use wide field-of-view images. On the other hand, small objects require high resolution images, which in combination with the wide field-of-view requirement leads to a very high dimensional input array. *Foveated vision* is nature's method of choice in solving this problem and is a dominant characteristic of the

vision system of virtually any vertebrate species with well developed eyes [1]. The *fovea* is anatomically defined as a small, central region on the retina, with a very high density of receptive cells (cones). The density of the receptors (and with it the visual acuity as well) decreases exponentially from the fovea towards the periphery. To make up for any potential loss of information incurred by the decrease in resolution in the periphery, the eyes are rapidly re-oriented via very fast (up to 900°/s), ballistic motions called *saccades*. *Fixations* are the periods between saccades during which the eyes remain relatively fixed, the visual information is processed and the location of the next fixation point is selected.

Foveal image processing reduces the dimension of the input data, but in turn generates an additional sequential decision problem. Choosing the next fixation point requires an efficient gaze control mechanism in order to direct the gaze at the most visually salient object.

From an engineering standpoint, a sequential attention mechanism is a very attractive approach, because it has the potential of requiring only sparse local models [2]. However, the visual attention mechanism raises a plethora of difficult questions. In the first place, since the next fixation point is generally not in the fovea, its selection must be done based on coarse, low resolution visual information, without a thorough understanding of its semantics. The question is then, what low level features are necessary in order to decide what to attend to in the next fixation. Koch and Ullmann [8] propose a saliency map theory which is a task independent, bottom-up model of visual attention. In this framework, Itti and Koch [6], extract three types of feature maps (a color map, an edge map and an intensity map) and fuse them together in a unique map (termed *saliency map*). However, the selection of the next fixation must require some top-down control since low-level visual information is not usually sufficient. Hence the second major question is how to implement a high level, top-down mechanism, to control the low level, reactive attention? Tsotsos et. al. [14] propose a model of visual attention which tries to selectively tune visual processing by means of a top-down hierarchy of winner-take-all processes. Finally, since the vision system samples the environment, some information must be retained from one fixation to the next, and integrate across saccades, to produce a global understanding of the scene.

^{*}First author of this paper is a student.

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Table of Contents A Reinforcement Learning Model Of Selective Visual Attention

1. Understanding the eBook A Reinforcement Learning Model Of Selective Visual Attention
 - The Rise of Digital Reading A Reinforcement Learning Model Of Selective Visual Attention
 - Advantages of eBooks Over Traditional Books
2. Identifying A Reinforcement Learning Model Of Selective Visual Attention
 - 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 A Reinforcement Learning Model Of Selective Visual Attention
 - User-Friendly Interface
4. Exploring eBook Recommendations from A Reinforcement Learning Model Of Selective Visual Attention
 - Personalized Recommendations

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

- 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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