Why do computers need attention?

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The focus of this book is to present a multi-disciplinary perspective on modeling of attention. In this introductory chapter we first address the question of why one should care about modeling attention, then we detail the structure of this book and explain who are the targeted readers.

1. Why care about attention and attention modeling?

First step in perception of living beings …

Any animal [1] from the tiniest insect [2] to humans is perfectly able to "pay attention". Attention is the first step of perception: it analyses the outer real world and turns it into an inner conscious representation. Even during dreams and REM sleep (Rapid Eye Movements), eye movement activity suggests that attentional mechanism is at work. But, in this case, it analyses a virtual world coming from the inner subconscious and turns it into an inner conscious representation. Attention seems to be not only the first step of perception, but also the gate to conscious awareness.

… from foetus to death, awake and during dreams …

Attention probably arises during embryonic development in parallel with sensory systems. The development of attention may correlate with the first REM dreams beginning around the sixth month of foetal development [3]. This mechanism is one of the first cognitive processes to be set up and factors like smoking, drugs, alcohol or even stress during pregnancy may lead to later attention disorders and even a higher chance of developing psychopathologies [4][5]. In cognitive disorders like in autism or schizophrenia, attentive processes are highly affected, as suggested by studying eye tracking traces which can be very different between patients and the control groups [6][7]. The attentive process is set up as early as the prenatal period when it already begins to operate during babies dreams. Until death, it occurs in every single moment of the day when people are awake, but also during dreams. This shows the importance of attention: it cannot be dissociated from perception and consciousness. Even when a person is sleeping without dreaming and the eyes are not moving, a person can be awakened by important stimuli. Attention is never turned off; it can only be reduced to a standby mode

(excepting drug-induced states when consciousness is altered or eliminated as in coma). It is thus safe to say that if there is conscious life in a body, there is attention.

… attention is the gate to consciousness …

As a gateway to conscious awareness at the interface between the external world and internal experience, attention can be both conscious (attentive) and unconscious (pre-attentive) and it is the key to survival. Attention is also a sign of limited computation capabilities. Vision, audition, touch, smell or taste, all provide the brain with a huge amount of information. Gigabits of rough sensorial data flow every second into the brain, which overloads the capacity to think and respond coherently. Attention provides the brain with the capacity of selecting relevant information and prioritizing tasks. While there are a lot of definitions and views of attention the one core idea which justifies attention regardless of the discipline, methodology or intuition is “information reduction” [8].

Attention only began to be scientifically studied from the 19th century with the arrival of modern experimental psychology. Some thoughts and concepts related to attention may be found in Descartes and Malebranche, but no rigorous and intensive scientific study was done until psychologists developed the tools to quantify perceptual and motor performance.. How did philosophers since antiquity miss such a key concept as attention for so long? Part of the answer is given by William James, the father of psychology, in his famous definition of attention: “Everybody knows what attention is”. Attention is so natural and self-evident, so linked to life and partly unconscious, so obvious that … nobody really noticed it until recently.

… attention in computers might be a first step …

However, little by little, a new transversal research field has coalesced around the concept of “attention,” gathering first psychologists, then neuroscientists, and, since the end of the nineties’ engineers and computer scientists. While covering the whole research on attention would require a series of books, the topic is here narrowed to focus on attention modeling, a crucial step towards wider artificial intelligence.

Indeed, this key process of attention is currently rarely used within computers. As with the brain, a computer is a processing unit. As with the brain it has limited computation capabilities and memory. As with the brain, computers are required to analyse a surfeit of data. But unlike the brain they do not pay attention. While a classical computer will be more precise in quantifying the whole input data, an attentive computer will autonomously focus on the most “interesting” data which has several advantages:

- It will be faster and more efficient in terms of memory storage due to its ability to process only part of the input data.
- It will be able to find regularities and irregularities in the input signal and thus be able to detect and react to unexpected or abnormal events.
- It will be able to optimize data prediction by describing novel patterns, and depending on the information reduction result (how efficient the information reduction was), it will be capable of being curious, bored or annoyed. This curiosity which constantly pushes to the discovery of more and more complex patterns to better reduce information is a first step towards creativity.

… to real artificial intelligence

As in humans attention is the gate to awareness and consciousness, in computers attention can lead to novel emergent computational paradigms beyond classical pre-programmed machines. To perform tasks autonomously, machines must be able to select and prioritize

information. While the path towards self-programming computers is still very long, computational attention is developing at an exponentially increasing pace, letting more and more applications benefit from it.

2. Who should read this book and why?

A first point in this book is that we had a multi-disciplinary approach of attention modeling in a world with little communication between those disciplines. This is especially the case for engineering and cognitive psychology/neuroscience. Engineers are at least aware of the fact that attention is studied in psychology and neuroscience because the first computational model [9] was based on the Koch and Ullman architecture [10]. From that point new models emerged and some of them are very far from the biological considerations of Koch and Ullman. Despite this diversity, engineers and computer scientists like the “cognitive” or “biologically-inspired” labels even if they do not really know what a “cognitive model” should be. Despite this fact, few engineers take the time to read and understand papers on attention modeling in neuroscience. The other way around, neuroscientists are also aware about the existence of attention models in the engineering domain but often do not follow the rapid evolutions in this area. One of the main goals of the book is to show to each community some insights on what the others do and what they achieve because we think that having different views on the same issues can help improve knowledge and progress in both communities.

The second point of the book is that chapters are of a mixed complexity so they can be interesting both for students and specialists. Following the same idea, there is also a balance between theory and practical approaches leading to both deeper understanding of attention and fast ability to test and improve existing models. This book intends to be accessible by a wide range of people. Students can easily read some of the chapters and can progressively go deeper in the topic with others. Specialists can directly focus on more complex chapters, but they can also benefit from practical reviews of others.

A third point of this book is an exhaustive application review and future research avenues that can help the reader to orient his research or application development efficiently. People from industry or researchers focusing on applications related to human perception can improve their applications by incorporating attention-related algorithms. Sometimes we realize that some applications could be improved by using attention or saliency models, but the literature is very scarce because people working in this community are not yet aware about what attention models can bring to them.

If you are a student in engineering but also in neuroscience or even psychology interested in researching the field of attention modeling this book is everything you need to start quickly and efficiently. You can quickly acquire the state of the art in attention modelling, but also see practical and exhaustive reviews.

If you already work in the field as an engineer, you will find a quick introduction to psychological and biological approaches to attention and you will be able to go deeper in the concepts linked to attention modeling and the brain.

If you already work in the field as a neuroscientist, you will find engineering approaches to exponentially improve attention models and implement them into real-life applications. Some of the concepts used by engineers are clearly inspired from biological facts, but other much less. The latter models are also interesting because if they achieve good results in predicting human gaze, maybe part of the concepts they use might be found as relevant in the brain.

If you work in industry and focus on perception, images or sound, you might find here your next innovation. From video surveillance to ads optimization passing by compression, robotics and computer graphics, many domains can benefit from attention models.

3. Book structure

In this book, a synthesis of what attention is, how it can be measured and modeled and an overview of current and emerging applications is presented. The structure is organized around three parts.

The first one focuses on fundamentals and is a comprehensive introduction to attention modeling. These chapters attempt to answer basic questions one may have before modeling attention: why model attention in computers, what is attention or more precisely what are attentions,, how to measure attention and where it is localized in the brain.

The second part deals with attention modeling itself. It begins with practical guides on signal detection and neurophysiology from the study of a single neuron to visual performance. Afterwards, attention modeling in engineering and computer science is introduced. After two chapters on the bottom-up attention models for still images which are the most common in computer science another chapter presents attention modeling for video sequences. The set of four chapters which follow describe anything which needs to be known about model validation in computer science to assess how well the attention models can predict human eye fixations: the datasets which are used as ground truth, the metrics used to compute the similarity between the ground truth and the saliency models output, the influence of several parameters on the validation results and the validation itself on a set of state of the art models for still images and videos.

The third part discusses current developments in attention modeling in computer science with chapters on 3D saliency, multimodal saliency and the link between saliency and proto-objects. Finally, this part presents and exhaustive review of attention modeling applications followed by more in deep chapters on some of the possible applications in object recognition, video quality and robotics.

Finally, new research directions and foreseeable evolution of the field are discussed in the conclusion.

Summary:

- Attention is of utmost importance: first step of perception, it is the gate to consciousness. It is active from before birth until death, and during sleep and waking.
- Attention is so fundamental, and perhaps obvious, that it was not recognized as a legitimate object of inquiry until relatively recently.
- The study of attention has spread from philosophy and psychology to neuroscience and computer science.
- Attentive computers can benefit substantially from an implementation of attentive mechanism in their quest for artificial intelligence. This book focuses on the computational aspects of attention.
- The multi-disciplinary approach presented here targets students and researchers (from both engineering and neuroscience communities) and developers from industry who work in applications on perception, video, or sound who might find here their next innovation.

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