Chapter 1
Why Do Computers Need Attention?

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

1.1 Why Care About Attention and Attention Models?

1.1.1 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 rapid eye movement (REM) sleep stages, eye movement activity suggests that attentional mechanisms are at work. But, in this case, it analyses a virtual world coming from the inner subconscious and turns it into an inner conscious representation.

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1.1.2 . . . 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 autism or schizophrenia, attentive processes are highly affected, as suggested by eye tracking studies which show strong differences between patients and control groups [6, 7]. The attentive process develops as early as the prenatal period when it already begins to operate during babies' dreams. Until death, it operates during every single moment of the day when people are awake or dreaming. This shows the importance of attention: it cannot be dissociated from perception and cognition. 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, there is attention too.

1.1.3 . . . 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 prioritising 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 in the nineteenth 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 neglect such a key concept as attention for so long? Part of the answer may be given by William James, the father of psychology, in his famous definition of attention: "Everybody knows what attention is". Perhaps attention is so natural and self-evident, so linked to life and partly unconscious, so obvious that . . . nobody really noticed it until recently.

1.1.4 . . . Attention in Computers Might Be a First Step . . .

However, little by little, a new interdisciplinary research field has coalesced around the concept of "attention", gathering first psychologists, then neuroscientists and, since the end of the 1990s, engineers and computer scientists. While covering the whole spectrum of research on attention would require a series of books, the topic is here narrowed to focus on modelling of attention, a crucial step towards general artificial intelligence.

Indeed, the concept of attention was rarely used within computer science until recently. 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 until recently. While a classical computer will be more precise in quantifying all of its 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 optimise 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.

The first effects of attention in computers begin to be observed by the attentional modules recently added in some AI machine learning models such as transformers. The ability to select the important information given a task is key for managing long-term information and also multi-modal data.

1.1.5 . . . 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 prioritise information according to its task relevance. While the path towards self-programming computers is still long, computational attention is developing at an exponentially increasing pace, letting more and more applications benefit from it. Since the development of deep learning, the frontiers of AI have been pushed back. This is especially the case since "attention modules" have been added to pure learning transformers and the convergence between deep learning and the possibility to focus on part of the data is a key for future advances in the field.

However, more bottom-up attention and online reactions are still needed and will probably develop in the next few years. Also the joint understanding of both text and images make visual search (with precise tasks) become convincing.

1.2 Who Should Read This Book and Why?

A first point in this book is that attention modelling has emerged in multiple scientific disciplines 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 modelling 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.

If you are a student in engineering but also in neuroscience or psychology interested in researching the field of attention modelling, this book should get you started quickly and efficiently. You can rapidly 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 modelling and the brain.

If you already work in the field as a neuroscientist, you will find engineering approaches to exponentially improve attention models and incorporate them into real-life applications. Some of the concepts used by engineers are clearly inspired from biological facts, but others 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.

1.3 Book Structure

The book structure is organised around four parts.

The first part, called "Foundations", focuses on fundamentals and is a comprehensive introduction to attention modelling. These chapters attempt to answer basic questions one may have before modelling attention: why model attention in computers (Chap. 1), what is attention (Chap. 2) and how to measure attention (Chap. 3).

The second part, called "Attention in the Brain", deals first with where attention takes place in the brain (Chap. 4). Follows a practical guide on signal detection and neurophysiology (Chap. 5) and a work on the passage from the study of a single neuron to visual performance (Chap. 6).

The third part, called "Attention in Computer Science", focuses first on how attention is viewed in engineering (Chap. 7). To be able to validate computational models one needs metrics which are described in Chap. 8. The parameters which might influence those metrics results are dealt with in Chap. 9. Then a review of the computational models for all modalities along with some applications and training/validation datasets is made in a large Chap. 10. A more in-depth state of the art on audio-video attention models follows (Chap. 11). Finally, a chapter focuses on attention in deep learning architectures and especially in transformers (Chap. 12).

The fourth part, called "Convergence: When the Brain Informs Computer Science (and Vice Versa)" contains first a chapter on how to inform brain research from results in computer science (Chap. 13). A theory of priority and control of attention in the brain can explain practical implications of attention (Chap. 14). The book is finally concluded with a chapter which intends to draw perspectives in the different fields of attention (Chap. 15).

1.3.1 Summary

- Attention is of utmost importance: the 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 recognised 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 mechanisms 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) who work in applications on perception, video or sound who might find here their next innovation.

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