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RESEARCH ARTICLE

A connectionist model of data compression in memory

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Abstract
Mental imagery is an integral part of daily life, yet it has been poorly studied. In order to effectively imagine, and make future predictions, it is necessary to obtain an accurate picture of the world. If one were to remember events in complete detail, the memory requirements would be oppressive. Hence, it is necessary to compress the data. In psychology, memory compression has been very poorly studied. On the other hand, in computer technology, video and image compression has been thoroughly researched and standards such as MPEG, JPEG and GIF are largely in use today. We take inspiration from these techniques to form a connectionist framework of data compression. We then apply this framework to a problem in spatial cognition — given the motion of an object in a particular trajectory, its future motion should be predicted. An initial solution to this problem without compression was demonstrated earlier. In this paper, we demonstrate that there is a large memory reduction compared to the earlier system, and that larger simulations that were previously not viable can be run in this system.

Introduction

In order to clearly understand the world, and act on the basis of incoming stimuli, it is necessary to calculate or imagine what will take place in the future. This mental imagery is very important in our daily actions, yet it has been poorly studied. In order to effectively imagine future events, a clear understanding of past events and how they changed and developed over time is required. However, a detailed and precise recording of even a few minutes of information would have oppressive memory requirements. Hence it is necessary to compress this data into a manageable size and create necessary abstractions so that the data that is being dealt with is much more manageable. How does the brain perform these calculations?

Although this is an important area, psychological research in data compression is new and not mature yet. Therefore, we approach data compression in a different manner. In cognitive science, computer systems usually take inspiration from biological systems, but in this paper, we take inspiration from computer technology to suggest how the brain may perform data compression. The storage

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of movies, music, and images requires effective data compression, and so data compression is a very thoroughly studied topic in computer science. There are a vast amount of compression technologies ranging from audio compression (e.g. MP3, Vorbis, FLAC) and image compression (e.g. JPEG, GIF, PNG, TIFF) to video compression (e.g. MPEG). We propose that the brain is performing compression that may be similar to some of the algorithms used by these data compression standards — and this is suggested by few studies — evidence is not strong, as studies are just emerging, but this proposal is an interesting start to research in this area. The goal of this research is to use inspiration from computer science in producing a biologically plausible model, and therefore, providing a framework to facilitate further psychological research in this important area.

Earlier we developed a model of perception and prediction to predict trajectories of moving objects. In this paper, we develop a framework for spatial data compression in the brain. We then apply a simplified computational version of this on the perception and prediction problem to demonstrate compression during memory processing.

Background

In this section, we review some of the prominent image and video compression algorithms that are in use. The purpose of this section is not to give a comprehensive review of all the compression methods but to introduce some of the more prominent ones. These methods are then compared with natural compression methods to determine similarities, and suggest that the brain may be using similar methods to compress data.

The most prominent video and audio compression standard is set by the Moving Pictures Experts Group (MPEG) (Gall, 1991, 1992). In the MPEG coding scheme, there are four types of frames: 1. INTRA(I) frames which are coded without reference to any other frame — such frames use only spatial compression (see below), 2. PREDICTED (P) frames which are derived from a previous frame, using the differences between the previous and the current frames. 3. BIDIRECTIONALLY (B) predicted frames derived from a past as well as a future frame, and 4. DC(D) frames coding only low frequency components. The term M represents the number of frames between successive I and P frames and is varied according to application. A typical coding scheme contains an I frame every 10—15 frames, and two B frames between I and P frames.

The MPEG compression algorithm has two compression techniques: (1) Spatial redundancy reduction — within an image, redundancies in space are used to compress the image, and (2) Temporal redundancy reduction between successive frames, that take advantage of the redundancy between one frame and another, and encode only the changes. These would be explained in greater detail as below:

1. Spatial redundancy reduction — This is the spatial compression of individual frames, and corresponds to JPEG, where high frequency components an image which are less easily detected by the human eye are compressed. GIF is another spatial coding technique where repeating sequences are coded as a 'chunk' to achieve compression.
2. Temporal redundancy reduction — The difference between two successive frames is very small. Changes between two subsequent images are coded as a vector transform and a difference image (this codes the difference between the vector transformed image, and actual image), and these two are added to form the next image. Both these take much less space than the actual image, and therefore, compression is achieved. This algorithm is called motion compensation.

There is ample evidence that the brain attends to changes in information rather than actual information as done in motion compensation (see below).

The hippocampus has been identified to be involved in episodic memory in conjunction with various parts of the brain (Anderson, Morris, Amaral, Bliss, & OKeefe, 2007). Because episodic memory involves the memory of a huge amount of information from the various sensory modalities as well as the internal states of the organism, the brain needs to have a compression mechanism to store this information. Ho (2012) proposed that the hippocampus subserves both the function of episodic memory as well as the compression function needed to store the memory involved (Ho, 2012)

System framework

In this paper, we are going to limit our study to spatial information and movement of objects in space. We suggest that compression of memory occurs in different ways in the brain, which include but are not restricted to:

1. Selective attention — certain pictures or parts of an image are attended to, and others are ignored. For example, when viewing a room, some prominent furniture is attended to while background paraphernalia is ignored. JPEG utilizes selective attention.
2. Top down information biasing — objects may be encoded as belonging to a category or pertaining to some rules. When these categories or rules are active, this activates the relevant image. For example, when the system encounters a familiar face, information about the face is already encoded in a higher level manner. When activated, all the features of this face are automatically active. Newer versions of MPEG use this technique.
3. Chunking — repetitive information is encoded as a single chunk. For example, the texture of a table mat is checkered so we just encode one chunk of this pattern, and be aware that this is a repetitive pattern throughout the table mat. GIF uses chunking to achieve compression.
4. Focusing on changes — when something moves or changes in anyway, it is commonly known that the brain focuses on the changes rather than all aspects of the incoming sensory information. For example, when what we expect does not match what is seen, this difference is attended to (e.g. memory prediction (Hawkins & Blakeslee, 2005), ART (Carpenter & Grossberg, 2003, chapter Adaptive Resonance Theory), prediction error (Hollerman & Schultz, 1998)). Motion compensation utilizes this principle.