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RESEARCH ARTICLE

Formal concept analysis approach to cognitive functionalities of bidirectional associative memory ☆

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Abstract
Pattern association is one among the ways through which human brain stores and recalls information. From the literature, it is evident that cognitive abilities of human brain such as learning, memorizing, recalling and updating of information are performed via concepts and their connections. In this work we have made use of Formal Concept Analysis (FCA), a mathematical framework for data and knowledge processing, to represent memories and to perform some of the cognitive functions of human brain. In particular, we model the functionalities of bidirectional associative memories. The proposed model can learn, memorize the learnt information, bi-directionally recall the information that is associated with the presented cue with the help of object-attribute relations that exists in the scenario and update the knowledge when there is a change in the considered scenario. Also when a noisy cue is given, the model is capable of recalling the most closely associated pattern by exploiting the concept hierarchy principle of FCA. Similarly, when a new information is presented on a learnt scenario, the proposed model can update its knowledge by avoiding the need to re-learn scenario. We illustrate the proposed model with a case study and validate with experiments on few real world datasets.

Introduction

Human brain is the most amazing, delicate and complex organ in the human body having around 10^{11} biological neurons. These neurons communicate with each other via

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electric pulses where each neuron is connected to 10^4 other neurons approximately. As a result, brain is able to perform intricate computations such as cognition and pattern recognition. Scientific literature has witnessed a long history of human's quest to understand the mechanisms and processes of the human brain so as to model and develop the intelligence systems. Wang, Wang, Patel, and Patel (2006) have narrated how the study of human brain evolved in the disciplines such as philosophy, physiology, psychology and then to computing. Memory plays an important role in natural and artificial intelligence (Wang & Wang, 2006). Constructing artificial systems that can solve different cognitive tasks such as memorizing, learning, inferencing and reasoning is one of the primary goals of cognitive sciences (Gärdenfors, 2000).

During the last 5 decades, several computational models are proposed and their performances are comparable with humans (Sowa, 2011). Artificial neural networks (ANN) simulate various tasks performed by human brain through different computational models such as feedforward network and recurrent network. Recurrent neural networks are the feedback networks with a closed loop having signals travelling in both directions (Basheer & Hajmeer, 2000). These networks are useful to store a set of encoded patterns in the form of memory through pattern associations. Hence these models are called as associative memory models whose main functionality is to associate the pairs of patterns each other so that we can recall a pattern by presenting its associated pattern as input. Auto-associative and hetero-associative memories are the two types of associative memories (Fu, 2003, chap. 2). In auto-associative memory, input and output patterns are of same type while in hetero-associative memory, input and output patterns are of different types. The most popular and widely used associative memory models are Hopfield networks, Bidirectional Associative Memory (BAM), etc. Hopfield network is an auto-associative memory model. However BAM network can perform both auto-association and hetero-association (Fu, 2003; Kosko, 1988, chap. 2). Hence in this research, we concentrate on BAM.

BAM is a recurrent two layer neural network. This network stores the object patterns through associations and responds to input to either of the layers. There are three varieties of BAM networks based on the type of information it process. These include binary, bipolar and continuous (Sivanandam & Deepa, 2007). Let **X** and **Y** are any two layers of neurons in a BAM network. All the neurons in layer **X** is connected to all the neurons in layer **Y**. Once the network is established, weights for each unit are calculated. Then, when an input pattern is presented to network, with the help of weights, network recalls corresponding associated pattern.

Concepts are regarded as the most fundamental units of human cognition and play a major role in cognitive tasks such as learning, memorizing and reasoning (Yao, 2004). Role of human cognition in contextual information retrieval was discussed by Tian, Du, Hu, and Li (2009). A concept is defined as a cognitive unit to describe a real world concrete entity and a perceived world abstract subject (Wang, 2010). Among different concept formation approaches available in the literature, mathematical lattice based framework, Formal Concept Analysis (FCA) has recently received more attention. FCA considers data represented in the form of formal context that contains objects of the domain, attributes that describe the objects and relation between them (Ganter, Stumme, & Wille, 2005; Poelmans, Elzinga, Viaene, & Dedene, 2009; Aswani Kumar, Dias, & Vieira, 2015; Kumar, 2012). From the formal context, FCA derives formal concepts and orders them according to subconcept–superconcept relation. We call concepts as *formal* concepts to denote that a concept is a rigorously defined mathematical object (Deogun & Saquer, 2004). Formal context representation of data is analogous to the way the data is represented in matrix based information retrieval models (Aswani Kumar, Radvansky, & Annapurna, 2012).

Binary relation between the objects and attribute pairs in FCA is analogous to the way that the object categories are formed in human brain (Rumbell, 2013). There are interesting studies in the literature that are mapping these two theories (Acevedo, Yáñez-Márquez, & Acevedo, 2010; Bělohlávek, 2000b). Considering the fact that all stable points of BAM form a concept lattice, these investigations have used BAM for representing, storing and retrieving formal concepts. Further an interesting architectural similarity can be derived between BAM and FCA by considering from the context, objects as one layer and attributes as second layer of the network.

Motivated by the analysis of (Rumbell, 2013; Xu, Pang, & Luo, 2014), in this research, our aim is to model the functionalities of BAM namely learning, memorizing process, recalling the memorized concepts, handling the partial or distorted patterns recall and updating the memory. To achieve this aim, we propose FCA based model that perceives formal concepts as memory of the learnt topic or domain.

Background

FCA

FCA can be regarded as a mathematical framework to represent the way with which humans conceptualize real world objects (Ganter et al., 2005; Singh & Kumar, 2014). Main facets of FCA are formal context, formal concepts, concept lattice which can be used for conceptual understanding of the data. Formal context is a triple (**G**, **M**, *I*) where **G** is the object set (extent), **M** is the attribute set (intent) and *I* is the binary relation (incidence relation). From the formal context, FCA derives a set of formal concepts using concept forming operators. The notion of concept is rooted to Port-Royal logic, where a concept is determined by a set of objects that fall under the concept and a set of attributes covered by the concept. For a formal context, FCA defines two concept forming operators ($\uparrow\downarrow$) where $\uparrow: 2^{\mathbf{G}} \rightarrow 2^{\mathbf{M}}$ and $\downarrow: 2^{\mathbf{M}} \rightarrow 2^{\mathbf{G}}$ such that for every $\mathbf{A} \subseteq \mathbf{G}$ and $\mathbf{B} \subseteq \mathbf{M}$