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LEARNING IN THE CHREST COGNITIVE ARCHITECTURE

Fernand Gobet

Department of Psychology, Brunel University

Uxbridge

United Kingdom

fernand.gobet@brunel.ac.uk

Peter C. R. Lane

School of Computer Science, University of Hertfordshire

Hatfield

United Kingdom

p.c.lane@herts.ac.uk

Synonyms

Template theory

Definition

CHREST (Chunk Hierarchy and REtrieval Structures) is a *cognitive architecture* that closely simulates learning and the acquisition of expertise <<Link to Development of expertise>> in humans. The key features of CHREST include self-organization, an emphasis on bounded rationality <<Link to Bounded rationality and learning>> (cognitive limitations), a close link between perception, learning, memory, and decision making, and the use of naturalistic data as input for learning. CHREST has successfully simulated behavior in domains such as the psychology of expertise, the acquisition of language by children, concept formation, and the learning of multiple representations in physics.

Theoretical Background

The use of a *cognitive architecture* (a computational theory applied to several domains) to study learning offers several advantages. First, the similarities between models lead to a consistent and unified theoretical framework being applied to multiple domains. This parsimony strengthens claims that the underlying learning mechanisms are general. Second, well-specified computational models provide the only realistic means for identifying and evaluating major factors in learning from large, noisy and dynamically changing sources of information. Third, the use of computational models enables predictions to be made about the structures that are acquired, rather than simply explaining behavior *post hoc*. The extent to which simulations of actual human behavior are successful can be evaluated by comparing the behavior of the models with that of humans, using measures such as eye movements, reaction times, and types of errors.

CHREST (Gobet et al., 2001; Gobet & Lane, 2010) is a cognitive architecture that has been developed to understand the phenomenon of chunking <<link to Chunking mechanisms and learning>> in multiple domains and in its multiple forms: how chunks are created, stored, retrieved and used. It is an implementation of the *template theory of expertise* (Gobet & Simon, 1996) and derives from an earlier computational theory called EPAM (Elementary Perceiver and Memorizer; Feigenbaum & Simon, 1984), which was mostly applied to the understanding of *verbal learning* (i.e., learning of simple, semantically-poor verbal material).

CHREST consists of a number of memories and of mechanisms for interacting with the external environment (see Figure 1). It postulates two main types of memory store: short-term memories (STMs), which hold information from diverse input modalities, and long-term memory (LTM), which holds information in a *chunking network*. A chunking network is a discrimination network containing nodes (*chunks)* that grows dynamically as a function of the previous states of the system and the inputs from the environment.

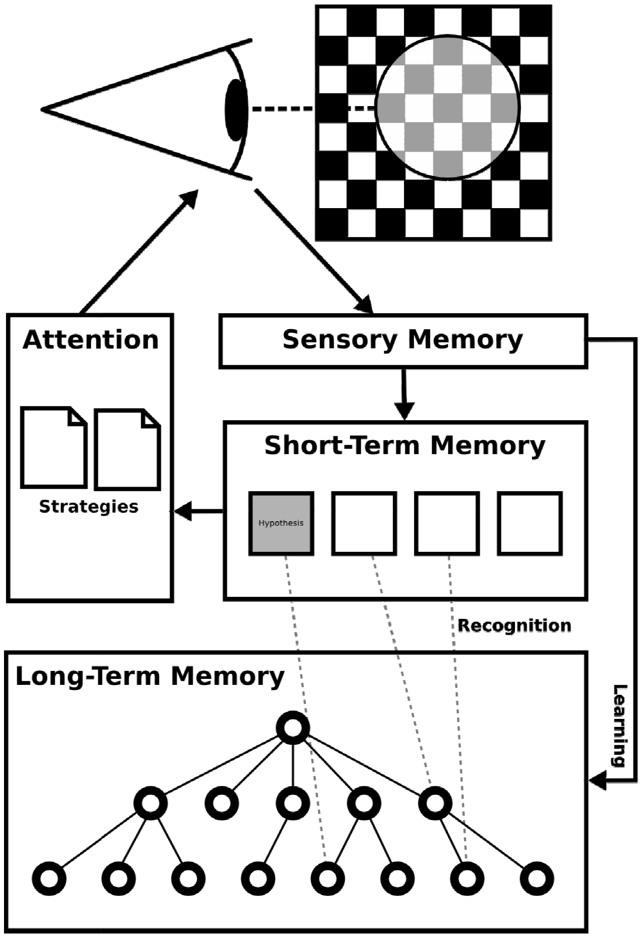

Figure 1. Key components of the CHREST architecture

The key learning mechanisms are the growth of the chunking network by the addition of nodes, enrichment of these nodes by supplementary information, and creation of links between nodes. A mechanism called *discrimination* creates new nodes and a process called *familiarization* incrementally adds information to existing nodes. Under suitable conditions, a mechanism called *template formation* creates <u>schemata</u> (templates) from existing chunks. This mechanism uses both stable information (for creating the *core* of the template) and variable information (for creating its *slots*). Templates are essential for explaining how experts can recall briefly presented positions very well, even with a presentation time as short as 1 or 2 seconds. They are also important for explaining how experts carry out planning – that is, search at a level higher than that of local actions. Other mechanisms create a number of *lateral links* (similarity links, production links, equivalence links, and generative links) between nodes. All these mechanisms are carried out automatically when a new scene is perceived. In simulations of the development of expertise, learning is carried out autonomously by scanning a large number of domain-representative stimuli (e.g., chess games played by grandmasters). In simulations of language acquisition, large corpora of child-directed speech are used.

With CHREST, cognition is the product of the interaction of several processes, including learning, memory retrieval, and decision-making. Knowledge directs attention and perception, and, in turn, perception directs the learning of new knowledge. As such, CHREST is in line with De Groot and Gobet's (1996) axiom that "cognition is perception." Another critical emphasis of the architecture is that human cognition is characterized by *bounded rationality*. The behavior of CHREST is constrained by several cognitive limits, such as: limited capacity of visual short-term memory (assumed to be 3 chunks), the relatively slow rate at which new elements can be learned (assumed to be 10 seconds for creating a new chunk), and the time it takes to transfer information from LTM to STM (50 milliseconds). All cognitive operations have a cost, which is measured by approximate but fixed time parameters. These parameters enable a close comparison to be carried out between human behavior and simulated behavior. While CHREST's structures and mechanisms are rather simple, it draws its explanatory power from the interaction of these mechanisms with the environment. As such, it is a complex dynamical system able to account for a wide range of behaviors.

A considerable number of simulations have been carried out with chess, the first domain of application of CHREST (Gobet et al., 2001). These include: the eye movements of chess novices and Masters when seeing a position for the first time; recall performance in numerous memory experiments where chess boards have been distorted in various ways or where the presentation mode has been manipulated (the measures include the percentage correct, the number and type of errors, and the grouping of the piece placements); and evolution of look-ahead search as a function of skill. Most of these phenomena are primarily explained by the acquisition of a large number of chunks (more than 300,000 for simulating Grandmaster level) and templates.

Phenomena in other domains of expertise have been investigated as well. Simulations with the African game of Awele indicated that CHREST can play at a fairly good level by sheer pattern recognition, while at the same time simulating several phenomena about the development of memory for Awele positions. Similarly, simulations about memory for computer programs replicated differences of recall as a function of the level of meaningfulness of the material. Finally, simulations on multiple representations in physics (basic material on electricity) focused on the acquisition of multiple diagrammatic representations and the use of these representations to solve new problems.

Beyond expertise, CHREST has been used to account for a number of phenomena in implicit learning, verbal learning, and concept formation. The presence of different perceptual modalities in the architecture and the provision for eye movements were exploited for exploring the role of expectations in cognition. Humans more readily direct attention to objects when they are placed in a likely location than in an unlikely location. With CHREST, perception is modeled as a cycle, with the eye guided by long-term memory knowledge to look at the parts of the scene where beneficial information is expected to be present. To explore the role of expectations in cognition, CHREST encoded information both in the visual and verbal modalities. The interaction between the two sources of information produced various measurable effects, such as the result that prior expectations improve speed and accuracy of recognition with partially obscured stimuli.

Most of the applications discussed so far dealt primarily with visual information. Two other strands of research on how children acquire their first language have investigated linguistic information. In the CHREST framework, first language acquisition can be seen as a kind of expertise, where children master their native language through the implicit acquisition of a great number of chunks. Simulations of the acquisition of vocabulary (Jones, Gobet, & Pine, 2007) focused on the mechanisms whereby information in short-term memory interacts with information in long-term memory – a topic that had been surprisingly neglected in the literature. CHREST provides a natural mechanism for this: the creation and use of chunks. Simulations of the non-word repetition task obtained an excellent fit with the human data, non only with normally-developing children but also with children with specific language impairment (SLI).

Another variant of CHREST, known as MOSAIC (Model of Syntax Acquisition in Children), has focused on the acquisition of syntactic categories, and more specifically the "optional infinitive" phenomenon. The optional infinitive phenomenon concerns typical errors made by children between 2 and 3 years of age in their use of finite verb forms (for example, *goes*, *went*) and non-finite verb forms (for example, *go*, *going*). For example, a child would say "her do it" instead of "she does it." In this example, not only is the verb misused, but also the pronoun. MOSAIC has successfully simulated several aspects of the optional infinitive phenomenon (Freudenthal et al., 2007), not only in English but also in Dutch, German, French, Spanish, and Q'anjobalan (a Mayan language). The success of the simulations can be explained by the three factors that interact in interesting ways: the model carries out rote learning; it creates and uses generative links; and it captures the statistical structure of the input. Together, four features make MOSAIC unique in our understanding of language development. First, the input given to the model is naturalistic (utterances spoken by parents interacting with their children in a play setting). Second, MOSAIC provides detailed simulations of the pattern of errors and their developmental trend. Third, the same model is used for simulating different phenomena (i.e., it is not the case that different phenomena are simulated by different models). Finally, simulations have been made in several languages with the same model – the maternal input used for training was the only thing that changed.

Important Scientific Research and Open Questions

CHREST, a symbolic system integrating perception with learning, captures many characteristics of high-level processing in human cognition while also accounting for lower-level aspects such as the details of eye fixations. The two-way interaction between perception and cognition was paramount in accounting for empirical phenomena, just like the incremental learning carried out by the chunking networks. Another important aspect of this modeling approach concerns the strong constraints inherent to the architecture, such as slow learning times or the limited capacity of the short-term memories. In this respect, the research with CHREST takes bounded rationality very seriously indeed.

A number of issues are still unanswered with the CHREST research. The role of strategies has sometimes been investigated within this framework, but we still know little about how they mesh with perceptual chunking. Although progress has been made in the last years about the neurobiological substrate of chunking, there are still many unknowns. In addition, the mapping between CHREST's components and brain areas still remains to be done. More generally, it is unknown whether aspects of CHREST – in particular the chunking mechanisms – could be extended to non-human primates and other animals. Another intriguing avenue for research that has remained untouched is the possibility of linking CHREST with a mobile robot. How would the presence of sensors and effectors affect what is being learned by CHREST? Finally, to what extent can a theory based on chunking mechanisms lay any claims towards being a successful unified theory of cognition?

Cross-References

→ Bounded rationality and learning
→ Schema
→ Decision making and learning
→ Chunking mechanisms and learning
→ Development of expertise

References

Feigenbaum, E. A., & Simon, H. A. (1984). EPAM-like models of recognition and learning. *Cognitive Science, 8,* 305–336.

Freudenthal, D., Pine, J. M., Aguado-Orea, J., & Gobet, F. (2007). Modelling the developmental patterning of finiteness marking in English, Dutch, German and Spanish using MOSAIC. *Cognitive Science, 31*, 311–341.

Gobet, F., & Lane, P. C. R. (2010). The CHREST architecture of cognition: The role of perception in general intelligence. In Baum, E., Hutter, M., & Kitzelmann, E. (Eds), *Proceedings of the Third Conference on Artificial General Intelligence* (pp. 7-12). Amsterdam: Atlantis Press.

Gobet, F., Lane, P. C. R., Croker, S. J., Cheng, P. C.-H., Jones, G., Oliver, I., & Pine, J. M. (2001). Chunking mechanisms in human learning. *Trends in Cognitive Sciences, 5*, 236–243.

Gobet, F., & Simon, H. A. (1996). Templates in chess memory: A mechanism for recalling several boards. *Cognitive Psychology, 31*, 1-40.

Jones, G. A., Gobet, F., & Pine, J. M. (2007). Linking working memory and long-term memory: A computational model of the learning of new words. *Developmental Science, 10*, 853–873.

Definitions

CHREST: A cognitive architecture, developed by Fernand Gobet and Peter Lane, emphasizing a close interaction between perception, learning, and memory. It proposes that human cognition is constrained by a number of limitations, such as span of attention and capacity of short-memory. Learning, which to some extent mitigates the limits imposed by bounded rationality, is done through the acquisition of chunks and templates. CHREST stands for Chunk Hierarchy and REtrieval STructures.

Cognitive architecture: A theory, expressed as a suite of computer programs, that provides specification for structures and related processes of the cognitive system. Models derived from the architecture are typically used to explain phenomena in several domains.

EPAM: A cognitive architecture developed by Herbert Simon and Edward Feigenbaum. Both the limits of human cognition (e.g., limited capacity of short-term memory) and the means to assuage these limits (through learning mechanisms) are emphasized. EPAM stands for Elementary Perceiver And Memorizer.

Verbal learning: The acquisition and retention of verbal information. This is typically studied with the “serial learning task,” where items have to be memorized in their original order, and the “paired-associate learning task,” where the associations between stimuli and responses have to be learned.