of concrete actions or stimuli, facilitating transfer between perception and action.

The chunking theory (Chase & Simon 1973; Gobet et al. 2001) includes many of these elements and, further, embodies them within an established chain of computational models. The basic elements of the chunking theory are that collections of primitive features or actions frequently seen or experienced together are learned as an independently referenced chunk within long-term memory (LTM). Several chunks may be retrieved and referenced within short-term memory (STM), and their co-occurrence used to construct multiple internal references. One such internal reference is the association of perceived chunks with action chunks (Chase & Simon 1973; Gobet & Jansen 1994). These ideas have been extended into a computational model of diagrammatic reasoning, CHREST+ (Lane et al. 2000; 2001). One consequence of assuming that chunks underpin human memory is that output actions are driven by the perception of chunks in the stimulus; this leads to observable effects in the relative timing of the action events.

The CHREST (Chunk Hierarchy and Retrieval Structures) computational model of expert perception provides a unified architecture for perception, retrieval, and action (e.g., see description in De Groot & Gobet 1996; Gobet & Simon 2000). The model employs a discrimination network LTM, a fixed-capacity STM, and input/output devices, with timing parameters for all cognitive processes. Perception in CHREST is a process involving multiple interactions between the constituent elements of its architecture. The process may be summarised as follows: An initial fixation is made of the target stimulus and the features within the eye's field-of-view retrieved. These features are then sorted through the discrimination network so as to retrieve a *chunk* from LTM. This chunk is then placed within STM. The model next attempts to locate further information relevant to the already identified chunk; it does this by using any expected elements or associated links of the retrieved chunk to guide further eye fixations. Information from subsequent fixations is combined with earlier chunks, within STM, building up an internal image of the external world. If the LTM suggestions for further fixations are not of use, then the eye resorts to bottom-up heuristics, relying on salience, proximal objects, or default movements to seek out useful further features.

How is this process related to problem solving? As with the earlier models of chess playing, chunks within LTM become associated with relevant action sequences. One application of the CHREST model is to problem solving with diagrammatic representations; for example, solving electric-circuit problems with AVOW diagrams (details may be found in Cheng 1996; 1998); this version of CHREST is known as CHREST+). As CHREST+ acquires information about the two forms of stimuli, it constructs *equivalence links* between related chunks stored in LTM. During perception of a novel problem, CHREST+ identifies known chunks within the problem, and uses these to index chunks in the solution representation. These solution-chunks act as plans, forming the basis from which CHREST+ constructs an action-sequence composed of lines to draw. The level at which the CHREST+ model is operating is very much in concord with that assumed by TEC: the input is composed of features, representing the tail-end of primitive perceptual processing, and the output is a plan, representing the initiation of output processing. Both the input and output chunks are constructed from compositions of features, and both interact with the STM in a common representational format.

Although internal representations are difficult to investigate, a number of testable predictions may be derived from the chunking theory, relating to the relative timing of action sequences (Chase & Simon 1973; Cowan 2001; Gobet & Simon 2000). An example of the process is found when drawing complex shapes, where the latencies between drawing actions are partly governed by planning activities, and these planning activities are mediated by the state of the drawer's memory. A typical series of latencies includes a limited number of isolated local maxima, corresponding to longer periods of reflection; although participants are often not aware of their presence, these maxima are evident when detailed timing information is gathered. Such patterns have been shown to correspond well with a theory that chunks underlie the planning and memory processes (Cheng et al. 2001), and have also been modelled using CHREST+ (Lane et al. 2000; 2001).

Without detailed modelling of the lower-level empirical evidence presented in the target article, it is not fair to claim that computational models such as CHREST embody all of TEC's central ideas. However, what is interesting is that the aims of EPAM/CHREST, to capture the relatively high-level processes of expert memory in symbolic domains, have led to a model of active perception with a similar style to that proposed by TEC. CHREST may also be used to formalise some of the assumptions of TEC and turn them into empirical predictions. For instance, some of the harder areas of TEC to formalise are the form of the internal representation, or the amount of exposure to a specific domain required to learn a particular association between perceptual and action events. CHREST itself, with detailed timing parameters applicable across many domains, can be used to investigate such questions, using the model to derive strong predictions for the temporal information separating the output actions.

Event coding, executive control, and task-switching

Nachshon Meiran

Department of Behavioral Sciences and Zlotowski Center for Neuroscience, Ben-Gurion University of the Negev, Beer-Sheva, Israel, 84105.
nmeiran@bgumail.bgu.ac.il **http://www.bgu.ac.il/beh/nachshon.html**

Abstract: Like the Theory of Event Coding (TEC), theories of executive functions depict cognition as a flexible and goal-directed system rather than a reflex-like one. Research on task-switching, a dominant paradigm in executive control, has revealed complex and some apparently counterintuitive results. Many of these are readily explained by assuming, like TEC, that cognitive control is based on selecting information from commensurate representations of stimuli and actions.

There is a great deal of commonality between the Theory of Event Coding (TEC) and the study of executive control functions in general. First, both of these research trends are moving away from the reflex metaphor, which has dominated cognitive research for some time (e.g., behaviorism and additive factors). The reflex metaphor suggests that cognitive processing is similar to simple reflexes in that there is a linear progression from input (perception) to output (response). TEC moves away from the reflex metaphor in that it points out the many interfaces between perception and action. Theories of executive functions also move away from the reflex metaphor in that they perceive the cognitive system as an abstract general purpose structure that is being modulated according to changing task demands (e.g., Logan & Gordon 2001).

Second, TEC helps in understanding specific cognitive control functions. One example comes from the area of task-switching (e.g., Allport et al. 1994; Monsell & Driver 2000; Rogers & Monsell 1995). Typically, task-switching experiments involve stimuli which are equally relevant to all the tasks. For example, Fagot (1994) used colored letters and the two tasks were letter classification and color classification. In order to ensure that task-switching was performed at a central level rather than at a more peripheral effector level, the same set of response keys is often used in all tasks. For example, a given key might be used to indicate the identity of a given letter (e.g., "A") in the context of the LETTER task, whereas in the COLOR task the same key indicates RED. The critical variable in the task-switching paradigm involves comparing task-switched trials to task-repetition trials. Two additional variables are task congruency (whether the same physical response is indicated as the correct response in all tasks) and task repetition. The effects of advanced task preparation are also being studied.

The four variables just described produce a complex pattern of interactions in reaction time (RT). First, there are the main effects for task-switching (switch RT > repeat RT), congruency (incongruent RT > congruent RT), and task preparation (unprepared RT > prepared RT). In addition, there are three replicable 2-way interactions: The task-switching cost becomes smaller but is not eliminated as a result of task preparation (switch × preparation), congruency effects are larger in switch trials than in repeat trials (switch × congruency), and the usual response repetition effect (response-repeat RT < response-switch RT) is found only among task-repetition trials but is either not found or even sometimes reversed in task-switch trials (switch × response-repetition).

Perhaps the most counterintuitive effect found is the complete absence in most experiments of a triple interaction between switching, task-preparation, and congruency. The reason why this result is counterintuitive is the usual assumption made by many authors, that task preparation amounts to the replacement of one Stimulus-Response (S-R) mapping rule by another. However, this very reasonable assumption is apparently wrong since it predicts greater interference from the wrong mapping in unprepared trials, which would result in the above mentioned triple interaction. Thus, the effect of task preparation seems to involve something else – not the change of an S-R mapping rule.

The mathematical model developed by our group (Meiran 2000a; Meiran et al. 2000) explains all of these interactions in RT quite successfully, and some of its critical predictions were supported empirically (Meiran 2000b). Its assumptions are very much in the spirit of TEC. For example, it assumes a close interaction between abstract representations of stimuli and abstract representation of responses in the course of response selection. This interaction is so close that response selection is based on determining how "similar" the target stimulus is to each of the responses. Task control in the model is based on selective attention but, in the spirit of TEC, it assumes that selection operates both on the stimulus side and on the representation of the responses. For example, a LARGE SQUARE target stimulus can be represented, mentally, so that SQUARE is emphasized while LARGE is de-emphasized. Similarly, a key-press indicating both LARGE and SQUARE can be represented, mentally, as indicating SQUARE more than it is indicating LARGE.

The final aspect of the model constitutes a slight deviation from TEC, at least as TEC is presently formulated. However, I assume TEC can accommodate this deviation without changing any of its more substantial aspects. Specifically, in the model, the cognitive process responsible for selecting which information will represent a given physical response (termed "response task-set") is based on linking the physical response (e.g., pressing the right key) with the nominal response it is meant to indicate (e.g., RED). This process is similar to the formation of an event code in TEC, except for the fact that the "event code" in our model does not contain a perceived action outcome (a perceived key-press) but, instead, represents an intended nominal response (e.g., RED). The rationale is that pressing a given key serves as a substitute to saying, for example, "this letter is RED."

One potential objection to the above argument is that all our published modeling work involves switching two tasks, UP-DOWN and RIGHT-LEFT. Importantly, the responses (e.g., the upper-right key), like the target stimuli (e.g., the upper-left corner), contained both vertical and horizontal information. One could therefore assume that directing selective attention to a given dimension also affected how the position of the key-press was perceived and that the event code integrates the physical response with its perceived position, as it has been biased by selective attention. However, this interpretation is unlikely to be correct since our model also fits the results using paradigms in which switching was between a CIRCLE-SQUARE task and a SMALL-LARGE task (R^2=.98; Meiran et al., in preparation), and attending to a given target dimension was unlikely to affect how the key-press was perceived. Given the similar results in the two versions of the paradigm, a more parsimonious assumption is that the event code integrates the key-press with its associated nominal response rather than with its perceived outcome.

A theory of representation to complement TEC

Ruth Garrett Millikan
Philosophy Department U-54, University of Connecticut, Storrs, CT 06269.
ruth.millikan@uconn.edu
http://vm.uconn.edu/~wwwphil/faclist2.html

Abstract: The target article can be strengthened by supplementing it with a better theory of mental representation. Given such a theory, there is reason to suppose that, first, even the most primitive representations are mostly of distal affairs; second, the most primitive representations also turn out to be directed two ways at once, both stating facts and directing action.

Hommel et al.'s Theory of Event Coding (TEC) in the target article can be strengthened by supplementing it with a better theory of mental representation. No explanation of the term "representation" is offered by the authors, but the quotations from Dretske (1981), the willingness sometimes to interchange the words "representation" and "information," coupled with statements such as "[t]hese codes are activated by, and thus represent, external stimulus information," strongly suggest some fairly simple causal or informational theory of representation. But Dretske (1986; 1988; 1995), along with many others, now recognizes that there can be no simple equation between mental representation and the occurrence in the brain of "natural information." We must add, at least, that a mental representation has representing as its function, using a sense of "function" in which functions can sometimes fail to be performed. Misrepresentation must not be ruled out by definition. This is usually taken to require that mental representations have been "designed," either by learning (Dretske 1988) or by natural selection or both, to represent what they represent, though, of course, what has been designed to do X may sometimes fail to do X. Better, the mechanisms that produce mental representations have been designed, by learning or natural selection, to produce and/or to learn to produce, representations that vary systematically so as to parallel variations in what needs to be represented (Millikan 1984; 1996; forthcoming). At first glance this may seem just a trivial addition to a causal or informational account of representation, but it is not. If the mechanisms that produce representations have been selected for by learning or by natural selection, this must have been owing to some systematic effects that the representations had, that is, to the uses to which these representations were put. Then it will be these uses that define the semantic contents of the representations, not their causes, and not whatever natural information they may or may not carry.

Now **Hommel et al.** "believe that abstract, distal representation has evolved as a solution to the problem of developing a representational scheme for the planning of goal-directed action" (sect. 5.2). But, from the above it follows that mental representations, even of the most primitive kinds, are most likely to represent distally. It is, for example, variations in the configurations of physical objects in one's immediate environment that have to be taken into account in order to appropriately guide most immediate physical activity, not the shifting quantities, qualities, and patterns of light striking the retina. Putting natural information to one side, what is mentally represented is only what natural selection has found it was useful to have represented. What a mental representation represents depends on how it is interpreted, rightly or wrongly, by the system that uses it. Consider the desert tortoise that automatically moves toward anything green. This disposition, hence the underlying neurology, has been selected for because it often effects movement toward vegetation. What the turtle per-