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Bridging the Gap Between Theories of *Procedural Working Memory* and *Action Control Research*

Gidon Frischkorn, Isabel Courage, Hannah Dames, David Dignath, Christina Pfeuffer, Moritz Schiltenwolf, Andrea Kiesel & Klaus Oberauer

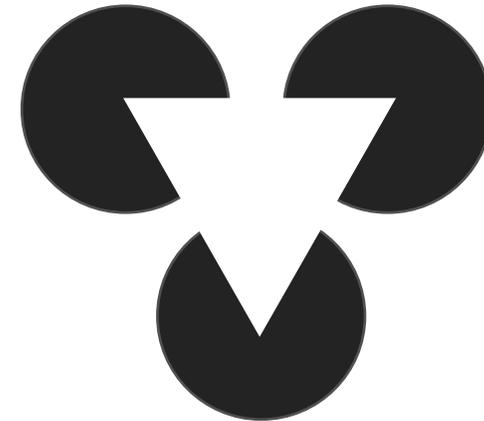
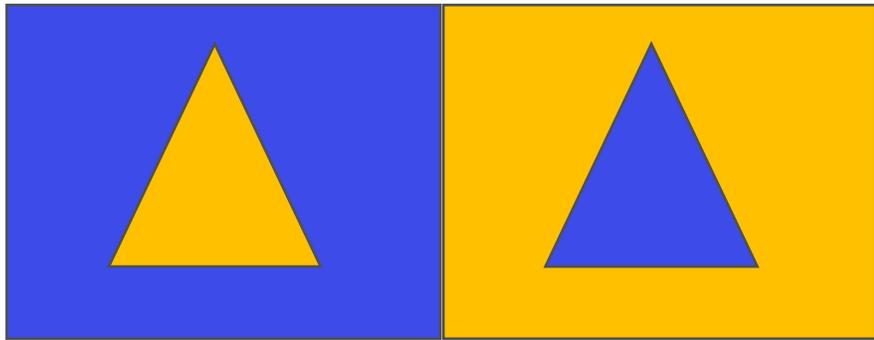


The binding problem



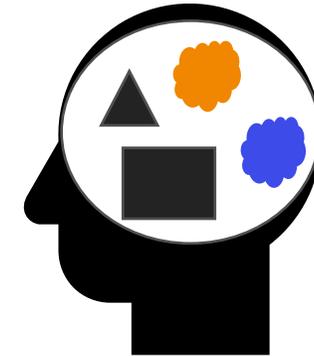
https://de.wikipedia.org/wiki/Anne_Treisman

- How do we process perceptual input so that we obtain object-specific perceptions



The binding problem

- Object perception requires a temporary, episodic representation.
→ The „object file“

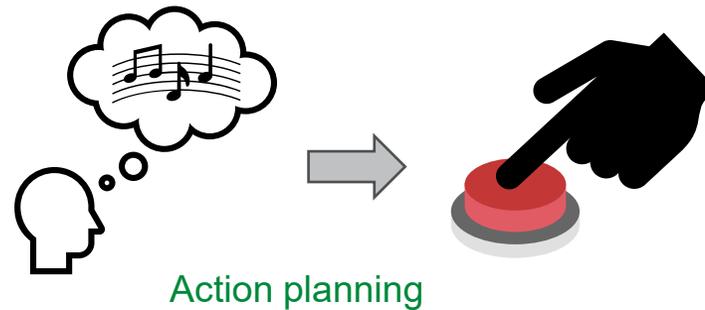
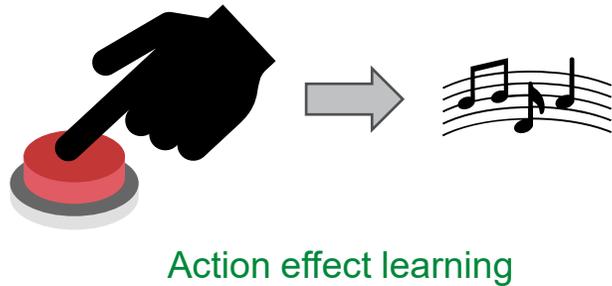


- Object files
 - are cognitive representations.
 - integrate information about the object's current characteristics.
 - indexed by spatiotemporal position.
 - are updated when the object „changes“.
- Mostly concerned with traditional view on perception (seeing, hearing)



Ideomotor theory

- Already in the 19th century, mentioning of the ideomotor phenomenon:
 - A thought can almost reflexibly trigger an associated muscular action.
- Ideomotor theory:
 - Challenges a demarcation between perceptual input/attention and motor output/reaction
 - Assumption of a bidirectional link between the performed action and the perceived action effect.



Theory of Event Coding (TEC)



<https://x.com/BernhardHommel>

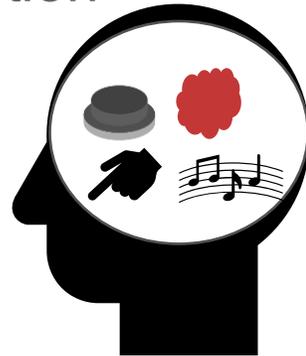
- At its core TEC combines the concept of *object files* with ideomotor theory:

→ Perception and action are not separated but intrinsically linked within a **shared form of cognitive representation** (common code).

→ Action control is exhibited through the representation of external and internal action effects.

→ Two basic processes:

1. Binding: Conjointly activated feature representations of the current event become bound together in an *event file*.



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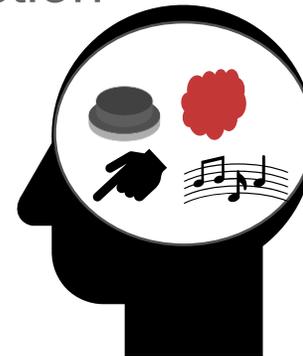
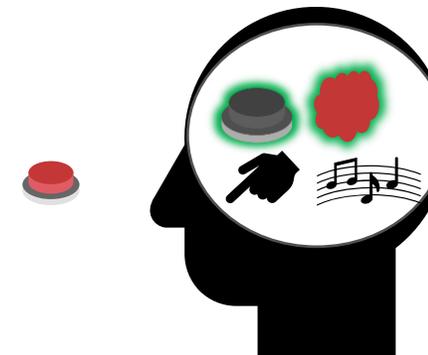
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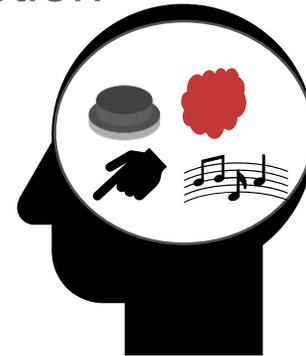
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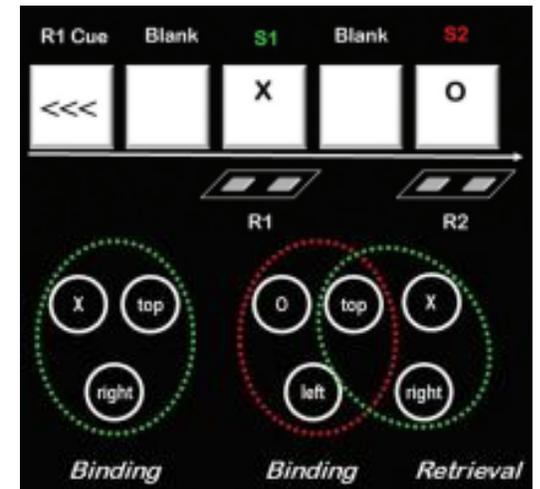


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TEC in experimental psychology: Research group „Binding and Retrieval in Action Control“

- The two core processes *binding* (to an *event file*) and *retrieval* (from an *event file*) can (partially) explain various effects in well-known paradigms of cognitive psychology.
- *Partial repetition costs* in stimulus categorization.
→ Impaired performance on partial repetitions of previous trial.



Hommel (2022)

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 - *Partial repetition costs* in stimulus categorization.
 - *Code occupation* in action planning.
 - Impaired performance on actions that require features of a planned action.

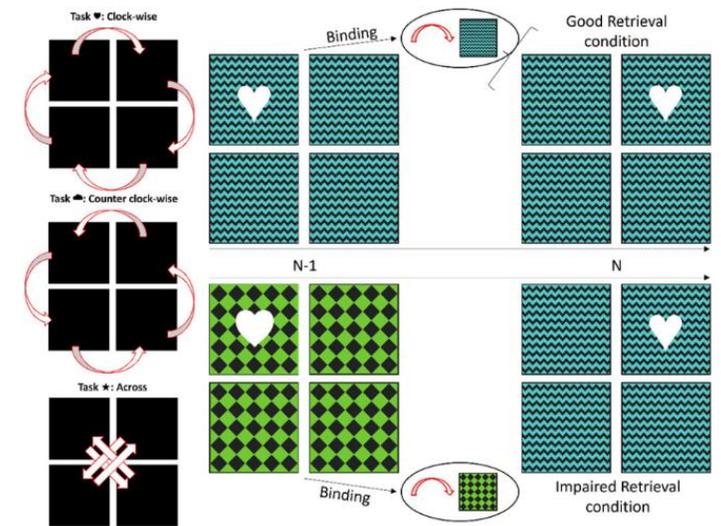


Stoet & Hommel (1999)
Mocke et al. (2022)

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- Partial repetition costs* in stimulus categorization.
- Code occupation* in action planning.
- Switch costs* in task switching.
→ Task performance as a function of retrieval conditions.

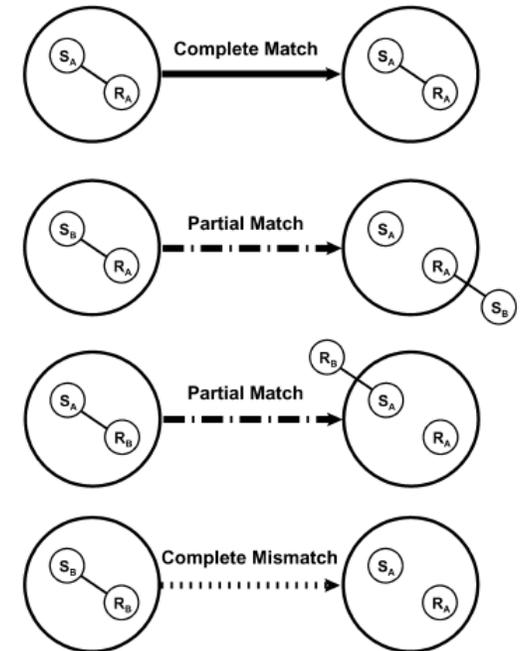


Schiltewolf et al. (2024)

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- Partial repetition costs* in stimulus categorization.
- Code occupation* in action planning.
- Switch costs* in task switching.
- Congruency sequence effects* in Stroop-like tasks.
→ Retrieval conditions can vary with congruency levels across trials.



Hommel et al. (2004)
Schiltenwolf et al. (2022)

TEC in experimental psychology: Research group „Binding and Retrieval in Action Control“

- TEC provides a framework that can be applied to various paradigms,
- But TEC never specifies the processes in a way that allow falsification.

Theory of event coding: Interesting, but underspecified

Chris Oriet, Biljana Stevanovski, and Pierre Jolicoeur

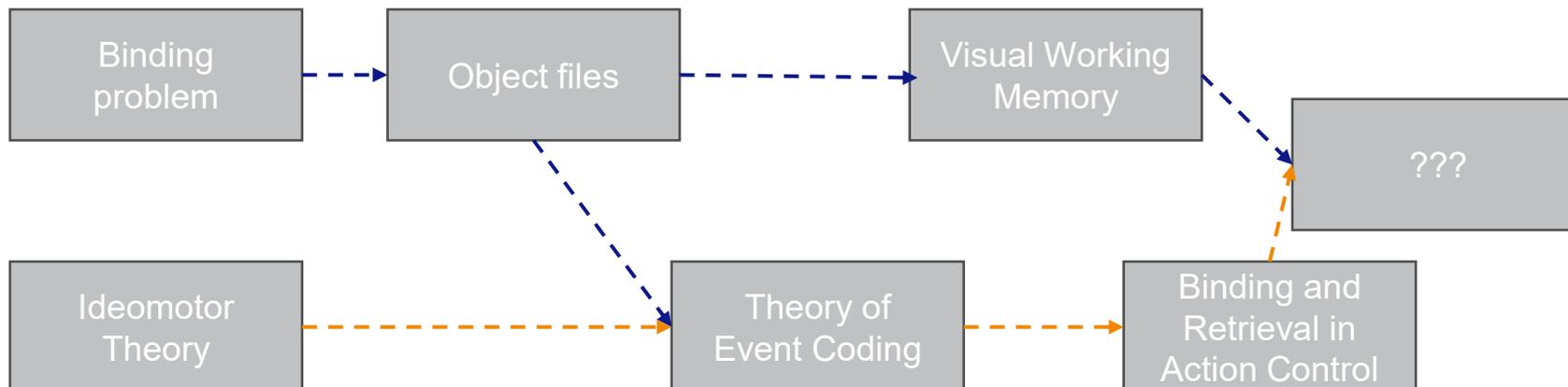
How specific and common is common coding?

Andries F. Sanders

TEC – Some problems and some prospects

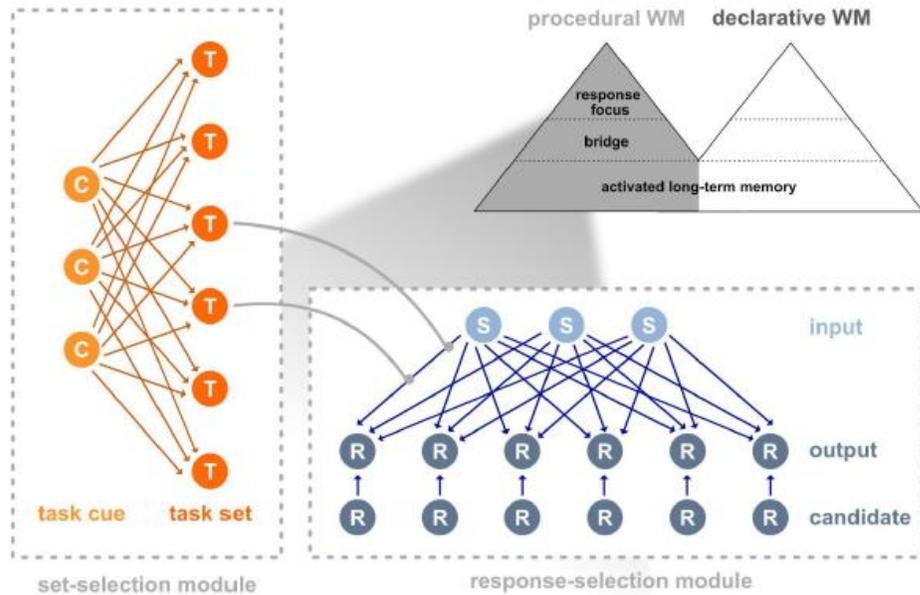
Julian Hochberg

- Looking back at how theories of *object files* have developed:



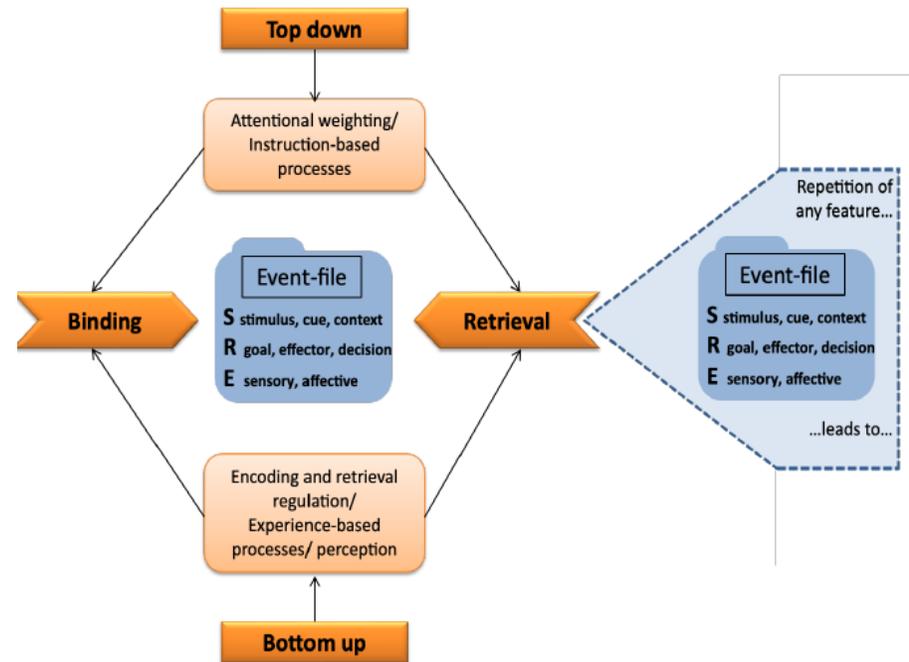
Meeting of WM and TEC

Illustration of the procedural WM model and its main components, the set-selection and response selection module.



Oberauer et al. (2013)

Illustration of the Binding and Retrieval in Action Control (BRAC) framework.



Note. Sketch of the BRAC framework. Adapted from Frings et al., (2020).

Frings et al. (2020)

Meeting of WM and TEC

		BRAC Framework	WM
General System Structure	Separation of Memory Systems	Single memory system with short-lived bindings; recent clarifications suggest transition from WM to LTM based on binding strength, repetition, and spacing.	Separation of WM (limited capacity, fast learning rate) and LTM (large capacity, slow learning rate, stores information permanently). LTM representations built in parallel to WM.
	Capacity Limits	Implicit capacity limits assumed, based on decay and interference within WM.	WM has limited capacity; LTM has no apparent capacity limit. Interference in WM as a limiting factor.
	Representation of Stimuli, Responses	Event files with neuronally distributed, multimodal feature representations; no clear distinction between perception and action.	Stimuli and responses represented as activation patterns in distinct layers.
	Representation of Task, and Control Sets	Task and control states included but not specifically detailed.	Task sets are represented as bindings in the response-selection module, with learned sets in the set-selection module.

Structure and Properties of Bindings	Formation of Bindings	Created based on co-occurrence, influenced by attention and saliency; bindings of all features in independent event files.	Rapid Hebbian learning binds active representations, represented in a weight matrix across events; strength influenced by activation levels. Allows for independent pairwise bindings between stimuli and responses.
	Episode Boundaries for Bindings	Bindings exist for an episode, with boundaries under investigation (decay and unbinding debated).	Bindings remain until actively removed; no causal role for episode boundaries.
	Code Occupation	Feature representations can only be in one event file at a time; unbinding needed for new bindings.	No constraint on binding features to multiple stimuli or responses.
	Sequential Effects on Bindings	Short-lived binding effects; full repetition benefits vs. partial repetition costs.	Previous actions affect subsequent actions due to temporary strengthening of stimulus-response bindings, incomplete updating of bindings, and residual activation.

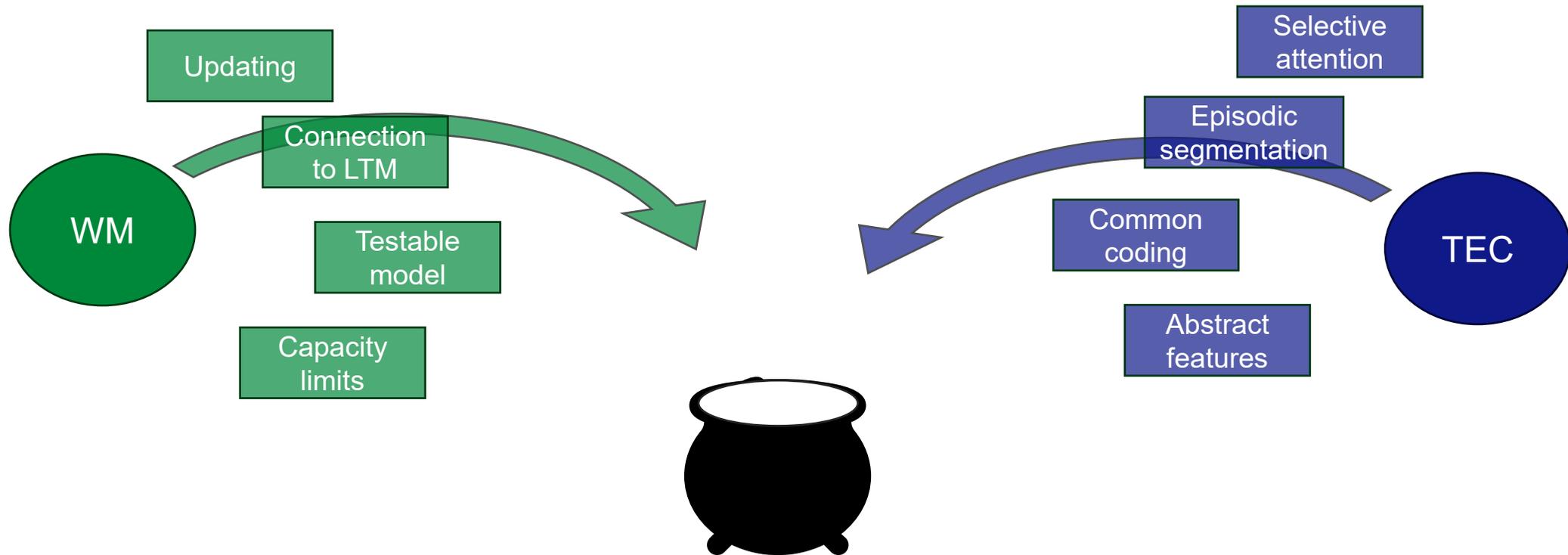
Meeting of WM and TEC

		BRAC Framework	WM
Proposed Processes	Selective Attention	Selective attention influences which features are bound; activated features have higher binding probability.	Features activated through attention are bound via Hebbian learning; selective attention modulates activation strength.
	Learning	Bindings as building blocks for learning; transition to LTM with binding strength.	Separate rapid binding in WM and slow learning in LTM; parallel updates in response-selection and set-selection modules.
	Retrieval	Feature repetition serves as retrieval cues; reactivates the entire event file.	Cue-based retrieval; stimuli act as retrieval cues for responses; task cues act as retrieval cues for task sets.
	Updating	Not explicitly specified; dissolution through decay or unbinding necessary for new bindings.	Explicit updating through delta rule; iterative process until match criterion is reached.

Practical Application in Experiments	Dependent Variables	Primarily reaction times, with some accuracy measurements; focus on sequential effects in prime-probe designs.	Equal weighting of reaction times and accuracy; general model for action control in simple tasks.
	Application in Paradigms	Broad application across various paradigms (e.g., stimulus categorization, action planning, task switching, Stroop-like tasks).	Applied to task-set switching, memory-set switching, and object switching within memory sets.

Meeting of WM and TEC

- Ingredients for a unified model of action control:



Take away

- Theories tend to evolve parallelly to each other.
- For me, it was enjoyable process to align to similar theories to identify their strengths and weakness.
- Drafting the manuscript was tough, but the reviewer/editor feedback was very positive.

→ If you want to read more about bindings, event files and working memory:

Frischkorn, G., Courage, I., Dames, H., Dignath, D., Pfeuffer, C., Schiltenswolf, M., Kiesel, A. & Oberauer, K. (preprint)
Bindings for Action: Bridging the Gap Between Theories of Procedural Working Memory and Action Control Research;
https://doi.org/10.31234/osf.io/ut4e9_v1



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