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The very same thing: Extending the object token concept to incorporate causal constraints on individual identity

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Abstract:

The contributions of feature recognition, object categorization, and recollection of episodic memories to the re-identification of a perceived object as the very same thing encountered in a previous perceptual episode are well understood in terms of both cognitive-behavioral phenomenology and neurofunctional implementation. Human beings do not, however, rely solely on features and context to re-identify individuals; in the presence of featural change and similarly-featured distractors, people routinely employ causal constraints to establish object identities. Based on available cognitive and neurofunctional data, the standard object-token based model of individual re-identification is extended to incorporate the construction of unobserved and hence fictive causal histories (FCHs) of observed objects by the pre-motor action planning system. Cognitive-behavioral and implementation-level predictions of this extended model and methods for testing them are outlined. It is suggested that functional deficits in the construction of FCHs are associated with clinical outcomes in both Autism Spectrum Disorders and later-stage stage Alzheimer's disease.

Keywords: Episodic memory; Action planning; Binding; Force-motion analogy; Medial temporal cortex, Posterior parietal cortex; Autism Spectrum Disorders; Alzheimer's disease

Introduction

Everyday life constantly challenges us to not only to categorize the objects we encounter, but also to re-identify some things that we see as being the very same individuals that were encountered in previous perceptual episodes. Re-identifying something – one's car, for example, or one's spouse – as the very same individual that was encountered on previous occasions clearly involves both a felt sense of familiarity and a recollection of specific features and context, the two components of the standard dual-process model of recognition (reviewed by Yonelinas, 2002; Eichenbaum *et al.*, 2007; Diana *et al.*, 2007; Yonelinas *et al*., 2010). On this standard model, recognizing an object as the same individual encountered previously involves reactivating an individual-specific representation, termed an "object token", in association with an episodic memory of the previous encounter. As defined by Zimmer & Ecker (2010), object tokens are "what" pathway representations, implemented in perirhinal cortex (PRC) within the medial temporal lobe (MTL), that bind features specific to and hence diagnostic of a recognized individual to categorical features of that individual. For example, one's object token for one's car binds features specific to one's car – its license-plate number, identifying dents or scratches, personal items carried within it – to the categorical features of its make, model, color, style, etc. as well as categorical features of cars in general. Reactivating an object token produces a feeling of familiarity with the individual object; reactivating an object token in the context of an episodic memory enables recognition of the individual object as the same thing that was previously encountered in the remembered context (Zimmer & Ecker, 2010). Object tokens thus correspond to the individual "items" in the Binding of Items and Contexts (BIC) model of recognition as a coordinated function of multiple MTL areas (Eichenbaum *et al.*, 2007; Diana *et al.,* 2007; Ranganath, 2010; Yonelinas *et al*., 2010). Object tokens provide an anatomically-specific functional model for the long-term memory (LTM) resident "singular concepts" (Rips *et al.*, 2006) or "singular files" (Bullot & Rysiew, 2007) that had previously been proposed as explanations of the ability to re-identify individuals ("re-identify" will be used throughout for individuals to avoid the ambiguity between individual and categorical "recognition").

While the object token concept and the BIC model are well-supported by laboratory studies of object re-identification (Eichenbaum *et al.*, 2007; Diana *et al.,* 2007; Ranganath, 2010; Yonelinas *et al*., 2010; Zimmer & Ecker, 2010), they are nonetheless challenged both by experimental designs that probe the sensitivity of re-identification to feature change or similarly-featured distractors and by psychological and philosophical studies of the criteria people employ to determine individual identity in circumstances in which it is not clear. False-memory studies, for example, demonstrate reactivation of object tokens in association with the wrong episodic memories (reviewed by Mitchell & Johnson, 2000; Henkel & Carbuto, 2008). Change-blindness studies demonstrate both insensitivity to ordinarily-diagnostic individual-specific features and mis-identification of individuals in the presence of distractors (reviewed by Resnick, 2002; Simons & Ambinder, 2005; Simons & Resnick, 2005). Experiments specifically testing the criteria used to re-identify individuals across perceptual encounters despite feature change and competition from similarly-featured distractors indicate the importance of appropriate casual histories linking the current encounter to previous ones (Rips *et al*., 2006; Gutheil *et al*., 2008; Hood & Bloom, 2008), the importance of different causal, featural and sortal criteria to the re-identification of different kinds of individuals (Rips *et al*., 2006; Xu, 2007; Rhemtulla & Hall, 2009), and the importance of continuity over time of psychological characteristics in the specific case of tracking the identities of individual human beings (Nichols & Bruno, 2010). Such criteria are consistent with those derived from the anecdotal analysis of everyday judgments and from philosophical thought experiments (Rips *et al.*, 2006; Bullot & Rysiew, 2007; Scholl, 2007; Bullot, 2009; Nichols & Bruno, 2010). These diverse results all suggest that the object token concept and the BIC model are incomplete, as they do not at present take causal criteria that constrain object identity between perceptual episodes into account in describing object re-identification.

The human ability to keep track of the identities of individual objects within a visual scene despite motion, feature change, and the presence of similarly-featured distractors has been intensively studied (reviewed by Treisman, 2006; Scholl, 2007; Flombaum *et al*., 2008; Fields, 2011a). Within a continuously-observed visual scene, each individual object is represented by a visuo-motor "object file" that binds position, motion, and feature information. Motion criteria dominate featural criteria in establishing object identity over time, allowing features to change arbitrarily as an object moves (Flombaum *et al*., 2008); however, motion details are suppressed in favor of feature details when an episodic memory of the scene is recorded, allowing memory for the features of the objects in the scene (Fields, 2011a). The emphasis on appropriate causal histories that consistently emerges in both philosophical and experimental studies of individual re-identification across perceptual episodes suggests that the mechanisms of object-token encoding and reactivation may be functionally analogous to those observed in short-duration visual occlusion experiments and the tunnel effect: an appropriate causal history may play the role in individual re-identification across perceptual episodes that a kinematically recognized trajectory (Flombaum *et al.*, 2008; Fields, 2011a) plays in the tunnel effect. Functional, developmental and learnability considerations lend plausibility to this suggestion. Human beings, particularly infants, may implement “Leibniz's Law” as a heuristic, provisionally identifying anything that cannot be distinguished from a previously-encountered object based on its features as “the same thing”; however, such a heuristic risks false negatives when features change over time, false positives if competitors with very similar features may be encountered, and failure if featurally-indistinguishable objects co-occur in one scene. While it has been argued that scenes in which featurally-indistinguishable objects co-occur are “uncommon in the real world” (Hollingworth & Franconeri, 2009, p. 165), scenes involving large numbers of objects that were indistinguishable for all practical purposes, such as forest trees, herd animals, or even hostile members of an unfamiliar tribe were commonplace in the ancestral human niche, and one would expect human perceptual systems to be capable of coping with them. Circumstances that confound Leibnitz's Law are even more common in the contemporary world of mass-produced manufactured objects, frequently-altered clothing, personal accessories and even hair color, and dense urban concentrations of people and objects. Causal histories, together with category-specific constraints on how objects of a particular kind move or change over time (Xu, 2007), provide feature-independent information with which both false positives and false negatives generated by Leibniz's Law can be resolved (Rips *et al.*, 2006; Scholl, 2007). Moreover, unless the environment is dominated by violations of Leibniz's Law, the use of historical information as an adjunct to featural information can be learned through non-specific experience. Rakison and Lupyan (2009), for example, have shown that infants readily learn typical motion patterns as components of high-level categories such as “animate object” and “vehicle”, and that they use such typical motion patterns as constraints on object identification (cf. Luo *et al.*, 2009 who also demonstrate infant use of motion information in object classification). Such considerations suggest that causal history information is employed in parallel with featural information during the process of object re-identification, as opposed to being employed as a secondary backup strategy only in “hard cases” in which purely-featural re-identification processes fail.

The present paper extends the object-token concept of Zimmer & Ecker (2010) to explicitly incorporate information about the causal history of an object between perceptual encounters and hence between recallable episodic memories. It then incorporates this extended object-token concept into the BIC model (Eichenbaum *et al.*, 2007; Diana *et al.*, 2007; Ranganath, 2010; Yonelinas *et al.*, 2010), thus extending this model to incorporate causal constraints on object identity. As between-episode history is by definition unobserved and hence unknown, it must be constructed as *fictive* history using individual- or category-specific constraints. The present model is based on two hypotheses: (1) that fictive causal histories (FCHs) are bound to the object file as an obligate step in the object-token encoding process, and (2) that the pre-motor action planning system constructs the required FCHs. The paper is organized as follows. The next section, “Object categorization and episodic memory encoding” briefly reviews the mechanisms of object-file, event file, and episodic memory encoding, with an emphasis on the role of categorization. It precisely formulates the principle question addressed by the paper – what structural or functional characteristics of object tokens enable the re-identification of specific individuals? – and shows that this question is not addressed by standard experimental designs that probe object recognition. The third section, “Extending the object token concept and the BIC model to include fictive causal histories” first shows that the object token concept (Zimmer & Ecker, 2010) and

BIC model (Eichenbaum *et al.*, 2007; Diana *et al*., 2007; Ranganath, 2010; Yonelinas *et al.*, 2010) as presented cannot adequately account for individual re-identification under conditions in which the features of the re-identified object undergo significant change, even if the model is extended to take category-typical featural change into account. It then reviews data indicating the human use of causal histories in object re-identification, and introduces and motivates the two hypotheses that humans construct FCHs as a part of the object-token encoding process, and that these FCHs are encoded by the pre-motor action planning system. The BIC model is then extended to incorporate these hypotheses. The extended "BIC-FCH" model provides a natural explanation for the fronto-parietal activations that are consistently observed in studies of episodic memory encoding and recall, and that have previously been interpreted in terms of the task-dependent allocation of attention or the implementation of conscious awareness (Wagner et al., 2005; Cabeza et al., 2008; Moscovitch, 2008; Ranganath, 2010). The fourth section, "Testing the BIC-FCH model" discusses both cognitive-behavioral and implementation-level predictions of the extended model, experimental designs to test them, and available data relevant to such tests.

Understanding the mechanisms underlying the ability to re-identify individuals is important not only to the development of adequate theoretical models of episodic memory, but also because they suggest both alternative developmental outcomes in children and specific loci of dysfunction in adults. The fifth section, "Relevance to pathology" discusses potential clinical presentations of either atypical or disrupted construction of FCHs by the action-planning system. It suggests that deficits in FCH construction may underlie common symptoms of both Autism Spectrum Disorders and later-stage Alzheimer's Disease.

Object categorization and episodic memory encoding

Eichenbaum *et al.* (2007) begin their review of evidence supporting dual-process models, and in particular the BIC model, of object re-identification with a scenario that can be considered canonical:

> "Imagine an occasion when you are walking across campus and see someone who seems vaguely familiar. When she greets you, you are quite sure you know this person, and yet you can not recall when you met her or why you know her. A casual conversation ensues and you search for clues with innocuous questions. Further embarrassment is avoided when she says something about a meeting last week. Suddenly you recall her name, where the meeting was, and some of the topics discussed there."

(Eichenbaum *et al.*, 2007, p. 123)

This scenario illustrates the principle claim of dual-process models, that familiarity and recollection are implemented by distinct processes that operate at potentially different time scales. It also illustrates a specific claim of the BIC model, that recollection of a context – i.e. of an episodic memory – is often essential to object recognition and hence to re-identification of a specific individual (cf. Zimmer & Ecker, 2010 for whom episodic memory reactivation is required for re-identification). The phenomenology of recollection does not, however, reveal the mechanism of re-identification: it is not clear how reactivation of the episodic memory of last week's meeting enables the identification of the person represented by the current object file – the unknown colleague – as the very same individual as one of the meeting participants represented in the episodic memory. It is tacitly assumed by the BIC model that a feature match between the current object file and one of the object tokens associated with a retrieved episodic memory is sufficient to identify the current and recollected objects as being the very same thing; however, the question of how similar the features encoded by the two representations must be to enable re-identification is not addressed within the model (cf. Zimmer & Ecker (2010) where this question is similarly elided). Characterizing the mechanism of individual re-identification at the level of detail needed to address this question requires placing the perceptual and memory-reactivation events implied by the recognition scenario into a mechanistic context, and determining what the process of re-identifying a currently-perceived individual adds to the process of categorizing that individual based on its features.

Visual encounters lasting for at least the visual short-term memory (VSTM) consolidation time – about 50 milliseconds (ms) in adults (Vogel *et al.*, 2006) – result in the encoding of intermediate visual representations, object files, that bind features co-occurring at a location or sequence of locations into a persistent "object" (Treisman, 2006; Scholl, 2007; Flombaum *et al.*, 2008; Fields, 2011a). While object files can be instantiated entirely within the dorsal visual processing pathway, for example in response to moving stimuli without statically-distinguishable boundaries or features (Gao & Scholl, 2010), under normal circumstances they are instantiated as co-activations and hence temporal bindings of dorsal-stream location and motion information with ventral-stream shape, color and surface feature information. It is the dorsal-stream information, however, that determines whether an object file is instantiated, and a single object file can represent an object undergoing significant changes in shape, color and surface features. Instantiation of an object file indicates to downstream processes that what is being observed in a *thing*, as opposed to a localized cluster of features of an otherwise-undifferentiated background. It is the obligate first step of object recognition, as it indicates that a collection of detected features and motions "belong together" and therefore constitute a discrete input to the process of object categorization, i.e. the process of determining what *kind of* thing is being perceived.

Categorization associates an object file with one or more object categories. Categories are long-term memory (LTM) resident distributed representations that bind typical feature information represented in lateral (LFG) and medial (MFG) areas of the fusiform gyrus for animate and inanimate objects respectively to typical motion information represented primarily in superior temporal sulcus (STS) and medial temporal gyrus (MTG) for animate and inanimate objects respectively, with the representation of animate objects biased toward the right hemisphere and that of inanimate objects biased toward the left (reviewed by Martin, 2007; Mahon & Caramazza, 2009). Activation of one or more categories by an object file results in a broad pattern of temporal-cortex activation in the region overlying the parahippocampal area of MTL with which the BIC model is primarily concerned. In the scenario quoted above, categorization is indicated implicitly by the words "someone", "she", "greets", "person", "know" and "conversation": the narrator clearly recognizes the unknown colleague as a fellow human, a woman, a social partner with friendly intentions, a speaker of a common language, and from the context of the interaction, a potential campus colleague. The feeling of familiarity develops, in the scenario and in the BIC model (Eichenbaum *et al.*, 2007; Diana *et al.*, 2007; Yonelinas *et al.*, 2010), in parallel with the process of categorization.

Recent experimental studies using static images of rich, cluttered natural scenes indicate that high-level object categorization (e.g. "animal" versus "non-animal") requires approximately 250 ms from stimulus onset, with more specific categorization (e.g. to type of animal) requiring at least 50 ms longer (Macé et al., 2009; Martinovic, 2009). Experiments using fragmented images that require category-driven object completion reveal top-down effects from approximately 200 ms, suggesting that categorization requires at least 50 ms after initial visual processing has been completed (Schendan & Maher, 2009). However, subjects exposed to images of common objects in natural backgrounds for only 130 ms were able to report the presence of objects in target (i.e. primed) categories, e.g. cars or people, even though they failed to categorize objects in non-target categories (Peelen *et al.*, 2009), indicating very rapid top-down modulation of recognition by task demands. Typical motion patterns serve as feature-independent diagnostic criteria within categories; studies using point-light displays show that categorization can be driven by the recognition of motion patterns in the complete absence of feature information (reviewed by Puce & Perrett, 2003; Blake and Shiffrar, 2007). Differences in typical motions between animate and inanimate objects, and between inanimate but self-propelled objects and inanimate objects that only move when acted on by external forces are available to and employed as categorization criteria by infants (reviewed by Baillargeon, 2008; Rakison and Yermolayeva, 2010); even infants can categorize point-light displays, and hence do not require static feature information for categorization (Simion et al., 2008; Kuhlmeier et al., 2010). Categorization times for moving objects are comparable to categorization times for static objects: temporal-lobe cell populations that respond to specific complex motions are activated within 200 ms from stimulus onset (Tkach et al., 2007; Mukamel et al., 2010), consistent with response times for relevant motion detection observed in athletic events (Mori *et al*., 2002). Adults can recognize point-light walker displays in 100 ms (Pavlova et al., 2006); infants older than 7.5 months can recognize such displays within 300 ms (Oakes et al., 2006). These results clearly indicate that categorical motion criteria are applied in parallel with featural criteria, not afterwards, during the categorization process.

Transient bindings of multiple localized, categorized, static or moving objects with goals and action plans – termed “event files” – provide intermediate representations that coordinate perception with action (reviewed by Hommel, 2004). Goals and action plans are represented by a fronto-parietal “praxis network” including areas of parietal, cingulate, and both lateral and medial frontal cortex (Johnson-Frey *et al.*, 2005; Culham & Valyear, 2006; Martin, 2007); coordinating goal-driven action planning with current and projected future positions of perceived objects requires both top-down (dorsal pathway) and bottom-up (ventral pathway) fronto-parietal attentional modulation (Corbetta *et al*., 2008). Event files are, therefore, substantially broader activation patterns than categorized object files. Categorization and hence recognition as a familiar type of object facilitates event-file binding (Colzato et al., 2006; Hommel & Colzato, 2009), as do affective associations of recognized shapes (Colzato et al., 2007). Unimodal event files are bound in 240 to 280 ms (Zmigrod & Hommel, 2010), indicating that event file binding is a parallel process acting across active categorized object files. Scenes containing localized, categorized objects are accessible to consciousness after approximately 270 ms (Sergent *et al.*, 2005), suggesting that the event-file level of correlated neuronal activity corresponds to the “global workspace” proposed as the basic substrate of conscious awareness and attentional control (Baars, 1997; Dehaene & Naccache, 2001; Dehaene & Changeaux, 2004). Spapé and Hommel (2010) suggest that failures of motion predictability initiate the “opening” of new event files, consistent with the role of trajectory information in determining when new object files are “opened” (Flombaum *et al.*, 2008; Fields, 2011a).

Temporally-continuous sequences of event files that have sufficient salience, emotional tonality, or task relevance may be encoded as episodic memories that capture the context, setting, participants, and motivational and affective characteristics of extended events (reviewed by Tulving, 2002). The primary mechanistic claim of the BIC model is that hippocampus (HC) binds context and spatial setting information encoded by a “where” pathway involving parahippocampal cortex (PHC) with categorized significant objects encoded by a “what” pathway involving PRC to encode episodic memories, and that these same representations are reactivated when the episode is recalled (Eichenbaum *et al.*, 2007; Diana *et al*., 2007; Ranganath, 2010). Both PRC and PHC are also active as components of “where” and “what” perception and imagination (Murray et al., 2007; Bird & Burgess, 2008; Graham et al., 2010), again indicating that reactivation of episodic memories at least in part involves the same networks, and possibly the same cell populations, as their encoding. Reactivation of episodic memories is known, however, to involve parietal and frontal areas, not just MTL (Wagner *et al*., 2005; Cabeza *et al.*, 2008;

Ranganath, 2010); this is evident from the fact that episodic memories commonly contain information about "how" and "why" objects came to be where they were in a specific recollected context. Experiments that demonstrate re-activation of feature-location, object-motion and target-action bindings present in recent events (Hommel, 2007; Keizer *et al.*, 2008; Spapé & Hommel, 2010) suggest that entire event files are reactivated by episodic-memory recall, and hence support the specific involvement of areas outside MTL in episodic recall. The BIC model as presented does not directly address the incorporation of "why" information – the intentional or goal-oriented aspect of action – or "how" information into episodic memories; hence it is not clear from the BIC model as presented how target-action bindings are accessed by the HC-mediated binding process contemplated by BIC. As shown below, this question is resolved by extending the BIC model to incorporate FCHs.

The encoding of an episodic memory entails the encoding of object tokens: object tokens are the PRC-encoded records of "what" particular objects participated in an encoded episode (Zimmer and Ecker, 2010). Reactivation of an episodic memory reactivates the object token in PRC. As in the scenario quoted above, this happens "suddenly", without disrupting awareness of an on-going event. The motivating question of this paper can now be starkly posed: what enables the re-identification of an object represented by an object file bound as a component of an event file coordinating on-going perception and action as the *very same individual* as an object represented by an object token retrieved as a component of a newly-reactivated episodic memory? If object tokens add individual-specific features to categorical features as proposed (Zimmer & Ecker, 2010), is there a particular stringency at which features from a current object file must match the individual-specific features of an object token to enable object-token reactivation and hence individual re-identification, or is the object token with closest match reactivated regardless of level of similarity? Unfortunately, many experimental designs that probe object recognition and episodic recall cannot directly address this question, because they conflate the re-identification of objects with the feature-driven re-identification of images. A particularly compelling example is the landmark, 2,500 image visual memory study reported by Brady *et al*. (2008). Subjects in this study were first presented with 2,500 images, each showing a commonplace object against a white background. They were then presented with a pair of such images, and asked to determine which "object" they had seen before in a time-limited, forced-choice design. One-third of the pairs showed images of completely dissimilar objects ("novel" pairs in Fig. 1 of Brady *et al.*, 2008), one-third showed images of objects in the same basic-level category ("exemplar" pairs), and one-third showed images of the same object in two different states or contexts ("state" pairs). The frequency with which subjects made the "correct" choice – i.e. identified the very same *image* that they had seen before – in the state-pair trials (87%) was statistically indistinguishable from the frequency of correct choices in the exemplar-pair trials (88%). These subjects were, therefore, making judgments of sameness of the images, not of the objects depicted by the images; hence the interpretation of the results in terms of memory for details of objects, and in particular as supporting a multiple-exemplar model of categories must be questioned. Indeed the most straightforward interpretation of this study is that it demonstrates an unexpectedly large episodic-memory capacity for the exact featural details of images presented in a single, invariant and largely distraction-free context.

Unlike the subjects in the Brady *et al.* (2008) study and many others like it, human beings under ordinary circumstances are faced with the task of re-identifying moving – in the case of animals or other people, actively behaving – objects in novel contexts. The narrator in the opening scenario is not, after all, confronted a week later with a photograph of the unknown colleague, taken during the remembered meeting, but with an actual person in a new context and doubtless with different clothing and other surface features. Eyewitnesses to crimes are similarly confronted not with images of the crime in process, but with actual suspects in a novel and often highly-distracting setting. It is difficult, however, to design laboratory experiments that replicate these real-life tasks, and thus probe both the level of featural similarity required and the potential role of non-feature information in re-identification. A time-limited, forced-choice study of the scale of Brady *et al.* (2008) carried out using actual objects presented in 3d, e.g. by putting them on a table, would not be feasible. Hence while some very clever designs involving real-world objects have been developed (e.g. Gutheil *et al*., 2008; Hood & Bloom, 2008), the most compelling evidence currently available for testing models of individual re-identification is the commonplace and everyday ability to rapidly and correctly re-identify individual people, animals, places and artifacts demonstrated constantly by human beings in uninstructed, uncontrolled settings. The next section employs such considerations to examine the limitations of the object token concept (Zimmer & Ecker, 2010) and BIC model (Eichenbaum *et al.*, 2007; Diana *et al*., 2007; Ranganath, 2010; Yonelinas *et al*., 2010) as presented, and to extend these to address the observed role of causal history (Rips *et al*., 2006; Scholl, 2007; Gutheil *et al*., 2008; Hood & Bloom, 2008) in individual re-identification.

Extending the object token concept and the BIC model to include fictive causal histories

Formal requirements on object token encoding

As noted in the Introduction, the object-token concept of Zimmer & Ecker (2010) answers the question of how object tokens specify and hence enable the re-identification of unique individuals by proposing that object tokens encode individual-specific, category-irrelevant properties, such as license-plate numbers, identifying marks, or personal decorations for cars, or names, particular facial features, idiosyncratic facial expressions, characteristic gait or other movements, or accent of voice for people. Such properties are "what" information encoded by PRC. The collection of such individual-specific properties defines a "singular category" with just one member, the individual to which the properties uniquely apply (cf. Rips *et al.*, 2006 who refer to this representation as a "singular concept"). An object token represents an individual by instantiating that individual's singular category, as shown in Fig. 1. When a novel object belonging to a known general category is encountered in a context sufficiently memorable to be encoded as an episodic memory, a new object token is encoded that both specializes the category to which the novel object belongs and incorporates features specific to the novel object (Fig. 1a). An encounter with a novel person, for example, specializes the general concept "human being", as well as more specialized but still multi-member concepts such as "woman" or "colleague", and adds individual-specific perceptible features such as facial features, hair color, style of dress, voice, etc. These properties together constitute the singular category of which the particular person is the unique member. The object token representing the person in context – in the scenario of Eichenbaum *et al*. (2007), an academic meeting – is bound as a component of the episodic memory representing the perceptual encounter. Binding within the episodic memory renders the object token, and hence the singular category, reinstatable and hence persistent. A second encounter with the same object – meeting one's new colleague a week after your first meeting – may initially activate only some of the features contained within the singular category, for example the same facial features and accent. Additional perceptual input – in the scenario, the unknown colleague's mention of the previous week's meeting – may be required to reactivate an episodic memory, and hence reactivate the object tokens bound to it. Each such reactivated object token is an instance of a singular category comprising expected individual features, as shown in Fig. 1b. If the features encoded by the occurrent object file on the second encounter sufficiently match those encoded by one of the reinstated singular categories, the object is re-identified. If the second encounter is recorded as an episodic memory, a new object token is associated with the reinstated singular category as an new instance and bound to the new episodic memory.

The re-identification process illustrated in Fig. 1b requires that the features and motions encoded by the occurrent object file are sufficiently similar to those encoded by some LTM-resident singular category to enable categorization of the occurrent object within that singular category, as opposed to encoding of a novel singular category as illustrated in Fig. 1a. In the context of the Eichenbaum *et al.* (2007) scenario, it requires some minimal level of similarity between the unknown colleague and one of the participants in the remembered meeting for re-identification to occur; mention of the meeting and hence recall of the episodic memory does not *guarantee* that the unknown colleague is re-identified as one of the participants, regardless of featural similarity. Human re-identification abilities clearly impose such a minimal-similarity constraint under ordinary circumstances; otherwise it would be impossible to avoid re-identifying someone who falsely claimed to be a participant in a recallable episode, it would be impossible to say, “no, you weren't there.” It is not clear, however, what this minimal level of individual-specific featural similarity that enables re-identification is, or how it depends on the recollected context. Experiments such as that of Brady *et al.* (2008) show that feature matches must in some cases be exact to enable re-identification: images depicting very minor changes in the state of an object were rejected as “different” in over 80% of trials (Fig. 1, Brady *et al.*, 2008). Change-blindness studies, on the other hand, demonstrate that features can in some cases significantly diverge but still enable re-identification (Simons & Ambinder, 2005; Simons & Resnick, 2005). It is, moreover, precisely the categorically-irrelevant features – the ones specific to an individual – that can diverge. The object token concept as presented (Zimmer & Ecker, 2010) does not address the question of why feature matching appears to have different stringencies in different contexts. Moreover, it does not resolve the question of whether singular categories are sets of features that are updated after every re-identification event to maintain consistency with the most recent observation, or are sets of exemplars – effectively sets of object tokens – that may have inconsistent features.

The object-token framework of Fig. 1 can be extended by incorporating category-specific expectations about the featural similarities of category members, and category-specific rules for maintaining feature consistency or currency. People routinely employ category-specific expectations about feature similarity, assuming that unused artifacts of the same make, model, style, and color will be featurally-indistinguishable, for example, but that human beings, animals, other natural objects, and old or used artifacts will be featurally unique (Rips *et al*., 2006; Xu, 2007; Bullot, 2009). People also treat some features as more “essential” and hence diagnostic than others (Xu, 2007). Extending the framework in this way does not, however, resolve the question of why stringent feature matches are required for object re-identification in some contexts but not in others. Indeed the usual deployment of category-specific expectations about featural uniqueness exacerbates the re-identification problem; objects such as human beings that are assumed to be featurally unique are nonetheless routinely re-identified despite significant featural change, raising the question of whether individual-specific features play a primary role in re-identification at all (Scholl, 2007; Hood & Bloom, 2008; Nichols & Bruno, 2010). In the limit of extreme featural change, for example the featural changes undergone by a human being across a lifespan, the concept of a singular category comprising reliably-diagnostic, individual-specific perceptible features is rendered so ill-defined as to become theoretically vacuous. Most theorists of natural language semantics reject purely descriptive (i.e. featural) models of term reference for this reason (reviewed by Reimer, 2009).

Experimental and anecdotal analyses of object re-identification under conditions of uncertainty consistently demonstrate that human beings rely not only on the perceptible features but also on the causal history of an object to determine its identity (Rips *et al.,* 2006; Scholl, 2007). In the experimental design of Gutheil *et al*. (2008), for example, both adults and 4 – 5 year-old children were required to determine which of two identically-featured plush toys they had interacted with previously. Both children (80% to 87% depending on conditions) and adults (93% to 100% depending on conditions) based their determinations of identity on the causal history of the toy. The design of Hood & Bloom (2008) demonstrates that children, like adults, value objects with known and personally-significant history over identically-featured copies (cf. Frazier & Gelman, 2009 who demonstrate a similar result for objects with publicly-significant histories). The history of an object between perceptual episodes is not, however, a perceptible property; the between-episode history of an object is not encoded in the object file. Hence history is not a component of the standard (Zimmer & Ecker, 2010) object-token concept, and is not considered in the BIC model as presented (Eichenbaum *et al.*, 2007; Diana *et al.*, 2007; Ranganath, 2010; Yonelinas *et al*., 2010). Incorporating causal history into the object-token concept and the BIC model, as the data appear to demand, requires answering the fundamental question of how the unobserved history of an object can be represented within the object-token encoding process.

The first hypothesis of this paper is that human beings employ category-specific constraints to construct FCHs for objects, and that re-identification requires the construction of an FCH linking a previously-encoded object token to an occurrent object file. An FCH, on this hypothesis, provides temporal continuity to a sequence of object tokens encoded during distinct perceptual interactions in the same way that a recognized trajectory provides temporal continuity to a sequence of object files encoded within a single perceptual interaction. The simplest FCH is the assumption, employed by people to re-identify their cars in parking lots or the furniture in their houses, that inanimate objects left to themselves do not do anything. Assuming this FCH for most ordinary objects allows human beings to solve the otherwise-intractable Frame Problem, the problem of determining how to act in the absence of complete knowledge about what might have changed as a consequence of ongoing actions (reviewed by Shanahan, 2009). Unobserved animate objects, however, are expected to carry out independent, category-consistent, goal-driven actions. The unknown colleague in the scenario of Eichenbaum *et al.* (2007), for example, would be expected to have carried out a rich variety of actions during a week of non-observation. From the perspective of the narrator, however, these complex expectations can be reduced to a simple FCH: the unknown colleague has been here on campus. This FCH provides a continuous causal path from last week's meeting to the present encounter, and is consistent with a tentative categorization as an academic colleague. It may be false – the unknown colleague may have flown to Antarctica and back – but it is consistent with everything that the narrator has observed, and is the minimal assumption that provides a continuous causal path while maintaining consistency with observations.

A formal incorporation of FCHs into the object token encoding process of Fig. 1 is illustrated in Fig. 2. The result of encountering a novel object is no different from that shown in Fig. 1a: nothing is known about a novel object other than what can be perceived; hence a singular category comprising its categorical and individual-specific features is instantiated when its object token is bound as a “what” component of an episodic memory. Reactivation of features on a second encounter generate a feeling of familiarity as described above. Re-identification, however, requires both feature matching and the construction of an FCH linking a previous object token, reactivated in association with an episodic memory, to the current object file (Fig. 2a). This FCH must be consistent with categorical constraints on possible motions or actions (Scholl, 2007; Xu, 2007); someone encountered on the campus of a U.S. university will not be identified as a familiar colleague, regardless of featural resemblance, if one's last encounter with that colleague was 30 minutes ago, via a phone call to Antarctica. While an exact feature match that conflicts with categorical motion constraints can produce surprise, under most circumstances human beings re-identify individuals without the need for conscious deliberation. The encoding of FCHs can, therefore, only require information that is available to the binding process over the timecourse of episodic memory encoding, i.e. information encoded by the current event file, the previous object token and its associated episodic memory, and the singular and general categories representing the object. The addition of FCHs to object tokens converts a timestamped sequence of object tokens (Fig. 1b) to a linked list of object tokens, as illustrated in Fig. 2b. Linking object tokens by FCHs links the episodic memories to which they are bound into a historical sequence of episodes: a "life" of the re-identified individual. Such lives provide a persistent structure to the singular category upon which annotations of feature changes and *post-hoc* inferences of context-dependent, individual-specific behavioral regularities can be based, enabling the singular category to serve as an inferentially-productive "model" of the individual. The implementation of implicit object models by linked lists of exemplars is typical of event-oriented spatio-temporal database systems, which have substantially greater query-answering capability than earlier, timestamped-exemplar "snapshot" systems (reviewed by Pelekis et al., 2004). In the case of human individuals, models of behavioral tendencies have been shown to be important enablers of re-identification across both radical featural change and causal discontinuity (Nichols & Bruno, 2010).

Implementation of fictive causal histories in Temporal and Parietal cortex

The BIC model as presented is concerned with HC-mediated binding of context and spatial setting information encoded by PHC with categorized significant objects encoded PRC (Eichenbaum *et al.*, 2007; Diana *et al*., 2007; Ranganath, 2010). As noted above, however, the events which are encoded as "context" within PHC are represented as they happen by activations extending across the temporal, parietal, and frontal lobes. A primary function of these extended activation patterns is the planning and execution of context-appropriate goal-directed actions affecting one or more perceived objects. An action plan is effectively a prediction that a represented sequence of transformations will generate a goal state from an observed or imagined base state (reviewed by Schubotz, 2007; Bubic *et al.*, 2010). The second hypothesis of this paper is that FCHs are action plans that generate the current context in which an object is observed from the context represented by the most recent episodic memory containing a significant partial feature match to that object. Under this hypothesis, an object is re-identified as a previously-encountered individual if but only if (1) the features encoded in current object file significantly match those of an object token associated with a previously-encoded episodic memory, and (2) an action plan involving the object – the FCH – can be constructed that predicts the current observational context from the context recorded in the retrieved episodic memory. The facility of FCH construction can compensate for difficulty in feature matching, allowing the stringency at which a feature match is "significant" to remain vague and context-dependent. Familiar objects for which FCHs cannot be constructed will not be re-identified as known individuals, regardless of the quality of feature matches to retrievable object tokens.

Actions involve goals and hence agency. Human beings represent the observed or imagined actions of other agents as mirror-system activations in the action planning system (Rizzolatti and Craighero, 2004; Cattaneo & Rizzolatti, 2009; Gazzola & Keysers, 2009). Observed or imagined motions of inanimate objects that are caused by the actions of agents, such as manipulations of tools, are represented as left-hemisphere biased posterior-parietal cortex (PPC) activations (Culham and Valyear, 2006; Lewis, 2006; Martin, 2007; Mahon & Caramazza, 2009). Visuomotor networks in STS and SPL are involved in recognizing complex (typically animate) and simple (typically inanimate) motion trajectories as components of events (Nassi & Callaway, 2009; Fields, 2011a). Mirror activations within the right-hemisphere temporal-parietal junction (TPJ) area of IPL are particularly involved in associating inferred goals and intentions with manipulations carried out by agents (Rizzolatti & Craighero, 2004; Cattaneo & Rizzolatti, 2009). Is is hypothesized that FCHs, as plans representing actions by agents that affect their own states or those of other agents or inanimate objects, are represented by activations of these same systems; in particular, superior temporal sulcus (STS) for motions of agents, superior parietal lobule (SPL) for motions of inanimate objects, and inferior parietal lobule (IPL) for goal-driven manipulations.

Fronto-parietal activations have consistently been observed during episodic memory encoding and retrieval, but have been interpreted primarily in terms of task-specific but object non-specific attentional modulation (Wagner, 2005; Cabeza et al., 2008; Uncapher & Wagner, 2009; Ranganath, 2010) or the imaginative requirements of re-instating a conscious experience of the remembered event (Moscovitch, 2008; Ranganath, 2010). However, a meta-analysis of activation foci for both episodic memory retrieval and attentional effects in the left PPC suggests that object-nonspecific attention modulation cannot explain all episodic memory retrieval-related activation, particularly in IPL (Hutchinson *et al*., 2009). The hypothesis that FCHs are constructed by the same systems that represent motions and intentional actions predicts activation of both left and right IPL, as well as STS and SPL. Considering “attention” to be the selective amplification of one activation pattern at the expense of competitors (Chun *et al*., 2011), re-identification of an object is expected to produce object-specific and action-specific activations in these areas similar if not identical to those observed when a subject attends to particular occurrent objects or actions, as discussed in more detail below. Activations in these areas would be expected during both encoding and retrieval of episodic memories, with the specific activation pattern dependent on the kinds of objects for which FCHs are constructed, and the kinds of motions required by those FCHs.

The incorporation of FCHs as an implementation of causal continuity extends the BIC model, with its focus on MTL, to a broader “BIC-FCH” model that couples item-to-context binding in MTL with FCH construction in the superior temporal lobe and PPC. The BIC-FCH model model further differentiates familiarity from recollection by adding a temporal-parietal activation loop between feature-driven familiarity and object-driven episodic recollection, as shown in Fig. 3. The feeling of familiarity results from activation of PRC-encoded feature representations as predicted by the standard object token concept (Zimmer & Ecker, 2010) and the BIC model (Diana *et al.*, 2007; Yonelinas *et al*., 2010). However, many candidate object tokens, and hence many candidate episodic memories, may be activated by the features associated with an occurrent object file. Recognition of a known agent or a known object and hence recollection of a specific previous episode requires the resolution of this ambiguity by the construction of an FCH that links a specific object from a particular previous episode to an object in the current event file by a causal path. Construction of an FCH involves a search for actions capable of mapping a previous “what” and “where” to the occurrent “what” and “where” (Schubotz, 2007; Bubic *et al.*, 2010). Identification of a suitable action answers “why” and “how” an agent or an object could have gotten from the previous episode to the current one, allowing re-identification of the agent or object as a unique, known individual.

As discussed above, the search for an FCH is constrained by the motions and actions that are categorically associated with the objects or agents represented in the occurrent object file. These categorical constraints are specialized both to the particular locations and motions represented in the occurrent event file and to the particular locations and motions represented in event files reinstated from retrieved candidate episodic memories. The constructed FCH is an action plan that satisfies both categorical and contextual constraints. The computational complexity of this constraint-satisfaction problem is significantly reduced by the architecture of the action-planning system, which represents actions by force-motion combinations that can be executed by the body (Bubic *et al.*, 2010). In this representation, constraint satisfaction requires coherently scaling the forces and motions used or observed in some previous episode to match the forces available and motions required to produce the goal configuration of agents and objects from the base configuration. Inferences that perform such force-motion scaling are structure mappings (reviewed by Markman & Gentner, 2001; Gentner, 2003; Holyoak, 2005); they are used ubiquitously among vertebrates to perform tool improvisation (Fields, 2011b) and among humans to carry out analogical reasoning in the force-motion domain (Fields, 2011c). Within the BIC-FCH model, individual re-identification is an effectively analogical process; an individual can be re-identified across perceptual encounters if an FCH can be constructed that is structurally analogous to previously observed or experienced actions.

As indicated in Fig. 3, the BIC-FCH model hypothesizes “how” and “why” inputs to HC from SPL and IPL respectively. These inputs are bound by HC to the “what” and “where” inputs from PRC an PHC respectively to form episodic memories that record not just items and contexts but also actions and the goals driving them. Hence on the BIC-FCH model, episodic memories involving re-identified individuals are expected to have fictive “tails” that correspond to constructed, i.e. assumed histories of contexts, actions and goals. Reactivation of an object token from such an episodic memory would reactivate the context of the remembered episode, but also a substantially fictive history of the represented individual that extended back toward previous recallable episodes and forward toward the present situation. Recallable individual histories, however fictive, implement the “models” of individuals illustrated in Fig. 2b in the relatively precise functional-anatomical sense defined by Pezzulo & Castelfranchi (2009) and Bubic *et al*. (2010). Such models are inferentially productive in that they allow predictive planning based on the anticipation that future goals and actions will be analogous if not straightforwardly similar to past goals and actions.

Testing the BIC-FCH model

The BIC-FCH model makes both cognitive-behavioral and implementation-level predictions that distinguish it from feature-driven categorization-based models, including BIC (Eichenbaum *et al.*, 2007; Diana *et al*., 2007; Ranganath, 2010; Yonelinas *et al*., 2010), of individual re-identification. The most fundamental model prediction is that human beings encode FCHs in the course of re-identifying everyday objects, other people, and themselves. At the implementation level, the model requires active involvement of the action-planning system in all instances of object re-identification across lapses in observation, not just in “hard cases” where features alone would produce ambiguous results. It predicts that disruption of this system will lead to failures in object re-identification even if familiarity, feature memory, and memory for episodic contexts are fully preserved.

The BIC-FCH model can be tested at the cognitive-behavioral level by experimental designs that probe memory for unobserved events. On standard episodic-memory models, unobserved events are “remembered” only as a result of memory failure, e.g. mis-assignment of an object token to the wrong episodic memory (Henkel & Carbuto, 2008). If subjects must construct FCHs in the course of object re-identification, however, they would be expected to report actions embedded in FCHs as memories, without the delay required for conscious deliberation. Adults or children in the study of Gutheil *et al*. (2008), for example, would be expected to report without delay that the toy that the experimenter carried out of the room was with the experimenter during the period of non-observation, as being continuously with the experimenter during this period would be an essential component of an FCH enabling the toy's re-identification in the presence of an identically-featured competitor. The reportability of unobserved events is expected to depend on the facility of FCH construction, and hence on the content of the singular category associated with a re-identified object. Subjects would be expected to report unobserved locations or actions of familiar objects, animals or people with a facility comparable to that of reporting observed facts regarding such objects, animals or people. Reports of unobserved locations or actions of unfamiliar objects, animals or people, for whom a subject encoded only a rudimentary singular category, would be expected to require conscious deliberation. Forced-fabrication designs, such as those of Chrobak (2010), in which familiarity can be manipulated may be useful for investigating the dependence of FCH recall on the facility of FCH construction. Autobiographical reports provide a special case in which the observed object is familiar and observation is continuous, but accessible episodic memories are spotty. Subjects would be expected to report FCHs as recalled facts of personal history, without deliberation, in place of or in addition to re-experienced episodic memories. The study of Mendelsohn *et al.* (2009), which reports increasing autobiographical confabulation over time in a healthy individual, provides a design which may be adaptable to directly probe autobiographical FCH construction.

As the BIC-FCH model predicts that featural and causal constraints on object identity are imposed in parallel, it predicts that they will compete in cases in which featural similarity and causal history conflict. This prediction can be tested by designs that present subjects with a single object during a familiarization stage, and then with two competing objects and the task of identifying which is the same one encountered previously at the test stage. Feature-history conflict should emerge whenever featural similarity slightly favors one of the competing objects while facility of FCH construction favors the other. The classic experiment of Simons & Levin (1998), in which subjects failed to notice a change of conversation partner in situations in which FCH construction would strongly favor object continuity, provides positive evidence for feature-history conflict of the kind predicted.

Additional evidence for FCH construction may be obtainable from both learning and forced-choice re-identification designs. In the BIC-FCH model, FCH construction is facilitated by structural similarities among the actions associated with an object. Learning environments in which novel objects exhibit only small qualitative changes in motion patterns and responses to external forces would be expected to facilitate individual re-identification, while re-identification would be expected to be inhibited by learning environments in which objects exhibit large qualitative changes in motion patterns or responses to external forces. The use of “blickets” (Gopnik & Schultz, 2004) or similar unfamiliar devices for which behavior can be arbitrarily manipulated independently of observable surface features in a design similar to that of Gutheil *et al*. (2008) would provide a useful probe of the dependence of re-identification on behavioral consistency across time. A same/different forced-choice design in which distinct but identically-featured objects were presented in a sequence of different contexts, with the causal plausibility of the context transition as the manipulated variable, would provide a probe of the dependence of both re-identification time and re-identification success on causal plausibility of the context transition. With the addition of a familiarization period in which a “history” of transitions of the “same” object was presented, such a design could also probe the dependence of response time on the historical consistency of context transitions. As feasible designs along these lines would require use of images, they would have to control for subjects recognizing image features as opposed to objects, e.g. treating the depicted context as a background image and ignoring the physical constraints that the depicted context transitions would impose on a real-world object.

The BIC-FCH model predicts that all FCHs include “why” information (Fig. 3). It therefore predicts that human beings will remember and report unobserved histories of inanimate objects as involving actions by agents. The human tendency to “over-attribute” intentionality to purely mechanistic causal interactions is well documented (Scholl & Tremoulet, 2000; Atran & Norenzayan, 2004; Rosset, 2008) and has previously been explained in terms of selective pressures acting over evolutionary time (Barrett, 2000; Boyer & Bergstrom, 2008). The BIC-FCH model suggests that such over-attribution is a side-effect of the action planning required for object re-identification.

Testing the BIC-FCH model at the implementation level using functional imaging or functional disruption, e.g. by transcranial magnetic stimulation (TMS), would require designing contrasts that clearly differentiate object-specific FCH construction from object-nonspecific task demands. As noted above, selective amplification of one visuo-motor activation pattern at the expense of competitors is required by tasks requiring attention to actions or moving objects (Chun *et al*., 2011); selective amplification of one visuo-motor activation pattern at the expense of competitors is also required, on the BIC-FCH model, for FCH construction and hence for object re-identification. It is entirely possible that subjects experience the construction of FCHs, in cases in which sufficient time for conscious awareness is required, as "paying attention" to an object. Hence object re-identification and object-specific attention may activate the same regions of PPC and adjacent temporal cortex because they are, in fact, the same task (Fields, 2011a).

Pairing object re-identification tasks with control tasks requiring spatially-focused attention but not manipulation or other executed or imagined actions would be expected to remove object-nonspecific activations of attention control areas such as cingulate and dorso-lateral prefrontal cortex that are commonly observed in episodic memory paradigms (e.g. Mendelsohn *et al.,* 2009; Summerfield *et al*., 2009). Contrasts between re-identification tasks involving inert objects, self-propelled objects, animals, and people would be expected to differentiate activations of distinct areas within PPC. For example, re-identifications of inert objects across distinct contexts, and hence across context transitions requiring motion, would be expected to preferentially activate SPL (object motion) and TPJ (intentional manipulation of the object by an agent), while re-identifications of animals or people across distinct contexts would be expected to preferentially activate STS (agent motion) and IPL (intentional action). Activations in all of these areas have previously been attributed to object-nonspecific attentional effects (Wagner, 2005; Cabeza et al., 2008; Uncapher & Wagner, 2009; Ranganath, 2010); hence appropriate control tasks with equivalent attentional requirements but without motion analysis or action-planning requirements would be required to isolate FCH-specific activations. It has been demonstrated that the specificities of networks with mirror functionality, some of which span STS, IPL, and downstream pre-motor areas, are sensitively dependent on individual experience (Heyes, 2010); hence individual-specific activation-contrast analysis of the type performed by Gazzola & Keysers (2009) may be necessary to adequately test these predictions.

Relevance to pathology

The incorporation of FCH construction into object re-identification introduces the possibility that specific functional variants or dysfunctions of the action-planning system may present clinically as specific disruptions in object re-identification abilities. Two cases of variant functioning are of interest: the construction of atypically-precise FCHs that over-constrain object identities, and failure to construct FCHs. These variant functions may be expected to produce clinically-significant outcomes both in early development and in later life.

It has been suggested that over-activation of dorsal-stream trajectory information relative to ventral-stream feature information in object files may result in the encoding of object tokens that are over-constrained by motion information, and hence result in failure to re-identify individuals if they execute unexpected motions (Fields, 2011a). The BIC-FCH model extends this suggestion from the domain of perceived motions to that of constructed FCHs. If categorical constraints on actions (for agents or self-propelled objects) or passive motions (for inanimate objects) were atypically narrow, FCH construction would be limited to histories satisfying these narrow constraints. Atypically narrow action or motion constraints could result from learning in motion-impoverished environments, or from dorsal-stream over-activation and hence overly-specific encoding of trajectory information during learning. If active during the period from late infancy to early childhood during which object categories are being learned, the latter mechanism would be expected to result in systematically narrow categorical constraints on actions and motions, systematically over-constrained FCHs, and hence pervasive difficulties in re-identifying objects when they acted, moved, or were moved in ways not previously experienced. In late infancy or early childhood, such difficulties could be expected not only to disrupt re-identification of family members and other individual human beings, but also to disrupt the re-identification of ordinary objects across changes in location or context. Pervasive difficulty in individual re-identification could be expected to present clinically as failure of appropriate emotional attachments, failure of age-appropriate name and common noun learning, and adverse emotional responses to changes in context, all common symptoms of Autism Spectrum Disorders (ASD; APA, 1994). The BIC-FCH model thus suggests that ASD may be, at least in part, a disorder of individual object re-identification. ASD patients are known to exhibit specific visual deficits, particularly in the perception of biological motion, the understanding of facial expressions, and the grasping of complex scene gestalt (reviewed by Simmons *et al*., 2009); however, specific deficits in individual object re-identification across perceptual episodes have yet to be investigated.

Failure to construct FCHs due to specific disruptions in the pre-motor action planning system would, on the BIC-FCH model, result in pervasive failure of individual object re-identification, with the types of objects affected dependent on the areas (e.g. IPL versus SPL) affected by the functional disruption. Specific disruption of FCH construction would be expected to present as a “re-identification agnosia” in which particular individuals could not be re-identified across contexts, even if they could be correctly categorized and both semantic knowledge about the unidentifiable individual and episodic memories containing the individual as a participant were spared. As components of the action-planning system are involved ubiquitously in the management of attention (Corbetta *et al.*, 2008), predictive reasoning (Bubic *et al.*, 2010), and self-relevant “default” social cognition (Buckner *et al.*, 2008), deficits in individual re-identification would be expected to present in combination with attentional control, planning, and social-cognition deficits. These deficits present in the expected combination in later, demented stages of Alzheimer's Disease (AD), with patients often failing to re-identify family members and other familiar individuals even though they can sometimes recall facts about these individuals and deep episodic memories of contexts in which the unidentifiable individuals were participants (reviewed by Minati *et al.*, 2009; Jicha & Carr, 2010). Spared deep episodic recall in such cases would be expected not to include “how” and “why” information; whether this is true remains to be investigated. Disruptions of episodic recall have been observed in some patients with non-neurodegenerative PPL lesions (reviewed by Cabeza et al., 2008; Olson & Berryhill, 2009); however, neither individual re-identification nor the preservation of “how” and “why” information have been specifically tested in such patients.

Conclusions

Ordinary human social life would be impossible without the ability to re-identify individual people, animals, and things across gaps in observation and in the presence of both feature change and similarly-featured distractors (e.g. Dunbar, 2003). It has long been known that human beings employ causal constraints to resolve ambiguity in cases in which re-identification is uncertain (Rips *et al*., 2006; Scholl, 2007). The implementation of this ability has, however, not been characterized. The present paper proposes a mechanism by which causal constraints can be applied to individual re-identification: the construction of fictive causal histories. It extends the well-supported BIC model of the role of hippocampus in episodic memory encoding and recall to incorporate this mechanism. The resulting BIC-FCH model is based on the hypothesis that the pre-motor action planning system constructs FCHs, and hence that a temporal-parietal loop of activation, specifically involving both IPL and SPL, is an obligate component of episodic memory encoding and recall. The BIC-FCH model is supported by both cognitive-behavioral and neurofunctional data, but new experimental designs that specifically control for attentional effects and other confounding factors will be required to test it.

The BIC-FCH model implies that human beings not only assume that objects are persistent through time (Scholl, 2007; Baillargeon, 2008), but that they also assume, via the construction of FCHs, specific unobserved histories for every individual object that they re-identify as being the very same thing as encountered previously. It implies, in other words, that "mental time travel" (Suddendorf & Corballis, 2007) is as post-dictive as it is predictive, that the remembered past – even the past of episodic memories – is as much a cognitive construction as the anticipated future. If the BIC-FCH model proves to be correct, it will show that the cognitive ability to plan manipulations of objects is the foundation on which the assumption of object persistence and hence the possibility of a remembered past are built.

Statement regarding conflict of interest

The author states that he has no financial or other conflicts of interest relevant to the research reported here.

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Figures

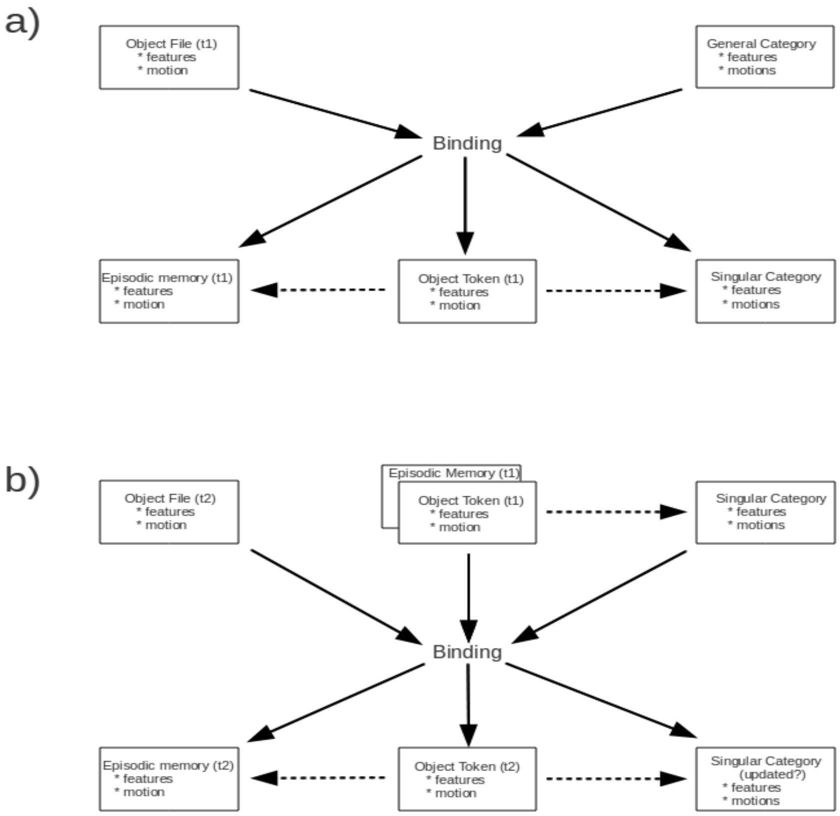

Fig. 1: Components of a categorization-based model of individual re-identification. a) Binding of an occurrent object file representing a novel individual results in the encoding of three distinct representations, all of which capture the occurrent features and motion of the novel individual: a timestamped episodic memory representing the event in which the novel individual is participating, a timestamped object token representing the occurrent state of the novel individual, and a new “singular” category. b) Binding of an occurrent object file representing a familiar individual results in the encoding of a timestamped episodic memory representing the event and a timestamped object token representing the occurrent state of the individual. The singular category representing the individual may be updated to incorporate altered features, or may accumulate exemplars depending on the details of the model. The notions “t1” and “t2” represent timestamps.

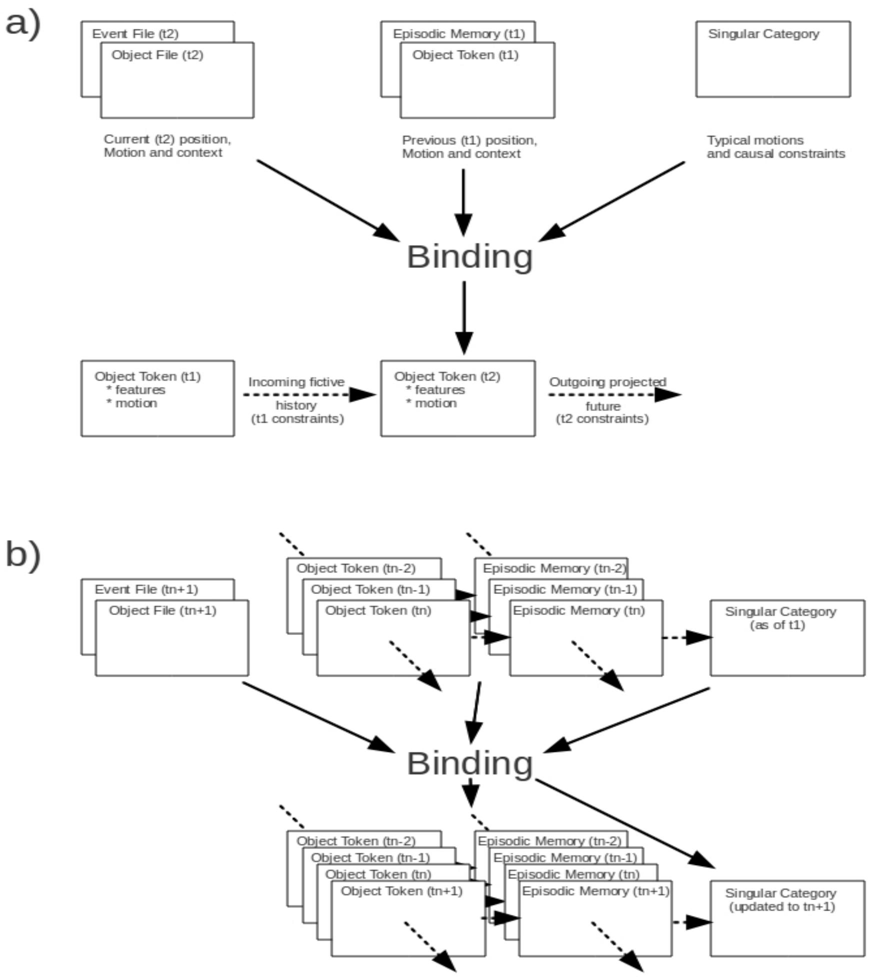

Fig. 2: Incorporation of fictive causal histories into a categorization-based model. a) Binding of occurrent object and event files to a previous (timestamped t1) object token, associated episodic memory and associated singular category generates a new object token (timestamped t2) linked to the previous object token by an FCH and extrapolated forward by a projected future. Both interpolation and extrapolation are based on the motion and action constraints available in the singular category as it enters the binding process, i.e. the motion and action constraints it encoded as of t1. b) Binding an occurrent object and event file to existing linked lists of object tokens and associated episodic memories appends current (timestamped tn+1) object tokens and episodic memories to the linked lists and updates the feature and motion information in the singular category as required by the current object and event files.

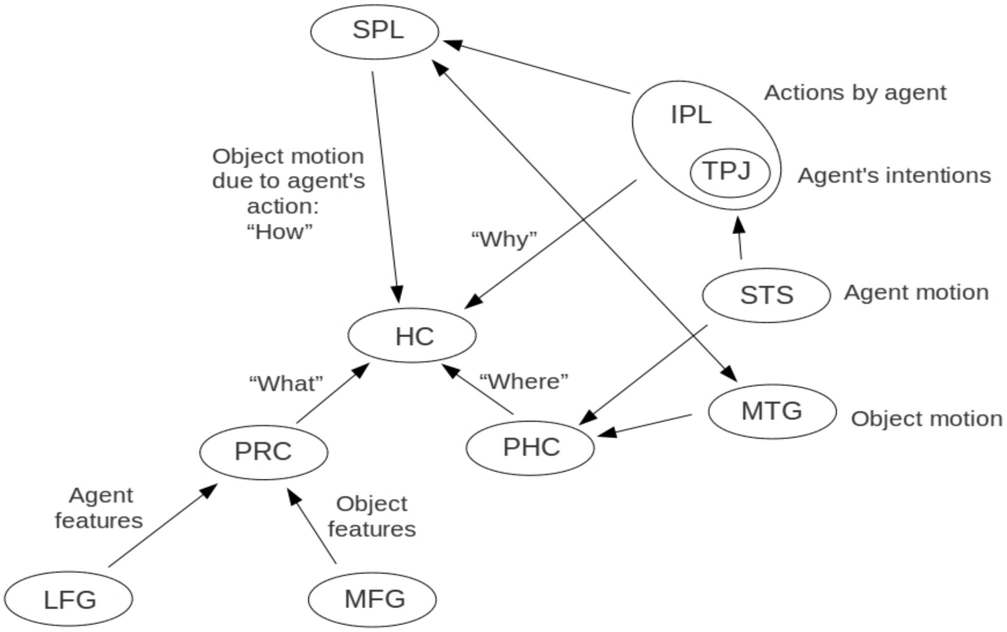

Fig. 3: Schematic representation of the temporal-parietal activation loop proposed by the BIC-FCH model. All abbreviations are as defined in the text.