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Conscious intention and motor cognition

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The subjective experience of conscious intention is a key component of our mental life. Philosophers studying 'conscious free will' have discussed whether conscious intentions could cause actions, but modern neuroscience rejects this idea of mind–body causation. Instead, recent findings suggest that the conscious experience of intending to act arises from preparation for action in frontal and parietal brain areas. Intentional actions also involve a strong sense of agency, a sense of controlling events in the external world. Both intention and agency result from the brain processes for predictive motor control, not merely from retrospective inference.

Introduction

Wittgenstein famously asked 'What is left over if I subtract the fact that my arm goes up from the fact that I raise my arm?' [1]. The conscious experience of intending to move one's arm is a partial answer. The term 'intention' covers several distinct processes within the chain of information processing that translates desires and goals into behaviour. Searle [2], for example, has distinguished between prior intention (e.g. to telephone a friend this evening), and intention-in-action, which would occur during the process of reaching for the phone. This review focuses on laboratory experiments investigating conscious states associated with simple manual actions, corresponding roughly to Searle's intentions-in-action. Much of the information processing underlying our actions is 'automatic'. We are aware only of the tip of the action iceberg. This article reviews two key sections of the iceberg that we do often experience: our own intentions to act, and the sense that our actions cause effects in the outside world (so-called 'agency').

Recent computational models [3] identify specific components of the control of goal-directed action. Figure 1 shows a schematic example. A planner or inverse model selects appropriate motor commands, given a desired goal. The motor command is sent to the muscles and, at the same time, an efference copy of the command is sent to an internal predictive model. The predictive model estimates the likely effect of the motor command. Feedback provides further information about the actual movement, but only after the delays associated with sensory transmission. The predictive model bypasses these delays, allowing more rapid adjustments and thus more fluent movement. These frameworks were designed to explain motor performance, rather than subjective experience. However, they are valuable in considering the question of which components of action control are conscious, and which are unconscious.

Several researchers have sought to relate the brain's preparation of action to the philosophical concept of

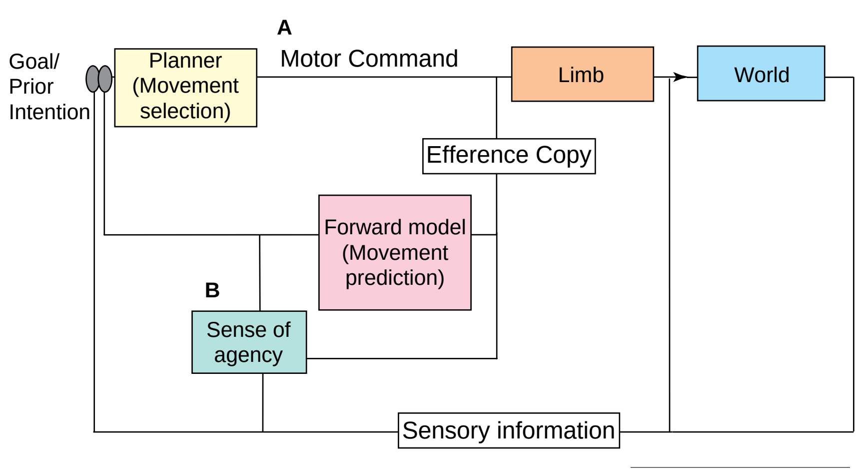

Figure 1. A computational framework for action. Based on [37]. **A** marks a point after movement selection where conscious awareness of intention might arise. **B** marks an integration of efference, predicted feedback and sensory information, which might lead to the sense of agency.

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‘free will’. Descartes proposed that the mind selects between alternative actions, and then causes the body, via the brain, to perform the selected action. This concept of action is deeply embedded in many modern societies, and is a key part of our folk psychology. However, it is incompatible with modern neuroscience, because it is strongly dualist, and implies mind–body causation (see Box 1). Most neuroscientists instead believe that conscious experiences are consequences of brain activity, rather than causes. The neural bases of conscious intention have been studied much less than the neural bases of conscious perception, for at least three reasons. First, experimentalists can study perception by the classic psychophysical method of manipulating a stimulus and seeing how the percept changes. We have no such control over the inputs to the systems for intentional action. Instructing subjects to perform intentional actions gives us only weak, indirect tools to study intention. Second, the conscious experience of intending is quite thin and evasive. It often lacks the vivid quality of visual phenomena, for example. Third, the dominant behaviourist view in 20th century psychology [9], viewed actions as conditioned responses to environmental stimuli, and distrusted the concept of intention. This trend has recently reversed. Neuroscientists have demonstrated systematic relations between the conscious experience of action and specific brain processes. Philosophers have used neuroscientific data to clarify conceptual questions about the generation and phenomenal content of action. This review summarizes some recent empirical evidence, and investigates the concepts of intentional action that emerge.

Human action comprises a spectrum extending from direct responses to immediate stimuli, to much longer-range actions. The former class of actions are often called ‘automatic’, whereas the latter may be called intentional. Intentional actions typically depend only loosely on immediate stimulation, but depend heavily on task context, and memory for previously learned associations. Effortful cognitive processes of planning and deliberation typically precede their selection. Their preparation and execution can require focussed attention, and their outcome might be closely monitored for future learning.

Box 1. Benjamin Libet and mind–body causation

Libertarian free will suggests that our conscious intentions cause our actions. This idea is deeply embedded in human culture, and particularly in European culture since Descartes. However, it clearly implies both dualism and mind–body causation, because a conscious thought (i.e. my intention) would need to drive the motor areas of the brain, and thus the muscles of my body, to realize my action. Attempts to identify the crucial interface where the mind controls the brain have been as unsatisfactory as Descartes’ original suggestion of the pineal gland. The search is clearly misguided, because conscious experience is a consequence of brain activity, rather than its cause. A classic study by Libet and colleagues [4] highlights the tension between folk-psychological beliefs about free will and a scientific account of intention. Libet *et al.* asked their subjects to fixate a spot rotating every 2560 ms on a screen. Subjects made a voluntary movement of the right hand whenever they ‘felt the urge’ to do so. A random time later, the rotating spot stopped, and subjects indicated where the spot had been when they first felt the urge to move, the time of ‘conscious will’. The average time of this ‘W judgement’, as Libet called it, was 206 ms before the onset of muscle activity (Figure I). Libet also measured the preparatory brain activity preceding voluntary action, or readiness potential (RP), in the same trials. RP onset preceded W judgement by several hundred milliseconds. This suggests that the initiation of action involves an unconscious neural process, which eventually produces the conscious experience of intention. Conscious intentions therefore occur as a result of brain activity, and do not cause brain activity. Libet’s experiment has been widely criticized [5]. The particular numerical values in such studies depend strongly on how the subject divides attention between the clock and their internal stream of consciousness. The temporal order of brain activity and reported subjective experience [6] is not reliable evidence for causation. However, the basic result has been replicated [7,8], and the experiment appears to offer one of the few viable methods for experimental studies of awareness of action.

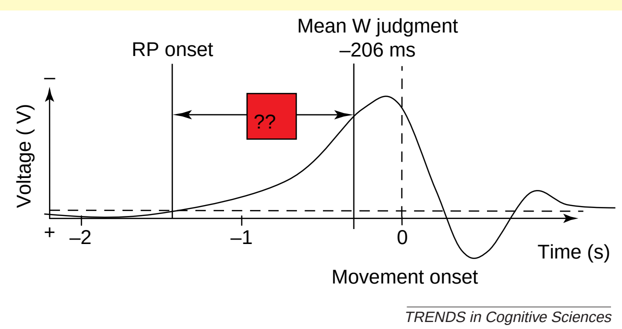

Figure I. Schematic results of Libet’s findings. Neural preparation in the motor areas of the brain can begin over 1 s before movement onset. The conscious experience of intending the movement, by contrast, begins much later, on average 206 ms before movement onset. As causes necessarily precede effects, conscious intention cannot be the cause of the neural processes that lead to action. Data values taken from [4].

Neural correlates of conscious intention

What is the relation between preparatory activity in the brain and the conscious experience of intention? A Cartesian dualist position holds that conscious intention causes brain activity. The seminal studies of Benjamin Libet (see Box 1), suggested that conscious intention occurs *after* the onset of preparatory brain activity. It cannot therefore cause our actions, as a cause cannot occur after its effect. Two other possibilities remain. Either conscious intention could be part of an illusion of mental causation, retrospectively inferred to explain behaviour [10]. Alternatively, conscious intention could be an immediate *consequence* of the brain processes which prepare action. On this view, intention is a conscious correlate of preparatory neural activity [11].

Several recent studies using Libet’s method point towards the second conclusion. Preparatory activity in the motor areas of the brain initiates action, and produces a conscious sensation of intention as a correlate. First, Lau *et al.* [12] used fMRI to study the brain activations involved in reporting the time of conscious intention (Libet’s W judgement; Box 1). In a separate control condition, subjects made identical voluntary actions, and judged the time of the action itself, rather than the time of intention. The processes of internally-generated action are common to both conditions, but the W condition is assumed to accentuate conscious intention and its neural substrate, relative to judging the action. Results showed greater activation in the pre-supplementary motor area

(SMA), and intra-parietal sulcus for judging intentions compared with judging actions. Sirigu *et al.* [8] studied the same conditions in patients with focal cerebellar or parietal lesions, and in a control group. Whereas all groups showed comparable awareness of the time of action, the parietal group alone showed a specific delay in the awareness of conscious intention compared with the other groups. Parietal patients became conscious of intentions only just before the action itself. Taken together, these results are consistent with the view that the frontal and parietal lobes jointly form a circuit which elaborates and monitors motor plans in advance of action, producing a conscious experience of intention as part of this simulation. The division of labour between frontal and parietal lobes remains unclear.

Action generation

Voluntary action is often presented as a single psychological process, without clearly identifiable subcomponents. This unitary view can be explained by two important features of action generation. First, actions seem to aim towards a goal, as if pulled teleologically from the intention through to the intended effect. James [13] used the term 'ideomotor' to refer to this property. Recent studies of imitation [14] and reaction [15] performance have quantified this goal-directedness, but have not directly related it to conscious intention. Second, all stages of voluntary action involve a pervasive process of information expansion. In computational motor control [16], for example, actions begin with a relatively simple description of a goal (e.g. 'I want to stand up'). The brain must expand this task-level representation into an extremely detailed movement pattern specify the precise kinematics of all participating muscles and joints. Generating this information is computationally demanding. The brain's solution to the problem may lie in the hierarchical organization of the motor system. Details of movement are decided at the lowest level of the motor system possible. Only the highest levels are available to consciousness.

These two general principles can explain why most studies view conscious awareness of action as a single experience, linked to a single underlying neural process. Libet's method, for example, assumes that conscious intention can be pinpointed to a single moment in time, and corresponds to a threshold level of a generative neural process, measured by the readiness potential. In fact, however, both brain process and conscious experience might each have several distinct components. Philosophers, for example, distinguish two aspects of will [17]. The first might be called 'internal generation'. This is the property that distinguishes willed action from involuntary responses such as reflexes. The second aspect of will is that it involves selection or choice between alternative possible actions. Some sort of selection process is necessary for a concept of free action: my free choice to do *A* requires that I could perhaps not have done *A*.

Action selection

Haggard and Eimer [7] investigated the relation between selection and conscious intention using a modification of Libet's paradigm. They asked subjects to choose freely on each trial whether to move the left or right hand. They divided each subject's trials into those showing early and those showing late judgements of intention, and looked for components of the movement related evoked potential showing temporal variations correlated with these judgements. The time of onset of the readiness potential did not correlate with the time of W judgements. This contradicts Libet's assumption that the readiness potential is the cause of conscious intention. However, the element of choice between left or right in the Haggard and Eimer experiment allowed them to use the lateralised readiness potential (LRP) as an internal marker of selection.

The LRP is the point at which the activity in the hemisphere contralateral to the selected hand exceeded the ipsilateral activity associated with the non-selected hand. Crucially, the process of selection must be over by the time the LRP begins. Haggard and Eimer found that the LRP began significantly earlier for actions having early W judgements than for those having late W judgements. Conscious intention was not linked to the very earliest neural preparation of actions, but rather to the specific preparation to perform a particular movement. The result is consistent with the view that conscious intention arises after the selection process, through development of a specific motor command for the selected action. This result localizes conscious intention to the stage marked **A** in the motor control model (Figure 1).

Other studies confirm that 'free' choice between manual actions involves unconscious processes. Ammon and Gandevia [18] found that appropriately-timed transcranial magnetic stimulation (TMS) over the SMA significantly biased choice between a left and a right hand action, yet subjects had no awareness of altered responding. A further study by Brasil-Neto *et al.* [19] reached a similar conclusion. They asked subjects to choose between a left or right hand action at the time of a GO signal provided by a TMS pulse over motor cortex. Actions within 200 ms of the go signal showed a preponderance of responses by the hand contralateral to the TMS pulse, whereas later responses were unaffected. Taken together, all these results suggest the interesting possibility that the process of selecting between alternative actions, which philosophers often consider the core of 'free will', could result from routine processes operating automatically and unconsciously.

Logical considerations also suggest that conscious intention should arise *after* selection. Consciousness presumably evolved because it is an efficient and functional way of using limited neural resources to optimise behaviour [11]. This precious resource would be most effectively used in representing the selected, to-be-performed action, and should not be wasted in representing alternative possible actions that are not selected.

Dual contents of intention: urge and effect

Experimental studies have generally reduced voluntary action to keypresses made to instruction. This approach ignores the reasons *why* we perform actions. In real life, actions aim at achieving goal events in the environment. These events generally have some reward value. It is therefore surprising that the psychology of intention has developed largely independently from the psychology of reward and motivation (but see [21]).

The subjective experience of conscious intention often contains two components: a sense of urge, or being about to move, and a reference forward to the goal object or event [22]. The first component is motoric, egocentric and internal. It presumably corresponds to Libet's W judgement, and to the sensations reported following SMA stimulation (see Box 2). The second component involves a prediction of the goal state, has sensory rather than motor content, and often uses an external reference frame centred on a goal or target location. The experience of intention, then, often includes a teleological pull towards the goal.

In general, the second, goal-related component has proved the easier of the two to study. James' ideomotor theory of action [13] emphasizes the effects of actions in the outside world. Actions themselves have a less important role in our mental life than their effects in the world. This view has been refined by Prinz's observation [23] that our subjective experience of action is anchored to the distal world, rather than proximal motor commands. Particularly compelling examples of this point occur in our perceptions of others' actions. For example, studies of imitation show that people typically imitate others' goals, not the movements they use to achieve them [24]. On executing and watching manual actions, people make predictive eye movements towards the target. They thus predict the goal, and the goal therefore dominates their visual experience of the action [25]. It has proved harder to show that goal prediction forms part of the subjective mental content at the moment of intention. However, an ingenious recent experiment [26] suggests that subliminally priming the effect of simple reactions produces an augmented sense of control of those effects. The priming presumably strengthened the prior thought representing the effect of action, producing greater perceived control.

Box 2. Cortical stimulation and conscious intention

The crucial role of the supplementary motor area in generating both actions and the conscious experience of them was elegantly shown by Fried *et al.*'s study [20]. Patients received direct stimulation of the cerebral cortex via two strips of electrodes as an exploratory investigation before neurosurgery for epilepsy (Figure I). Patients sometimes reported an urge to move a specific body part during low intensity stimulation of the SMA. Higher stimulation currents at the same site would then produce actual muscle contraction in the same body part. This result suggests that a conscious experience akin to intention can be experienced before actual movement, and is moreover a direct product of the neural processes in the SMA that generate movement. Fried's result is amongst the best evidence against the theory that conscious intention is merely a retrospective illusion, manufactured after our actions have occurred, with the benefit of hindsight. These data suggest that conscious intentions are at least partly preconstructions, rather than mere reconstructions.

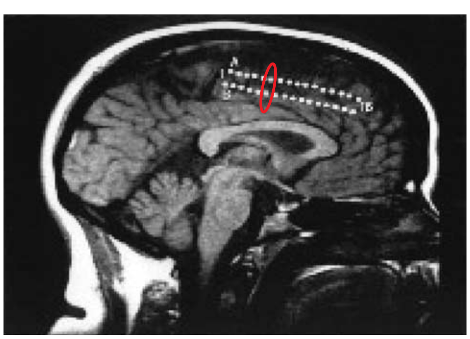

Figure I. Direct stimulation of the supplementary motor area in man. A strip of electrodes is used to stimulate the cerebral cortex as part of pre-operative procedure before neurosurgery for severe epilepsy. When the SMA (electrodes outlined in red) was stimulated, subjects reported the sensation of an urge to move their limbs. More intense stimulation at the same locations provoked physical movements of the corresponding limb [20]. Reproduced with kind permission of UCLA.

The 'sense of agency': an effect aspect of intention

Philosophers have used the term 'sense of agency' to describe the reflexive feeling that 'I' control events in the outside world. The control of one's own body movements might be a limiting case. The sense of agency arises from the second, effect-related aspect of intention. It is logically distinguishable from the experience of urge, or 'being about to do something'. For example the urge aspect of intention can occur without true action (see Box 2), whereas the sense of agency normally cannot. Developing research on brain–robot interfaces will allow interesting studies of whether the combination of urges and effects, without bodily action can evoke a sense of agency.

Wegner [10,27] has interpreted agency as an illusion of mental causation. For Wegner the three conditions for agency are priority, consistency and exclusivity in the relation between thought and action. Thus, when we have a conscious thought before action, and the thought-about event consistently occurs after the thought, and there are no other plausible causes, we experience ourselves as causing the event. This position combines Hume's sceptical view of causation [28] with Michotte's [29] view of the power of the 'causal impression'. Wegner's views emphasize the post-hoc reconstruction of agency, as opposed to the goal prediction aspect. Certainly, people can incorrectly infer agency based on repeated associations between events which are in fact unrelated. Superstitious actions provide examples from everyday life. Such beliefs might arise because one infers that one's action has lead to subsequent positive events.

An experiment by Wegner and Wheatley [30] demonstrates that people can experience control of events that they do not in fact cause, as long as appropriate conditions are met. In that study, priming subjects with a thought just before seeing a cursor movement, which was actually made by another person, encouraged subjects to attribute the movements to themselves. A similar overestimate of agency is seen in self-recognition experiments [31] where subjects decide whether the visual feedback of an action corresponds to their own movement of another person's.

If we accept Wegner's reconstructionism about agency, should we not equally be reconstructionists about conscious intention? If the mind can produce the trick that 'I' cause external events, could it also produce the trick that I had a preceding intention to make an action? Marcel's [32] recent discussion of Anarchic Hand Syndrome (AHS) suggests not. In AHS, patients with frontal lobe and callosal damage perform well-formed actions in response to environmental cues. However, these actions are contrary to the patient's will, and occur without preceding conscious intention. Della Sala *et al.* [33] give the example of a patient who reaches to grasp a cup, despite just commenting that she would leave the drink to cool before drinking it. On the basis of this case, Marcel suggests two ways in which an action can belong to 'I'. He calls these ownership of action, and ownership of the *source* of action. They correspond roughly to the effect and urge aspects of intention, respectively. The AHS patient clearly recognizes that the involuntary grasping movements are theirs. However, they do not accept that the 'I' is the source of action. Interestingly, the patient does not reconstruct a conscious intention to satisfy the logical role as the cause of the action that they accept as theirs. Intentions are not merely inferred retrospectively from actions. A sense of agency seems to require integration of information about events in our body, or the outside world and efferent signals (shown as **B** in the framework of Figure 1).

Linking actions to effects

Some recent psychophysical studies have linked the urge and effect aspects of intention. Rather than asking directly about perceived control, these studies focus on how intentional actions influence the subjective time of the effects of action. Haggard *et al.* [34] asked subjects to indicate the perceived time of either their actions, or of an external sensory event (a beep) evoked by their action after a 250 ms delay. These time estimates were compared with baseline blocks where subjects judged either an action that did not evoke a beep, or a beep that occurred without action. Estimates in the agency condition showed a strong perceptual attraction between action and effect compared with the baseline conditions. Subjects perceived their action as shifted in time towards the beep that it caused, and perceived the beep as shifted earlier in time towards the action that caused it (Figure 2). The effect was specific to intentional action, because involuntary TMS-induced twitches followed by beeps showed a perceptual repulsion.

These results suggest a mental process which binds intentional actions to the external events that they produce. The experience of agency over external events may represent the conscious superstructure of an evolutionarily older capacity for learning functional associations between actions and effects.

Haggard and Clark [35] investigated whether the binding effect could involve an element of post hoc reconstruction similar to Wegner's illusions of agent causation. Subjects made intentional keypresses, which evoked a beep. On some trials, preparation for the intentional action was interrupted by a TMS pulse which elicited an involuntary movement in the keypressing finger. The TMS pulse was followed by a beep in the same way as the voluntary action. Interest focussed on the perceived time of the beep in these TMS-interrupted trials. The beep might be shifted earlier in time towards the (uncompleted) intention that had aimed to produce it. Alternatively, the uncompleted intention might have no effect on the perceived time of the beep. The results showed no difference between TMS-interrupted intentional actions, and control blocks in which TMS and beep co-occurred without any preceding intention. The mere conjunction of an (incompleted) intention and the intended effect was not sufficient for binding, contrary to reconstructivism. Rather, the intention had to be related to the effect in a temporally precise way for binding to occur. Thus, the effect aspect of intention, like the urge aspect, seems not to be just a reconstruction, but a preconstruction, or a motor prediction.

Conclusions and future directions

The subjective experience of conscious intention is a key component of our mental life. Intention is a complex and elusive experience, which might involve reconstructive inferences. However it also arises as a direct consequence of pre-movement brain activity in the frontal and parietal motor areas. The supplementary motor area is a particularly important site for intention. The parietal and frontal lobes jointly develop, monitor and refine the motor commands for intentional action. These neural processes often give us the conscious experience of intention-in-action. Future research should identify the specific contributions made to conscious intention by each pole of this network. Studies of patients with focal lesions, and stimulation studies using TMS could be particularly productive.

The subjective experience of intention allows us to recognize whether an external event was linked to our own action or not, and thus to have a sense of agency. The motor system maintains a precise predictive model of how our voluntary actions produce their various effects, both in our own body and in the external world. Motor predictions influence the perceived time and perceived magnitude of

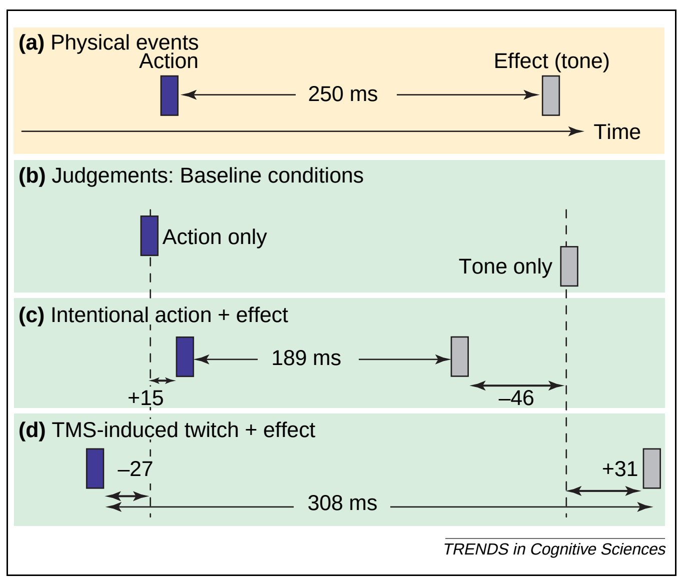

Figure 2. Intentional binding between voluntary actions and their effects. **(a)** Subjects make voluntary action to evoke a tone 250 ms later. **(b)** The perceived time of action and tone are first estimated in baseline conditions in which only the action or the tone occurs. **(c)** When action and tone occur together, the perceived time of the action shifts forwards in time from the baseline value, towards the tone. The perceived time of the tone shifts earlier in time, towards the action. Action and tone are bound together across time, implying a reduction in the perceived interval between them. **(d)** Replacing the intentional action with a physically similar involuntary movement evoked by TMS abolishes and reverses the binding effect. Data from [34].

external events [36]. This involves more than mere constant conjunction. Our sense of agency is presumably acquired through experience. But, once acquired, the mind carefully discriminates self-generated from external events, and gives us quite different subjective experience of each.

The phenomenology of intention is poorly understood. The subjective time of intentions has been a valuable experimental tool, because time offers a common measure for comparing awareness across different events. However, the phenomenal content of intention has hardly been studied experimentally. Reliable psychophysical procedures for investigating when and how the effects of an action are represented during preparation and intention would represent a major advance.

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