Language and space: some interactions

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Is language linked to mental representations of space? There are several reasons to think that language and space might be separated in our cognitive systems, but they nevertheless interact in important ways. These interactions are evident in language viewed as a means of communication and in language considered a form of representation. In communication, spatial factors may be explicit in language itself, such as the spatial-gestural system of American Sign Language. Even the act of conversing with others is a spatial behavior because we orient to the locations of other participants. Language and spatial representations probably converge at an abstract level of concepts and simple spatial schemas.

Is language related to our knowledge of space? The purpose of language would seem to be different from the purpose for which we represent space. Language mirrors the contours of our thought[1] and provides a means to communicate. Language lets us encode massive amounts of information and generate complex ideas that would otherwise be impossible. Spatial representations mirror the contours of our external environment and provide a means to reach, search and navigate[2]. Given these differences, one might expect language and space to be segregated in our cognitive systems.

In what follows, I suggest that despite differences in the neural and mental organization of language and space, these two domains interact. I review some ways in which the spatial context of communication can influence the production and comprehension of language. Then I review ways in which language as a symbolic system is likely to engage spatial representations when one thinks of objects and events in the environment.

Neuroanatomy of language and space

At a first glance, neuroanatomical observations are consistent with the idea that language and space are segregated. Language and space are mediated primarily by different cerebral hemispheres[3]. Profound impairments in language are associated with left hemisphere damage, and profound impairments of spatial representations are associated with right hemisphere damage.

The importance of language and space in our mental lives is reflected in the amount of brain that is dedicated to these cognitive domains. Both language and space are mediated by widely distributed neural networks[4]. Cortically, these networks include the posterior temporal-parietal region, and dorsolateral and medial prefrontal regions. Sub-cortically, they include parts of the basal ganglia and thalamus. Distributed language networks in the left hemisphere mediate components of language, such as phonology, lexical-semantics and syntax. Distributed spatial networks in the right hemisphere mediate components of space, such as reference frames anchored to the retina, head or trunk, and spatial locations indexed to movements of different body parts. Thus, the networks that mediate language and space are similarly organized, but largely in different hemispheres.

Despite these broad differences in the neuroanatomy of language and space, their segregation is unlikely to be absolute. A language network completely encapsulated from sensations would imply a radically different neural organization in the left and right hemispheres. Primary sensory and motor cortices connect to higher order networks in a reciprocal cascade[4]. Unimodal cortices process elementary sensations, which then combine with information from other sensory modalities to form more complex representations. For example, neurons in the posterior parietal and dorsolateral prefrontal cortex of macaque monkeys are especially responsive to combinations of visual and tactile stimuli tied to movements of specific body parts[2]. Evidence from brain damaged patients suggest that crossmodal and sensory–motor information similarly converge in humans[5,6] giving rise to the phenomenological experience of a unified spatial environment in which we perceive and act.

Why would the cascade of sensory information that modulates activity in the right temporal-parietal cortex not do so in the left? The synaptic connections between primary sensory cortices and posterior temporal-parietal cortex are similar in both hemispheres. It seems unlikely that sensory information, which accumulates into complex spatial representations in the right, would completely dissipate in the left. Alternatively, the sensory information in the left hemisphere might also modulate temporal-parietal activity, but differently from in the right, a possibility to which we will return later. Differences in such modulation are probably mediated by hemispheric differences in the dendritic patterns and neuronal physiology[7–9].

Language as a means of communication

Language as a complex system of communication includes verbal production and comprehension, as well as gestures, emotional prosody and the conventions of conversation. I will touch on three settings in which linguistic communication interacts with space. First, in American Sign Language (ASL), information is communicated spatially. Second, some words refer explicitly to spatial information. Third, an issue discussed in greater detail, the direction of space in which some speakers orient may influence their language.

American Sign Language (ASL)

ASL conveys information spatially using a system of gestures. Both hemispheres seem to be involved in

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processing sentences in ASL, in contrast to English. In functional neuroimaging studies, when subjects read written English sentences, left Broca's and Wernicke's areas are activated. By contrast, viewing films of signers producing ASL sentences activates right posterior regions in addition to the left hemisphere language areas[10].

Each hemisphere is probably mediating different kinds of information in ASL. In ASL, space is used to communicate both topographic information about the environment and grammatical relationships. Damage to the right hemisphere of ASL speakers can produce deficits in expressing spatial topographies, whereas damage to the left hemisphere can produce deficits in expressing grammatical relationships[11,12]. I will not discuss these interactions of language and space in ASL further (see Refs 12,13). I simply highlight the point that space can play different roles in ASL communication. Different neural substrates seem to mediate the topographic and grammatical uses of space.

Deixes

In conversation, speakers often anchor their utterances to their spatial environment. This anchoring is referred to as 'deixis', or pointing with words[14,15]. Deictic expressions can identify objects in space, as in the demonstrative determiners '*this*' or '*that*'. These deictic expressions and their comprehension are based on knowledge shared by the participants of the conversation and the context in which the utterances occur. Locative prepositions such as '*above*', and '*behind*', which convey explicit spatial information, also serve as deixes. The spatial relationship of objects may be anchored to the speaker, such as in '*the light is above my head*' or to another object in the environment, as in '*the light is above the table*'.

Reading sentences with locative prepositions activates parts of both parietal cortices[16]. Because the parietal cortex mediates spatial representations, comprehending these sentences appears to involve spatial processing. The left hemisphere may be critical in processing locative prepositions: left hemisphere damage is more likely than right hemisphere to produce deficits in comprehending these prepositions[17,18].

Spatial orientation

In conversation, we orient towards others in our spatial environment. Coslett and co-workers report that the direction in which some aphasic patients orient influences their use of language. They initially observed that a patient with ischemic infarcts of the left temporal-parietal and left anterior cingulate regions was poorer at understanding spoken language and producing words when orienting to his right than when orienting to his left[19]. He was also slower at naming pictures, and read single words more poorly when stimuli were located to his right than to his left. A contralesional attentional deficit was unlikely to account for his behavior because spatial orientation influenced his language even when there were no external stimuli to be apprehended. When generating nouns and narrating a fairy tale, he was less fluent and his story was less detailed when he oriented to the right than when he oriented to the left.

Coslett found similar spatial effects on language in a group of 30 individuals with single hemisphere ischemic infarcts[20]. Language was assessed using naming to confrontation, oral reading and matching auditory words to pictures. Five individuals' performances on some of these language tasks were influenced by their spatial orientation. All five had damage to the parietal cortex. In a follow-up study with 52 patients, Coslett and Lie[21] showed similar effects of spatial orientation on naming, reading, synonym judgement and sentence comprehension. All nine people whose language was influenced by the direction of space into which they oriented had left parietal cortex damage.

The spatial registration hypothesis

Why should the direction of space in which an individual orients influence language? Coslett proposes the 'spatial registration' hypothesis[20]. He argues that registering objects and events in space is of fundamental evolutionary importance. This registration determines an organism's ability to acquire sustenance and avoid danger in the environment. The locations of all stimuli are registered automatically, even when this information is irrelevant to the task at hand. An example of such automatic registration is the Simon effect[22]. If a red target requires a right hand response, then subjects respond more quickly to a red target on the right than on the left, even though target location is irrelevant to response.

Coslett claims that spatial registration effects extend beyond sensory and motor processing to cognitive operations. Parietal damage impairs contralesional spatial registration and consequently impairs the activity of even non-spatial operations like lexical retrieval and semantic search. The neural activity mediating language is probably modulated by head and eye position, similar to the way in which tactile processing is influenced by head and eye position[23]. Crossmodal (tactile–visual) integration in the posterior parietal cortex[24] may be accompanied by cross-material (spatial–linguistic) integration in the posterior left parietal cortex.

Language as a form of representation

Language as a system of symbols needs to be able to refer to spatial information, such as the geometry of spatial relationships, spatial perspectives, the separation of figure from ground, and the dynamics of force[25]. However, the formats of linguistic and spatial

Box 1. Spatial primitives, conceptual development, and mental models

One approach to investigating the meaning embodied in words is to examine how words might decompose into constituent primitives[a]. 'Primitives' refer to elemental properties that cannot be further simplified. Jackendoff suggests that the conceptual structure of verbs decomposes into primitives such as 'movement', 'path' and 'location'. He suggests that these primitives must somehow correspond with their linguistic counterparts[b].

Spatial primitives, or 'schemas', may play a critical role in the acquisition of concepts. Infants first learn perceptual–motor principles about objects and events in the world. These principles, presumably encoded as primitives, serve as the basis for more elaborate conceptual structures. For example, Mandler[c] suggests that infants first acquire knowledge of different kinds of motion in the world. Biological motion is self-propelled and non-biological motion is induced externally. Awareness of this distinction serves as the basis for knowledge of animacy and inanimacy, a fundamental semantic distinction.

Even if spatial primitives form the basis by which concepts are acquired, it is not clear that these primitives remain relevant after the concept has been acquired. They could very well be vestigial and be discarded. Alternatively, spatial primitives might underlie different domains of cognition. For example, Christman[d] reported that pictures with a left-to-right directionality are judged more aesthetically pleasing than pictures with a right-to-left directionality. Spatial primitives might also be concatenated to form more elaborate mental models with spatial properties[e].

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representations seem to be different. Language is usually algebraic and can convey propositional information. Individual words relate arbitrarily to the objects and events in the world. For example, nothing about the word '*dog*' refers necessarily to a specific class of objects. These objects could just as easily be referred to by another word, and certainly are in different languages[26]. Similarly, the structure of a sentence need not bear a necessary relationship to the structure of objects and events in the world.

Spatial representations, in contrast to language, are usually analog and convey geometric information. They comprise multiple levels, from early unimodal sensations to complex multimodal representations. Spatial representations often approximate the topography of physical space. For example, spatial neglect is a disorder in which patients with focal brain damage are unaware of objects and events in space contralateral to their lesion[27]. These patients also frequently neglect contralesional parts of imagined visual scenes[28].

Given these differences in the formats of linguistic and spatial representations, how might language and space interact? At issue is whether linguistic descriptions of spatial relationships are structured by perceptions[29–31]. In the next section, I will touch on the notion that language interacts with space at simple spatial primitives, or schemas (see Box 1), along the theoretical lines developed by Talmy[32] and Jackendoff[33] (also see Miller and Johnson-Laird[34]). Then I discuss in greater detail empirical evidence suggesting that the linguistic representation of events relates to spatial schemas.

The interface of language and spatial representations

Different kinds of information represented in the brain can be characterized by gradients along several parameters. Information can be perceptual or conceptual, geometric or algebraic, sensorial or amodal, and concrete or abstract. Spatial representations tend to be perceptual, geometric and sensorial, whereas language tends to be conceptual, algebraic and amodal. However, both language and spatial representations can be concrete or abstract. At the concrete end of language, sounds and vocalizations specific to individual languages form words and sentences. At the abstract end, concepts encode meaning in a way that is not restricted to the idiosyncrasies of any particular language (see Ref. 33 for thoughts on this conceptual structure). At the concrete end of spatial representations, perceptions are derived from actual spatial scenes. At the abstract end, simple spatial schemas are extracted from but do not directly reflect perceptual information. Language and space are likely to converge at the abstract levels of conceptual structures and spatial schemas.

What are spatial schemas? Based on his analysis of locative prepositions Talmy[32] proposes that spatial schemas are 'boiled down' features of a spatial scene. For example, '*across*' refers to a schema that describes a specific path of movement. This path is approximately perpendicular to the principle axis of the reference object, as in across a river or across a plank. When a movement proceeds parallel to the principle axis of the reference object, then '*along*' is more appropriate. Both '*across*' and '*along*' are abstracted from the actual scene. In these schemas only selective spatial aspects are deemed relevant. Other aspects of the scene, such as whether the referent object is in fact a river or a plank are not relevant and are not incorporated into the schema. Thus, the schemas are simple geometric forms such as points, lines and planes.

Box 2. Agrammatism and thematic role assignment

Agrammatism is an aphasic syndrome with impairments at the level of sentences[a]. People with agrammatism do not speak fluently, and putting words together in sequence requires effort. Their spontaneous speech is often 'telegraphic'. They communicate with simple phrases, such as '*dog eat*' rather than '*the dog is eating*.' They generally comprehend simple statements, but often have difficulty comprehending grammatically complex sentences. People with agrammatism omit function words (like prepositions, articles and conjunctions), more often than nouns[b].

The specific deficits in agrammatic patients vary, reflecting the selective vulnerability of linguistic processes involved in constructing and comprehending sentences[c]. However, most people with agrammatism fall into two broad categories. Some have difficulties with the relationship of words to each other (syntactic deficits). Others have difficulties processing grammatical morphemes (morphological deficits)[b]. Syntactic and morphologic deficits often co-exist but may dissociate.

Saffran Schwartz and Marin[d] drew attention to a group of agrammatic patients with syntactic deficits who could not process thematic roles in sentences. These patients can usually use general knowledge of the world to match sentences to pictures. For example, a boy may kick a stone, but a stone cannot kick a boy. However, reversible sentences, such as '*The boy kisses the girl*' and '*The girl kisses the boy*', describe events that are both possible. Patients with thematic role assignment deficits are especially prone to making errors with reversible sentences.

Investigators at the turn of the last century, such as Arnold Pick, assumed that producing sentences involves transforming a pre-linguistic message into language in discrete stages[e]. Recent models of sentence production, such as the influential one advocated by Garrett[f], also postulate cascading levels of representation, each with different operations. Garrett proposes a 'message' level prior to 'functional' and 'positional' levels in sentence production. The message level contains pre-linguistic information. The functional level selects abstract lexical items and establishes the argument structure of who is doing what to whom. The positional level inserts the appropriate grammatical morphemes. Neurolinguists have focused on the functional and positional levels. These levels might be considered the 'language proper' aspects of sentence production. Thematic role assignment deficits occur at the functional level[g,h]. Little about the message level is known, although some patients may have deficits at this pre-linguistic level following left brain damage[i].

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Talmy identifies several important features of these schemas[32]. Spatial schemas are discrete, rather than being continuous. A movement cannot be 30% 'along' and 70% 'across', for example. Consequently schemas lose some of the precision of perception. Schemas are also topological rather than imagistic. One might remember a ferry moving across a river, but most features of this image are not incorporated in the schema of 'across'. Rather, schemas encode spatial features in simple qualitative ways rather than with the metrics and richness of specific images. Schemas capture only some of the infinite possible spatial configurations. This design seems a precondition of communication, in which a wide variety of spatial situations need to be described rapidly.

Thus spatial schemas share properties associated with both language and perceptual representations. They are discrete and referential like most elements in language, and might be concatenated to form more complex structures. And they are analog (albeit simple), like the perceptions from which they are extracted.

Spatial schemas in an aphasic subject

Working within a completely different tradition, Chatterjee and co-workers reported evidence that conceiving events and actions are related to spatial schemas. This investigation began with a man with agrammatism (see Box 2) whose production and comprehension of sentences was influenced systematically by spatial factors[35,36]. He had flawless comprehension of single words and a superior vocabulary. However, this spontaneous speech was syntactically disorganized. He rarely produced complete sentences and his utterances had few inflections, auxiliary verbs, and closed class words. He described his problems: '*Well, uh, essentially language abandon preposition. I telegraph… I, I… consciously, uh, continuity…I, I, uh, this subtle of prepositional phrases this simply cannot do. Under stress, under stress rapid I just flustered … but continue to do basically*.'

The influence of space on this patient's language emerged when he was assessed for his ability to express or understand who does what to whom in sentences (thematic role assignment). In describing pictures, he was more likely to describe the figure on the left as the agent regardless of whether this figure was the doer or the recipient of the action. He also used a similar spatial strategy on an

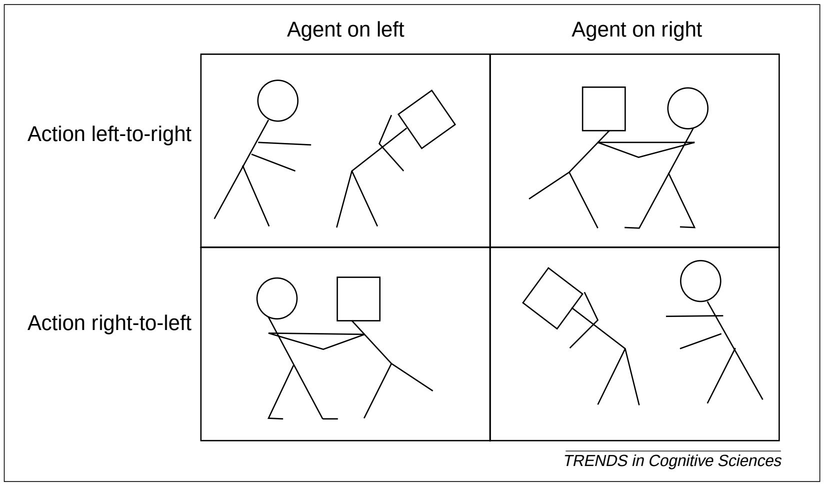

Fig. 1. Examples of visual stimuli used in the sentence–picture matching task. One of the following pictures appeared on a computer monitor after the subjects heard sentences such as '*The circle pushes the square*' or '*The circle pulls the square*'. (Modified from Ref. 39.)

anagram task. When presented with words on individual cards, he ordered the words into active sentences that were grammatically appropriate. However, with passive sentences, he invariably produced semantically impossible sentences, such as '*The girls are climbed by the stairs*.' He picked '*girls*' as the agents and placed that card on the left of the sentence, impervious to the sentence's syntactic construction.

This individual's spatial bias in describing pictures extended to comprehension, as evidenced by his matching of sentences to pictures[35]. With active sentences he was far more accurate if the agent was on the left and the action moved left-to-right than the agent was on the right and the action moved right-to-left. By contrast, with passive sentences his performance was reversed.

Chatterjee and co-workers speculated that their subject's spatial biases might reflect a primitive structure of mental representations of events. Hughlings Jackson in the nineteenth century viewed the nervous system as being organized hierarchically, with higher processes inhibiting lower ones[37]. Jackson thought that 'dissolution' of higher functions released more primitive behaviors. Accordingly, the dissolution of our subject's linguistic abilities by brain damage might have released a primitive pre-linguistic representation, making the underlying spatial schema explicit.

Spatial schemas in normal people

If events are encoded with spatial schemas, then subtle spatial biases might also influence normal subjects' conception of actions and thematic roles. Chatterjee and co-workers found that normal right-handed subjects tend to locate agents to the left of patients, and to conceive of actions as proceeding from left to right[38,39]. These biases emerged in several experiments: when subjects drew events in response to sentences; when they drew either the agent or the recipient of the action in response to sentences or phrases; and when they drew trajectories of actions conveyed by verb phrases.

As English is read from left to right, could these spatial biases be produced by habitual exposure to English? Perhaps, but the results of one experiment are not explained easily by the surface structure of written English. This experiment capitalized on the fact that different verbs convey opposite spatial trajectories[39]. The verb '*push*' conveys an action moving away from the agent, whereas the verb '*pull*' conveys an action moving towards the agent. Normal subjects matched sentences they heard to pictures faster when pictures depicted the agent on the left and with the action proceeding from left-to-right (see Fig. 1). The influence of the direction of action is not accounted for by the surface structure of English sentences. If these subjects simply mapped the subject–verb–object sentence structure onto the agent–action–patient depiction in pictures, they would not have processed actions from left-to-right more quickly. When the direction of action proceeds from left-to-right, the subject–verb–object sentence sequence maps onto agent–action–patient depictions with '*push*' verbs, but to patient–action–agent depictions with '*pull*' verbs.

Speculations about the neural bases for spatial schemas

Why should actions correspond to a schema with a left-to-right trajectory? We encounter events moving in every direction, so the perceptual experience of events in the environment would not produce a schema with a specific direction. Perhaps these directional biases follow from properties of left hemisphere processing.

The left hemisphere seems critical to mediating actions in general. Damage to the left hemisphere is associated with apraxias, or deficits of meaningful

Outstanding questions

- What neurophysiological and neuroanatomical properties predispose ensembles of neurons to encode either linguistic or spatial information?
- What parts of the brain mediate interactions of language and space, and what are the consequences of damage to these areas?
- Can the effects of spatial orientation on language be used to rehabilitate aphasic patients?
- Is there a limited set of spatial schemas, and how are these extracted from imagistic representations?
- Are there differences in the neural mediation of verbs and locative prepositions and their spatial schemas?
- How do cultural and biological variables contribute to spatial schemas?
- Are spatial schemas used in cognitive domains other than language?

Box 3. Nouns and verbs

Considerable evidence suggests that the brain processes nouns and verbs differently[a–c]. Lesion studies suggest that noun retrieval deficits are associated with left temporal lesions and verb retrieval deficits are associated with left premotor lesions. This neural differentiation is not surprising, given that nouns and verbs have different semantic and syntactic properties. Nouns prototypically refer to objects in the world, while verbs prototypically refer to actions in the world. Verbs play a syntactic role in setting up the argument structure of sentences, a role not played by nouns. Lesion and fMRI studies suggest that the meaning of nouns is linked to sensory features. According to this view, access to the meaning of nouns automatically, and perhaps necessarily, activates brain structures that are also used to perceive the object referred to by the noun. (For a critique of this view, see Ref. d.)

Verb retrieval deficits following brain damage have not been studied in the same detail as noun retrieval deficits. Verb retrieval deficits are associated with agrammatic production, because verbs play a critical role in setting up the structure of the sentence (but see also Ref. e). The syntactic properties of verbs may be processed in different brain regions from their semantic properties. Furthermore, verbs that belong to different semantic categories, such as those describing actions (e.g. *run*) versus those describing mental states (e.g. *love*), might also have different neural underpinnings.

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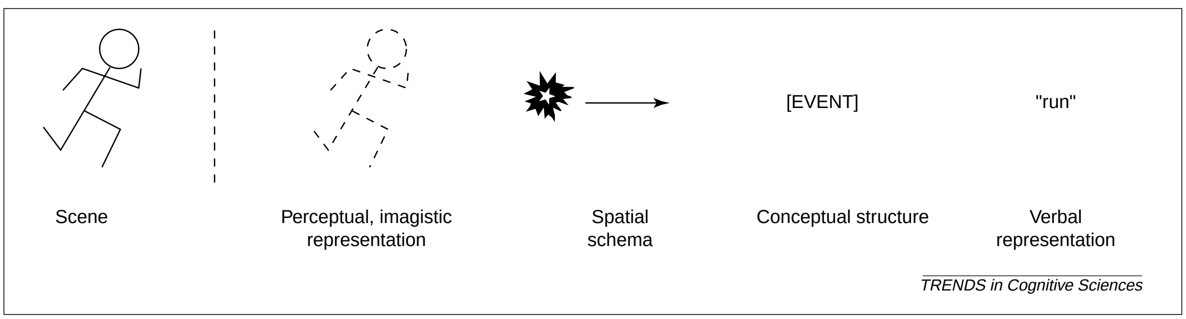

Fig. 2. A general sketch of the relationship of spatial scenes in the environment and their mental representations. The perceptual or imagistic representation is geometric and reflects sensory features specific to the actual scene. The spatial schema abstracts a simplified form that retains an analog structure. The conceptual structure is language-like in that it is algebraic and can convey propositional information. The verbal representation encodes the actual word representing the spatial scene.

actions[40]. Damage to the left parietal cortex can also impair the ability to prepare for and switch to different kinds of actions, a form of motor attention[41]. The left hemisphere also directs attention with a left-to-right vector[42]. These features of the left hemisphere, the encoding of actions and the deployment of spatial attention with a left-to-right vector, might predispose the left hemisphere to mediate a left-to-right schema for actions (see also Box 3).

One possible explanation is that the left and right hemispheres tend to encode different kinds of spatial representations[43]; the left mediates schematic and the right imagistic representations. Language that relies on schematic representations, as in relational concepts encoded in verbs and locative prepositions, might rely on an intact left hemisphere. Conversely, language that relies on imagistic representations, as in the spatial topography expressed in ASL, might rely more on an intact right hemisphere (see Fig. 2).

Conclusion

Despite reasons to think that mental representations of language and space are likely to be segregated, these cognitive domains make contact at critical junctures. These points of contact are evident in both the communication and the representation of language. The interactions reviewed here suggest that language and space are not modular cognitive systems in the strong sense of being informationally encapsulated from each other. Rather, at certain points the information from one domain bleeds into the other. Careful consideration of these points of contact is likely to reveal insights into how thoughts relate to actions and events in the environment.

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