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Competing interests

The author declares no competing interests.

SOCIAL DECISION-MAKING

Navigating social knowledge

Everyday phrases like ‘top dog’ and ‘low status’ suggest that we may mentally represent social and spatial information similarly. To what extent is that true? New research suggests that, like physical space, social knowledge is encoded as a cognitive map in the human brain and represented with a grid-like code.

Meng Du and Carolyn Parkinson

Imagine that you are starting a company. Among the potential partners you know, who has the competence to help you succeed in business management? Who could help you gain public awareness and popularize your brand? How can you create a team with complementary skills? In everyday life, you likely engage in countless acts of reasoning about individuals’ various traits and comparing them to each other. How does the brain support our ability to do this? New work by Park et al.[1] suggests that the human brain represents and infers abstract relations between people using a grid-like code, similarly to the way it represents relations between locations in physical space.

To examine this, the researchers first taught participants about a set of entrepreneurs who varied in two attributes: competence and popularity. These attributes varied independently across entrepreneurs. Days later, participants completed a functional magnetic resonance imaging (fMRI) study involving a partner selection task. In each trial, participants were shown one of the entrepreneurs (e.g., Bob in Fig. 1a), followed by two others (e.g., Alice and Carlos in Fig. 1a), and had to select the best partner for the first entrepreneur out of the two available options (Fig. 1b). In making their choices, participants were instructed to weight popularity and competence equally. The entrepreneurs can thus be thought of as populating a two-dimensional (2D) space spanned by the dimensions of popularity and competence (Fig. 1c).

However, participants never saw the entrepreneurs arranged in a 2D space as visualized in Fig. 1c. Instead, in the pre-scan task, they learned information about pairs of entrepreneurs in a piecemeal fashion (e.g., whether Alice was more or less competent than Bob; whether Alice was more or less popular than Carlos), and then integrated that information to build a 2D cognitive map of the relative competence and popularity of the entrepreneurs. This is in some ways similar to everyday life, where one often has to cobble together discrete observations (e.g., of particular individuals’ traits or of interactions between pairs of people) to infer how people relate to one another. When participants viewed the entrepreneurs’ faces during the partner selection task, several brain regions encoded the distances between entrepreneurs in this 2D cognitive map. These regions included entorhinal cortex, hippocampal cortex, medial prefrontal cortex (MPFC), orbitofrontal cortex, posteromedial cortical areas and the inferior parietal lobule. In these brain areas, the faces of entrepreneurs that were closer together in the 2D (popularity × competence) cognitive map of social knowledge evoked more similar neural response patterns.

Next, the researchers examined how the brain supports the ability to infer new imagined trajectories between ‘locations’ in this conceptual space (e.g., to determine how much Alice or Carlos would benefit Bob as potential collaborators, based on their relative competence and popularity; Fig. 1d). To do this, they built on recent suggestions that grid cells may support the brain’s ability to compose new routes and shortcuts in both spatial environments and abstract conceptual spaces[2].

Grid cells were famously first discovered in rat entorhinal cortex; these cells fired whenever an animal’s position coincided with any vertex in a grid that tiled their environment[3]. Together with other spatially tuned cell types in the hippocampal formation, grid cells are thought to support the brain’s ability to navigate space. How do grid cells contribute to an internal map of space? If one tiles a flat surface with geometric shapes (such as squares or triangles) without any overlaps or gaps, the intersections of vertices of those shapes provide local points of reference for the surface. Although many people are most familiar in everyday life with grids composed of squares, grid cells encode hexagonal lattices that are ideally suited to representing locations in 2D planes because they afford the highest possible spatial resolution of such surfaces[4]. In their study, Park et al.[1] provide the first evidence that such an encoding scheme also supports the ability to mentally ‘navigate’ abstract social knowledge.

In a grid-like representation, trajectories in the representational space that are aligned with the encoded grid intersect with more grid cell firing fields (Fig. 1d), and thus elicit stronger neural responses, than trajectories that are misaligned with the grid. In the example visualized in Fig. 1d, if participants encoded the trajectory from Bob to Alice when viewing Alice’s face, and the trajectory from Bob to Carlos when viewing Carlos’

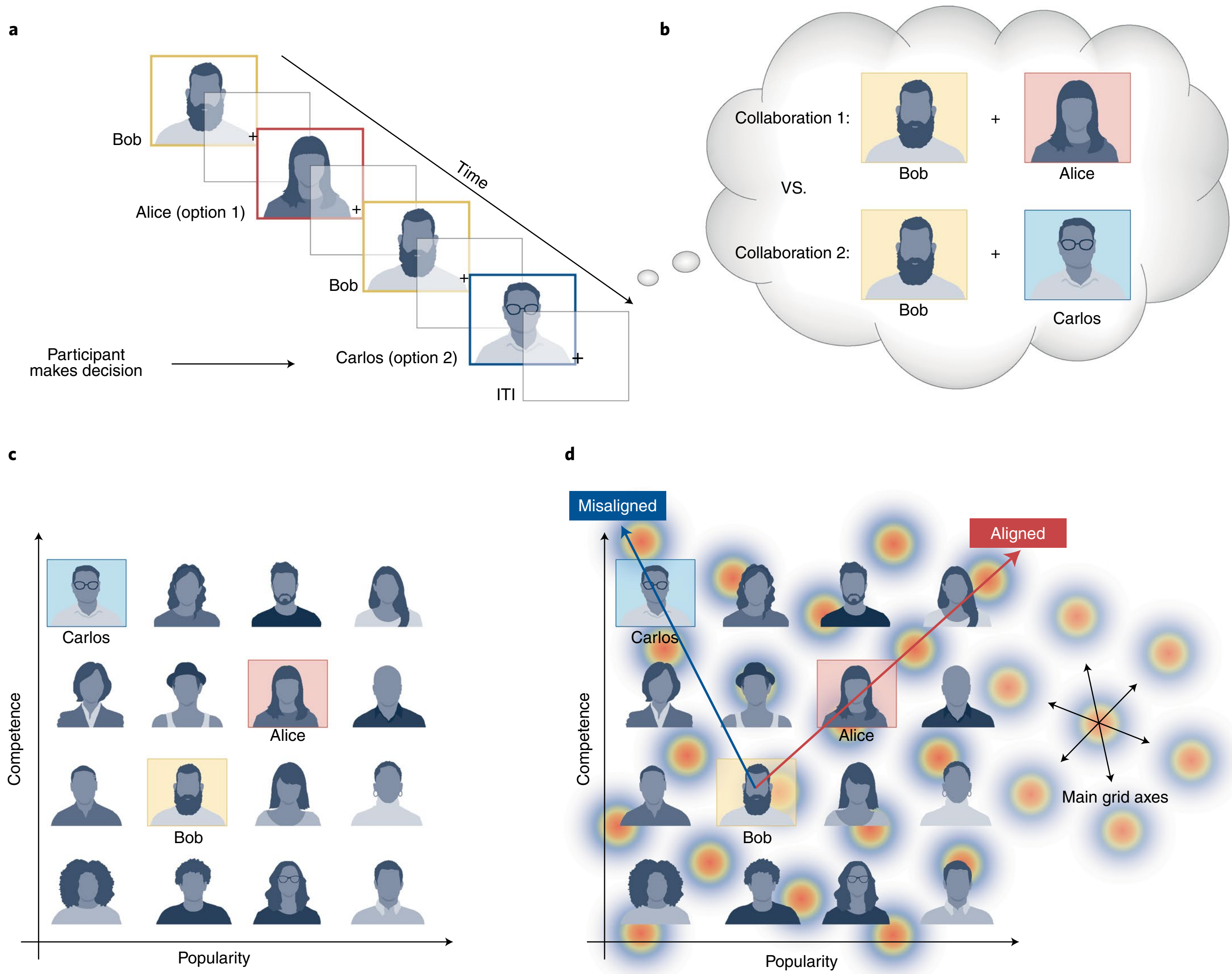

Fig. 1 | Investigating the encoding and navigation of social knowledge. a, In each trial of the partner selection paradigm administered during fMRI scanning, participants first saw one entrepreneur (Bob), followed by two potential business partners (Alice and Carlos). **b**, Participants then had to choose the best business partner for Bob, based on what they had learned prior to scanning about his potential business partners' popularity and competence. **c**, The entrepreneurs can be thought of in terms of a cognitive map defined by the two dimensions of social knowledge (popularity × competence) that participants learned about prior to scanning. Several brain regions encoded the entrepreneurs in this way, including portions of the hippocampus, entorhinal cortex, medial prefrontal cortex (MPFC), precuneus and posterior cingulate cortex. **d**, The researchers also found evidence for grid-like encoding of social knowledge by comparing the magnitudes of neural responses evoked for 'thought trajectories' that were aligned (from Bob to Alice) versus misaligned (from Bob to Carlos), with a grid based on responses in entorhinal cortex. Responses aligned with one of the main axes of the grid (depicted at right) pass through more grid cell firing fields (represented by circles), and thus elicit greater population-level activity, generating a macroscopic signature of grid encoding that can be detected with fMRI. Evidence for grid-like coding of social knowledge was found in regions that are widely implicated in social cognition, including the MPFC, the temporoparietal junction and the superior temporal sulcus extending into the anterior temporal lobe.

face, then Alice's face should elicit greater grid cell activity than Carlos' face. This is because the trajectory from Bob to Alice is aligned with the orientation of the grid, so this trajectory passes through more grid cell firing fields than the trajectory from Bob to Carlos.

How did the authors test for a grid code with fMRI? Although the coarse spatial resolution of fMRI makes it impossible to measure the firing of grid cells directly, prior work[5] revealed a macroscopic signature of grid-like coding that is detectable with fMRI. Briefly, the population-level mean activity of grid cells is higher when moving in a direction that is aligned, rather than misaligned, with one of the main grid axes (Fig. 1d), which themselves tend to be aligned across cells. Therefore, when observed with fMRI, brain areas containing populations of grid cells show a sixfold rotational symmetry as a function of the direction of movement through the cognitive map (in the current study, 'movement' corresponds to participants' mental traversal of a cognitive map of the entrepreneurs' traits as they completed the partner selection task). In other words, there is 60° periodicity or hexadirectional grid-like modulation: there are six possible trajectory directions, separated from one another in increments of 60°, that are aligned with the main grid axes and that therefore elicit equivalently robust responses (Fig. 1d). This population-level signature of grid coding allows researchers to use fMRI to test whether the brain encodes 'thought trajectories' within 2D representational spaces, including abstract conceptual spaces defined by knowledge of other people's traits or social status, using a grid code.

The authors found evidence for grid-like encoding of the social space in the entorhinal cortex, as well as in other brain regions including the MFPC, the superior temporal sulcus (STS) extending into the anterior temporal lobe (ATL), and the temporoparietal junction (TPJ). Neural responses in these regions exhibited hexadirectional grid-like modulation aligned to the grid orientation defined based on responses in entorhinal cortex. This could reflect grid cells outside of entorhinal cortex encoding social knowledge in a manner that is aligned with representations within the entorhinal grid system; it could also reflect interactions or synchronized inputs between the entorhinal grid system and these other brain regions. The MPFC has previously been found to have grid-like encoding of space[6] and conceptual knowledge[7], and the TPJ has, to some extent, shown grid-like encoding of conceptual knowledge[7]. That said, the spatial extent and magnitude of the effects in some regions implicated in the current study are noteworthy, as the brain regions that evinced hexagonal modulation aligned to the grid orientation in entorhinal cortex, such as the TPJ and STS, are also areas that are widely associated with social cognitive processes.

One possible explanation for this functional overlap in regions such as the TPJ and STS could be that it arises because the task requires participants to take the perspective of the first entrepreneur shown in each trial—in other words, to engage in perspective-taking on the 2D cognitive map. Another possibility is that these brain regions contain a grid-like encoding scheme that is preferentially used to represent social knowledge, which may not have been engaged as robustly in prior work using non-social content. The latter possibility is particularly interesting given that these regions are involved in encoding knowledge about other people, including their mental states, personalities and relationships[8–11]. Future work can tease apart these possibilities by decoupling the task structure (e.g., tasks that involve perspective-taking versus tasks that do not) from the domain of knowledge (e.g., social versus non-social).

Future research will benefit from taking into account the roles that other brain regions play in 'navigating' abstract knowledge. For example, it has been suggested that the superior parietal lobule (SPL) supports flexibly shifting attention not only in external space but also in mental representations of abstract knowledge[12]. Consistent with this suggestion, response patterns in the SPL encode the 'directions' of attentional shifts in the space around oneself, as well as in mental representations of numbers (e.g., during mental arithmetic[13]) and social relations (e.g., when mentally 'navigating' social hierarchy knowledge[14]). These other studies implicated a different set of brain regions than the study by Park et al.[1]. However, whereas Park et al.[1] compared the neural encoding of thought trajectories in conceptual knowledge that varied in terms of their alignment to a hexagonal grid (Fig. 1d), prior work focusing on the SPL[13,14] compared the neural encoding of thought trajectories with *exactly opposite* orientations (akin to comparing the encoding of the imagined trajectory from Bob to Alice to the imagined trajectory from Alice to Bob), which would be equivalently aligned to the hexagonal grid. In navigating social knowledge in everyday life, it is often important to distinguish thought trajectories in exactly opposite directions (e.g., navigating 'up' or 'down' in knowledge of social status), but grid-like coding of such trajectories would elicit equivalent fMRI responses. How do the functions of 'spatially' tuned cells in the hippocampal formation and other brain regions, such as the SPL, combine to support our ability to 'navigate' social knowledge? Subsequent work should pursue an integrative understanding of the mental operations that different brain regions contribute to support abstract social cognition.

Like physical space, social knowledge appears to be encoded as a cognitive map[15] and represented with a grid-like code in the human brain[1]. In addition to suggesting that spatial information and abstract social knowledge are represented and processed similarly by the brain, the current results raise exciting questions for future research. For example, would these findings generalize to other types of social knowledge (e.g., knowledge of social distance and personality traits)? Additionally, in the present study, participants learned about people who varied only in terms of two experimentally manipulated dimensions. However, although hexagonal grids are ideally suited for constructing high-resolution 2D maps, different geometric structures are ideal for representing higher-dimensional spaces[4]. What dimensions, and how many of them, organize the mental 'maps' of social knowledge that we draw upon in day-to-day life? If such maps exceed two dimensions, how are they encoded? Do the answers to these questions vary across contexts? Continuing this exciting line of research promises to advance our understanding of how the human brain 'navigates' the social world. ❐

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Competing interests

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