Imagine a bright day on a winter morning, walking down the streets of Bangalore. All of a sudden, a passerby asks you “How far to the Lalbagh Gardens?”

Questions such as these are quiet easy to answer if you are aware of the location. And your brain performs this function quite well. You stretch your head to see the destination (if it is near), point it out with your hand and verbally announce the distance and direction. The job done, the questioner offers gratitude and you both resume your activity.

You thought it was an easy accomplishment. But have you ever wondered: how does the brain comprehend distance and location? That pink, soft, mass hidden inside the skull is just a tangle of a million nerve cells communicating with each other through electrical signals. How can complex ideas such as space, time and location be comprehended by this tangle of electrical circuits?

Providing a direction and location you already know to another person can be done based on your experience about the location. This is termed as experience-dependent navigation and there are three essential elements to this: the evaluation of the information obtained visually and verbally (your current position), the integration of this information with past knowledge about the destination, and a comparison with internal state information (such as motivation, stress, and hormone status). A combination of these three factors determines the appropriate behavioral output. This bit explains the “answering” part but it doesn’t answer the primary question. How does the brain remember its location and distance?

The brain forms a map of the areas and environment that you frequent and it has specialized neuronal cells to do so. As you wander around a new environment, at least five sets of neurons initiate signaling (or fire up) to form a sort of “map” of the environment. Most of them are present in a part of the brain called the “hippocampus” and its adjoining areas.

The hippocampus may play a role in calculating the present position by keeping track of the previous movements through the environment, a process called “path integration”.

The word hippocampus means “water-horse” in Latin and the name originates from the strange semi-circular crescent shape of this part of the brain.
Experiments in rats have suggested the presence of other neurons. The grid cells are embedded in a network with “head direction” cells and “border” cells, and in many cases, cells with a combined function.

Interestingly, the firing of place cells is not controlled by the magnetic north nor does it depend on the time of the day. Rather, it depends solely on the location of the observer relative to the arrangement of objects within an environment.

The hippocampus may play a role in calculating the present position by keeping track of the previous movements through the environment, a process called “path integration”. Imagine your through the environment, a process of calculating the present position by keeping track of the previous movements in an environment. The neuronal activity helps in creating a three-dimensional map of any place inside your brain.

The firing pattern of a rat’s grid cell as the animal moves around in a one-meter square box. The red colour is indicative of high grid-cell activity and dark blue implies no activity. The neuronal firing is spaced at regular distances, with the active areas forming a hexagonal grid pattern. Photo courtesy of www.Kavlifoundation.org

When you repeat the steps, for example on the second or third visit, the place field is strengthened, which indicates that place fields are related with memory formation, something that also occurs in the hippocampus (coincidence?).

Grid cells are neurons present in a portion of the brain called medial entorhinal cortex. Let us understand the location of this structure in the human brain. The mammalian brain is divided into four lobes: frontal, parietal, occipital and temporal. The entorhinal cortex is located in the medial temporal lobe and functions in navigation and memory formation. The name indicates that it is interior (ento) to the “rhinal fissure”, a furrow in the surface of the brain.

Grid cells make up a basic coordinate system, like the X- and Y-values that you draw in a graph. They fire when you traverse small, equidistant areas in a large region. So, as you walk and twist and turn and climb up or down in the Lalbagh garden (or anywhere else for that matter), one single grid neuron fires up after every few steps, irrespective of any prominent landmark. In the brain, these activated grid cells lie equidistant from each other and are arranged in hexagonal shapes with each grid neuron occupying one corner of the hexagon.

Together, these hexagonal units create an exact map of a large three-dimensional area. The interesting thing about grid cells is that though they are anchored to external landmarks, they can persist in darkness, suggesting that you can even form a grid coordinate map of an entire area even if you walk with closed eyes. Grid cells in the same area of the medial entorhinal cortex fire with the same spacing and orientation of the grid, but different phases, so that adding all the phases together they cover every point in the environment. The grid system provides a solution to measuring movement distances and adds a reference to the spatial maps in hippocampus.

Experiments in rats have suggested the presence of other neurons. The grid cells are embedded in a network with “head direction” cells and “border” cells, and in many cases, cells with a combined function. Direction cells act like a compass and are active when the head of an animal points in a certain direction. Border cells are active in reference to walls that the animal encounters when moving in a closed environment.

To summarize, hippocampal neural activity helps in creating a three-dimensional map of any place inside your head with the help of a large network of place and grid neurons, helped further by boundary-, border- and head direction moving-cells.

So, the next time someone asks for directions, respond with “Wait, let me ask the water-horse!”

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