PRESENTATION

Labyrinths have always fascinated and captivated human beings. Initially, labyrinths were the protagonists of legends, rites and myths, such as the labyrinth built in Crete by Daedalus. There, he imprisoned the Minotaur that defeated Theseus thanks to the help of Ariadne, who gave him the thread he used to escape. Later on, labyrinths served as a religious symbol, an image of the tortuous passage to salvation, and were carved on the floors of churches and cathedrals, such as the great labyrinth of Chartres Cathedral (France), the largest of the Middle Ages. Starting with the Renaissance, mazes featured as ornamental elements and an amusement for the noble classes in their palace gardens, such as the "Labyrinth of Love" at Villa Pisani (Italy). With the start of science at the Modern Era, they also posed a mathematical challenge, giving rise to new branches of study, such as topology and graph theory. In the 20th century, labyrinths were a popular pastime and a tool for the study of brain function, first in animals and later in humans. Currently, mazes are used for neuroscience research as well as the diagnosis of some mental disorders and as a therapeutic treatment in rehabilitation.

This area, that of neuroscientific research, is what this exhibition aims to explore. It does so in a practical playful way, with labyrinths that turn visitors into subjects of study and allow them to directly experience the explanations and elements of information presented in the exhibition.

Theseus, after leaving the labyrinth, shows Athena the defeated Minotaur. Aison- Cup.
Red-figure technique. 420 B.C.E. Attica (Greece).
©National Archaeological Museum. Inv. 11265.
Photo: Fernando Velasco Mora.

PLAYING TO STIMULATE THE MIND

Maze games became popular in the early 20th century and had their heyday at the end of the 20Th century, with the advent of role-playing and video games.

Maze puzzles have continued to be popular. Scientific studies show that they increase cognitive stimulation, psychomotor skills, abstract thinking and spatial perception at all ages.

The first revolution took place in the 1970s with dungeon crawler board games and role-playing games. The most popular were *Dungeons & Dragons*[1] (1974) and *HeroQuest*[2], as of 1989.

The next revolution came between the 1980s and the late 1990s with two-dimensional labyrinth video games. *Pac-Man*[3] was the most successful *arcade game* of all time. *Snake*[4] became popular when it was included pre-recorded on some cell phones. *Wolfenstein 3D*[5], *Doom*[6] and *Quake*[7] introduced three-dimensional mazes for PC-console and popularized multiplayer games where orientation skills were encouraged in maze-like environments.

The negative side was the violence that characterized the latter, which encouraged aggressive behavior in some adolescents with underlying problems. These games are beneficial as long as they are not a person's only form of recreation, are combined with real social relations, exposure times are limited, the recommended age is respected, and there is no previous pathology or mental problem.

(1) *Dungeons & Dragons*. Design: Gary Gygax y Dave Arneson. Company: Tactical Studies Rules (TRS). (Fig.3)

(2) *HeroQuest*. Design: Stephen Baker. Company: Milton Bradley y Games Workshop. (Fig.8)

(3) *Pac-Man*. Design: Tōru Iwatani. Company: Namco y Midway Games. (Fig.5)

(4) *Snake*. Design: Taneli Armanto. Company: Nokia. (Fig.2)

(5) *Wolfenstein 3D*. Design: Alfonso John Romero y Tom Hall. Company: id Sofware. (Fig.7)

(6) *Doom*. Design: Alfonso John Romero, Tom Hall y John Carmack. Company: id Sofware. (Fig.1)

(7) *Quake*. Design: Alfonso John Romero y John Carmack. Company: id Sofware. (Fig.4)

(*) Pastimes. (Fig.6)
Credits: https://www.guiainfantil.com/articulos/ocio/juegos/laberintos-para-ninos-jugar-con-laberintos/
https://www.educaciontrespuntocero.com/recursos/fichas-laberintos/

LABYRINTHS

HOW DO WE GET THROUGH A LABYRINTH?

We are able to orient ourselves in a maze thanks to a combination of sensory input -mainly sight- and memory.

Our ability to find our way through and/or get out of a maze is based on our ability to perceive environmental cues through our senses, and our brain's ability to process and store this information, combining it with other data already recorded on our "hard drive".

If either our senses or our brain fails, are impaired or involved in a different task, our ability to cope with a maze is seriously diminished.

BUT WHAT CAN I SEE?

The absence of visual references influences and compromises our ability to orient ourselves in a labyrinth.

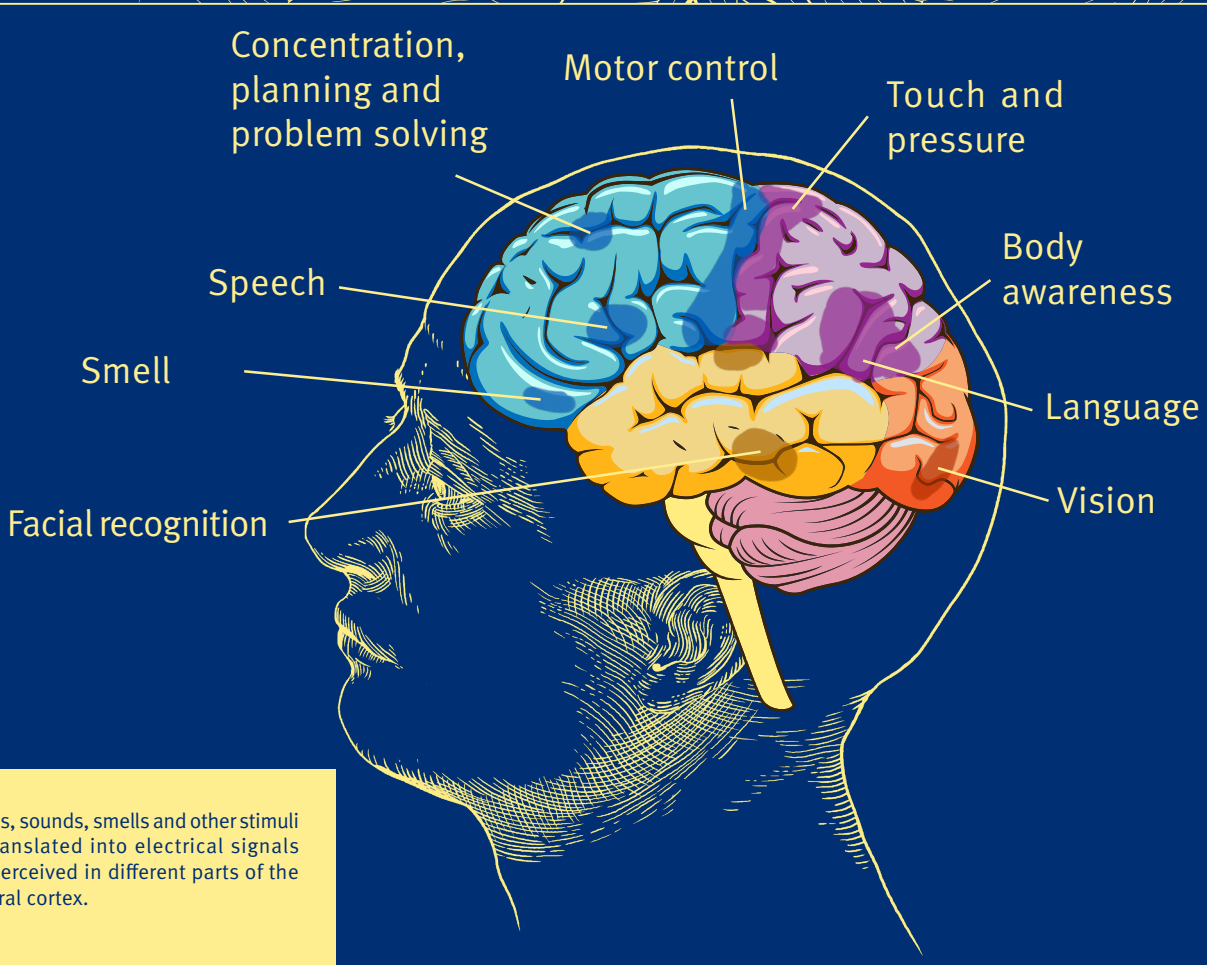
That is why it is easier to get lost or disoriented at night, especially in rural environments or in nature. And that is also why our ancestors preferred to move around and search for food during the day and take shelter at nightfall.

PROCESS (FROM THE LATIN *PROCESSUS*): 1. ACTION OF GOING FORWARD

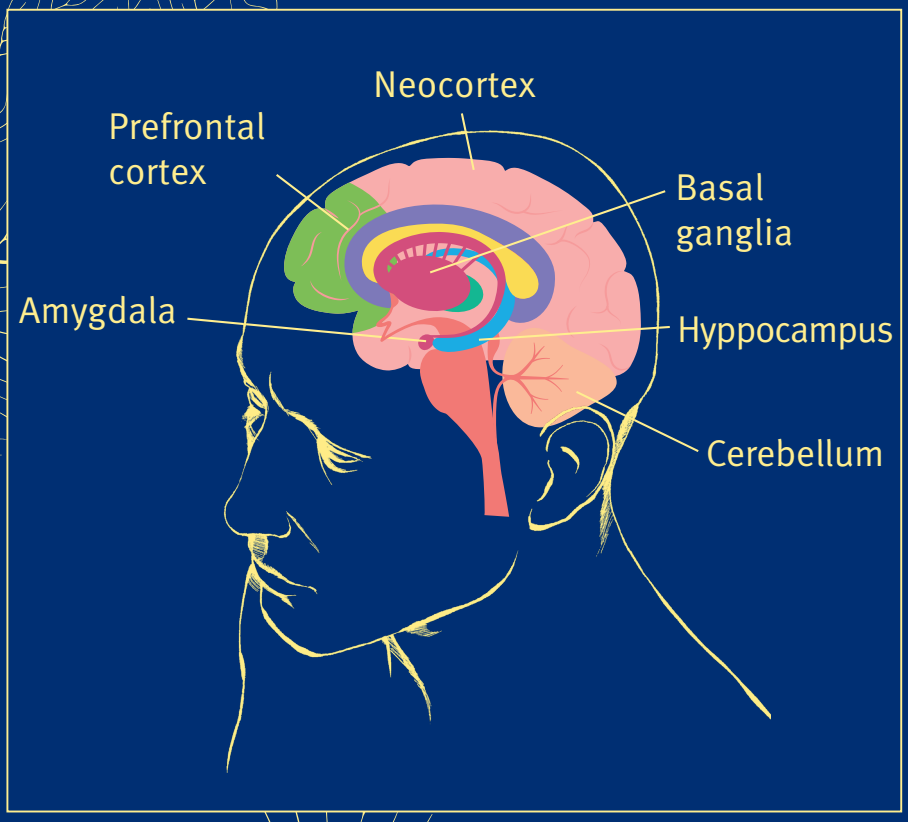
Invented by Robert Abbot in 1952, logic mazes are mazes that are visually very simple to solve but in which a series of rules must be followed. This requires a greater processing capacity on the part of the brain.

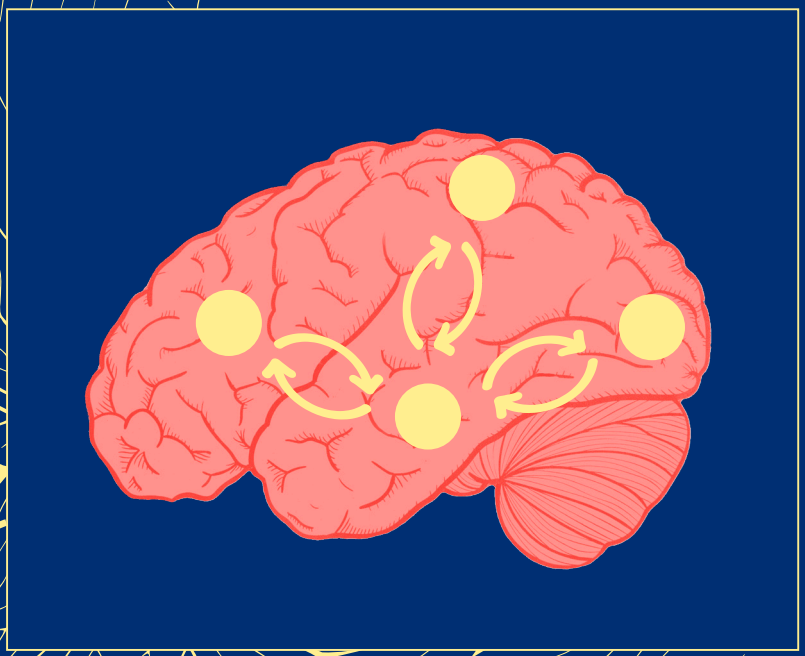
Vision and other brain processing systems, such as memory or logic, act jointly. Which system prevails depends on the circumstances. The most obvious example is the logic mazes we face, knowing beforehand that their difficulty does not lie in their layout (which, in fact, is usually very simple) but rather, in the obligatory nature of going through them by following a set of rules.

MAKE SENSE OF YOUR MEMORIES



Images, sounds, smells and other stimuli are translated into electrical signals and perceived in different parts of the cerebral cortex.





Perceived information is encoded so that different types of memories are formed: data, biographical events, emotions, automatisms such as riding a bicycle, etc. The figure shows the most relevant areas for encoding and storage.

Subsequently, these stored memories can be retrieved when needed. In this process, synchronized interaction between different zones is important, depending on the information involved. For example, to retrieve data or biographical events, the interaction between the hippocampus and the cerebral cortex is important.

ARE YOU READY FOR THE MEETING?

Sometimes we may also voluntarily prioritize one capacity - vision or brain processing - over the other.

In fact, we do so without being aware of the need to devote one of them - sight or memory - to a more urgent or important task. For instance, our ability to cope with a labyrinthine environment was modeled in our remote past by identifying possible signs of prey or predators, as well as locating food sources. Nowadays, our challenges arise in undertaking a phone conversation, a WhatsApp exchange, remembering important information, and so on.

THE SUPERMARKET LABYRINTH

A case study and an experiment to do on the way home.

Try walking along the aisles of the supermarket from the entrance to the fish stand and back to the exit. Repeat the experience while having to remember the items on your shopping list, a task that keeps the memory (partially) occupied.

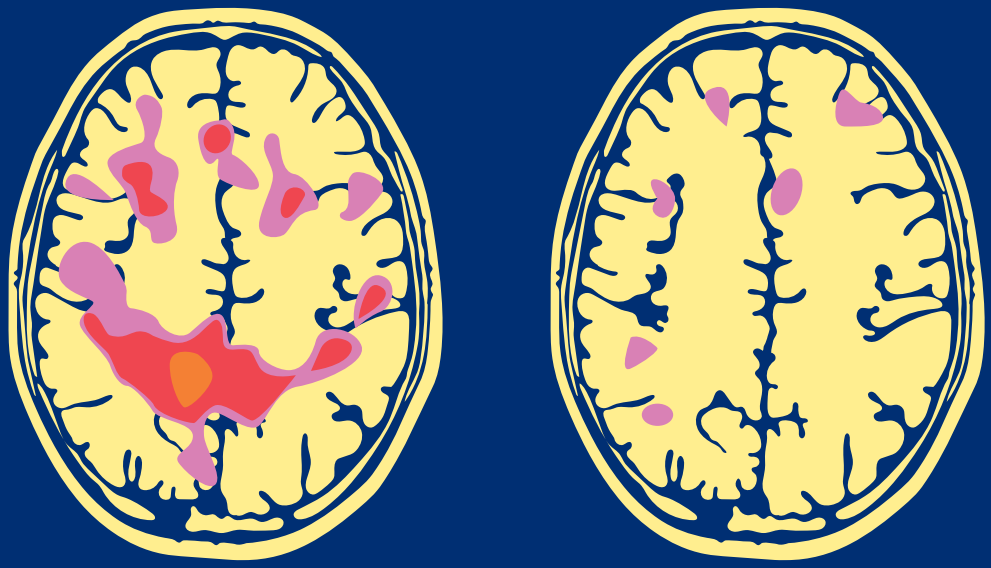
IF YOU DRINK ALCOHOL, YOU'RE LOST

Now that we know that we orient ourselves through a combination of sensory information and memory and that our ability to orient ourselves is compromised when either or both fail, it is easy to understand why it is so common for us to become disoriented and unable to find our way home after a night out. And it's not due to a lack of light at that time of night.

The image, obtained by PET (Positron Emission Tomography), shows the activation of the cerebral cortex when performing a task that requires memory to review a route (such as the way home or to work). The activity is much lower in a subject who consumes alcohol regularly despite the fact that the test was performed while sober.

15-year-old non-drinker

15-year-old regular drinker



Brain activity during the execution of memory exercises. The regular drinker is sober during the test.[1]

(1) Doctor Susann F. Tapert; University of California, San Diego.

DRIVING TEST

Drinking one drink too many, having memory lapses and not knowing the way home go hand in hand. If you have trouble finding your way, we got you!

BRAIN

THE INTERNAL NAVIGATOR OR “GPS” OF THE BRAIN

Our brain has a sophisticated spatial navigator.

Now that it is clear that our ability to navigate a maze depends on our senses (mainly sight) and the computational capacity of our brain, it is time to figure out how we orient ourselves in a maze-like environment. How our spatial localization system works: the brain’s internal positioning system or “GPS”.

WE LIVE SURROUNDED BY LABYRINTHS!

We constantly face labyrinthine environments equipped with our inner navigator.

Why is this internal positioning system so important? Because labyrinths can be a lot of fun when they are used as entertainment, in places like an amusement park or a videogame. But they are less amusing when they show up and interfere in our daily lives. And they do: every day we face a multitude of labyrinthine scenarios through which we move by using our brain's "GPS "(and sometimes the ones in our cars or smartphones). When we walk among supermarket shelves or through the aisles of a large shopping mall; when we get on the subway and choose the best route; or when we look for an alternative route to avoid traffic jams on our way home from work.

INTERNAL BRAIN NAVIGATOR: COMPONENTS AND USER'S MANUAL

Our inner positioning system or "brain GPS" consists of two elements or functionalities: a system to identify prominent signals and locate them, and a universal reference system within which we move around.

The reference system is a grid (analogous to a system of meridians and parallels) and is always the same in any environment: it is universal. The brain superimposes it on the scenario we are facing in order to have a guide that allows us to know at all times where we are and in what direction and how far we are moving through that environment.

Once the scenario has been integrated into this reference system, the brain identifies particular signals or landmarks and places them in one of these boxes.

In this way and with these landmarks as references, we can estimate how far we have come and in what direction: how many boxes we have covered and in which direction. And how far we have to go: how many boxes and in which direction we have to move to reach a specific landmark, such as a church we want to visit when we see its bell tower in the distance.

In fact, our brain employs a navigation system that works in a similar way to the maps in travel guides.

...AND ALSO, THE MEMORIES OF TOURISTS

When we move through a familiar environment, our brain calls up its stored map to quickly orient itself.

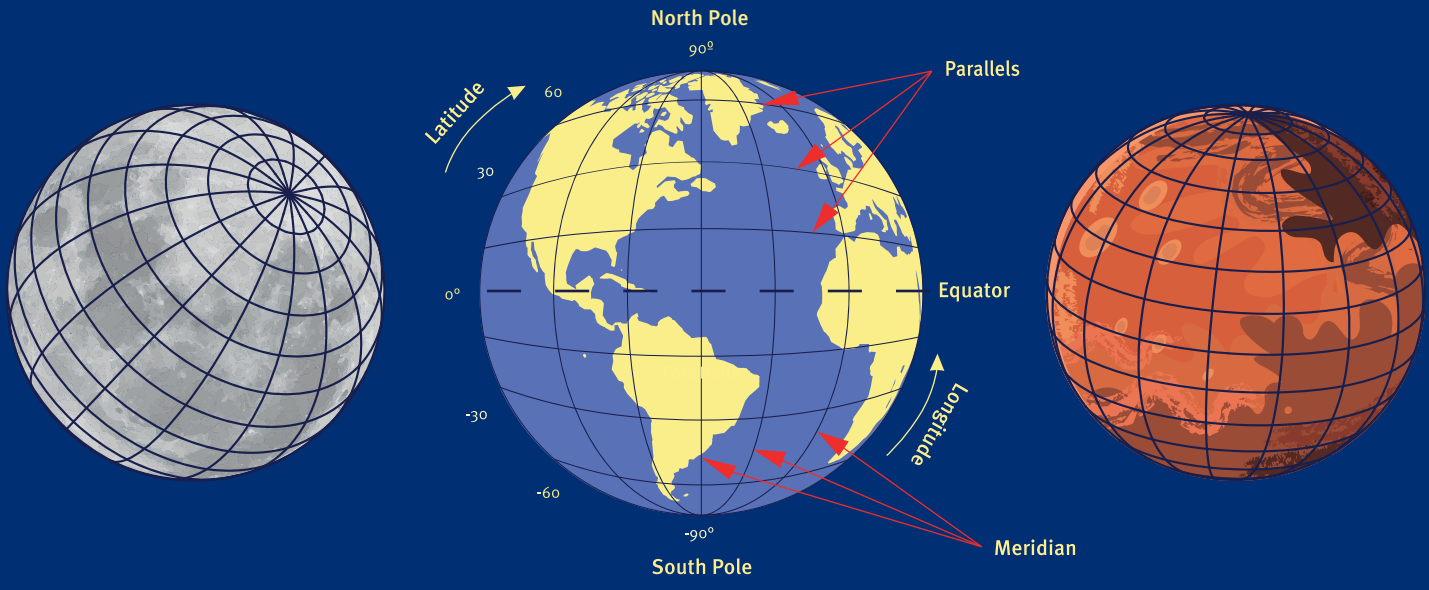
When we move through a familiar environment, our brain accesses its mental map file to retrieve that particular map with the exact positions of the landmarks in that environment and uses them to recognize where we are and how we have to move to get to the desired destination.

The difference is that we do not identify and fix the position of particular landmarks as we discover them, but instead, we start with that information in mind, which allows us to move faster and more safely because we make a more accurate estimate of our position at each moment.

This apparent security is also what sometimes plays a trick on us when the pieces of the scenario are changed unexpectedly. For example, going back to our supermarket case study, when the store we usually go to changes the location of different types of products or the distribution on the shelves from one day to the next.

UNIVERSAL: THAT WHICH IS COMMON TO ALL, WITHOUT EXCEPTION

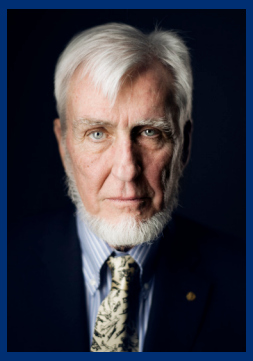
What does it mean that the reference system is universal?
That it is the same, regardless of setting or environment.



Moon **The Earth** **Mars**

A DISCOVERY THAT DESERVES A NOBEL PRIZE

The Nobel Prize in Physiology or Medicine 2014



John O'Keefe. 1/2 Prize

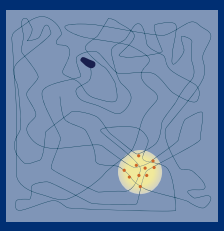
John O'Keefe discovered, in 1971, that certain nerve cells in the brain were activated when a rat occupied a particular location in the environment. Other nerve cells were activated elsewhere. He proposed that these "place cells" construct an internal map of the environment. The "place cells" are found in a part of the brain called the hippocampus.

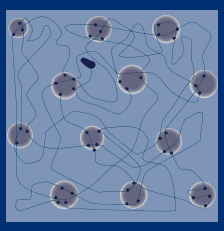
May-Britt. 1/4 Prize

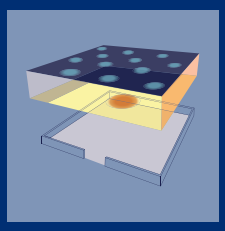
May-Britt and Edvard I. Moser discovered in 2005 that other nerve cells in a nearby part of the brain, the entorhinal cortex, were activated when a rat passed by certain locations. Together, these locations formed a grid, in which each "grid cell" reacted according to a unique spatial pattern. Jointly, these grids form a coordinate system that enables spatial navigation.

Edvard I. Moser. 1/4 Prize

The reticular cells, along with other cells of the entorhinal cortex that recognize the direction of the animal's head and the edge of the room, form networks with the place cells of the hippocampus. These circuits constitute a complete internal positioning system, a kind of "GPS", in the brain. The positioning system of the human brain appears to have components similar to those of the rat brain.





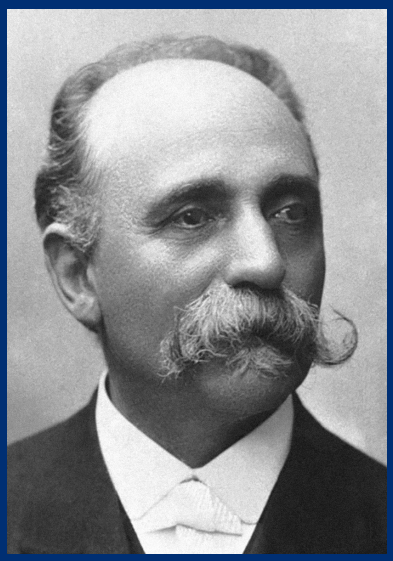


CAJAL: THE "BRAIN" OF NEURONS

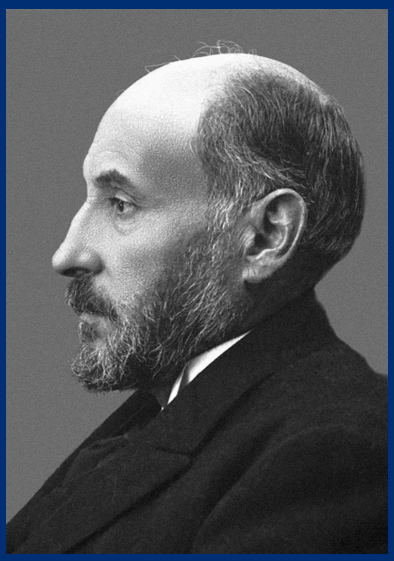
The Nobel Prize in Physiology or Medicine 1906

The 1906 Nobel Prize in Physiology or Medicine was awarded jointly to Camillo Golgi and Santiago Ramón y Cajal "in recognition of their work on the structure of the nervous system".

Our body is controlled by the nervous system. In 1870, Camillo Golgi discovered a technique for staining and studying nerve cells. Cajal began using Golgi's method in 1887 and inaugurated an era of extraordinary discoveries. He observed that neurons were independent cells. They constituted the structural and functional unit of the nervous system and communicated with each other by means of synapses, which allowed for the transmission of nerve impulses. Starting from still images obtained in his microscope, Cajal gave a functional sense to what he observed and predicted how information flows through the nervous system, laying the foundations of modern neuroscience.



Camillo Golgi
1/2 Prize



Santiago Ramón y Cajal
1/2 Prize

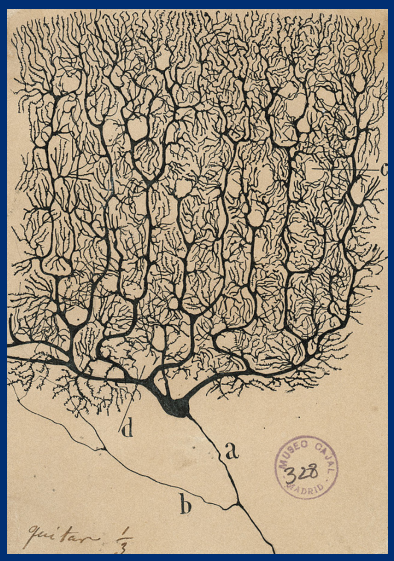


Illustration of Purkinje cell. Cover of *The beautiful brain.* Abrams Books (2017).

NEUROSCIENCE

THE LABYRINTHS OF NEUROSCIENCE

Why is it so important to understand how the brain's inner navigator works in detail?

Because then labyrinths become an instrument for the diagnosis and/or treatment of some mental illnesses and disorders.

As neuroscience has delved deeper into how the brain deals with, processes, and finds its way through mazes, labyrinths have become a tool increasingly applied in brain research and also in diagnosing neurological disorders and as a therapy to treat them.

FOLLOW THAT CAB!

The ability to orient oneself in a labyrinth can be trained.

In 2011, a study showed that London cab drivers have more highly developed regions of the brain where the information and memories on which our navigation system depends are stored. And also, that this increase in brain capacity was a consequence of practice. The more experienced cab drivers had a higher capacity. In other words, this capacity can be trained. Better yet, the ability to orient oneself increases with training. A discovery that opened the door to its application as a therapy for the brain.

SEA HERO QUEST: A RECREATIONAL COMPUTER APPLICATION FOR NEUROSCIENTISTS

This orientation game was designed by researchers to help them diagnose Alzheimer's and other dementias.

Difficulty with spatial navigation is one of the common symptoms of the early stages of Alzheimer's and other dementias. Understanding how that difficulty manifests would make it possible to diagnose these diseases in the earliest stages.

Sea Hero Quest is an orienteering game designed by neuroscientists at the University of East Anglia (UK) in collaboration with University College London, CNRS and other prestigious Universities, as an app for smartphones. The objective was to collect a huge volume of data from a large number of people of all ages, ethnicities, genders, backgrounds, etc. And use this data to determine how our ability to navigate evolves over time and what is the normal age-related decline. This in turn will allow for earlier diagnosis of disease when the patient's signs of loss exceed (or are shown in another way) those normal for their age range.

THE SCIENCE BEHIND THE VIDEOGAME

Today, more than 55 million people worldwide are living with some form of dementia.

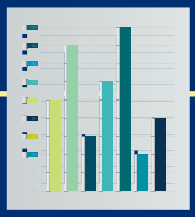
People with dementia could be better helped if experts could diagnose the disease earlier.

One of the first signs of dementia is that people begin to lose the ability to orient themselves.

But doctors have no way of knowing if people get lost because they have dementia or if it is due to other reasons.

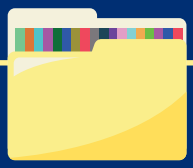
To help doctors diagnose dementia earlier, we needed to create a global benchmark of how healthy people navigate.

2.4 million people worldwide played a mobile game that can track an individual's spatial navigation capabilities.



Sea Hero Quest [1] produced the largest dementia study in history.

(1) It was developed by the UK-based company Glitchers in 2016 in partnership with Alzheimer's Research UK, University College London and the University of East Anglia, with funding from Deutsche Telekom.



Thanks to *Sea Hero Quest* we now have a huge amount of data and can create a worldwide reference for humans' spatial navigation. Preliminary results reveal that:

Our spatial navigation capabilities begin to decline in early adulthood; earlier studies suggested that this decline was to be expected later in life.

Where you live as a child affects your navigational abilities: people in Nordic countries (Finland, Sweden, Norway, and Denmark) have particularly good navigational capabilities.

There are differences in spatial navigation strategies between men and women. However, in places with greater gender equality, these differences practically disappear.

Sea Hero Quest will now be applied in a clinical setting to help predict the early onset of dementia, as well as to influence the treatment of patients already diagnosed with the disease.

ARE YOU FROM A TOWN OR A CITY?

People who live in the countryside can orient themselves more easily.

One of the first conclusions reached from the data collected by the game thanks to citizen participation - announced in March 2022 - is that people living in urban environments have poorer orientation ability (they seem to have a less effective inner navigation system) than people living in rural environments. The more grid-like or planned (wide, straight streets) the design of the cities or neighborhoods in which they live, the worse it gets. In short, whether the environment is more or less like a labyrinth, affects your orientation capacity.

WHAT IS A LABYRINTH CONFIGURATION OR “MAZE-INESS”?

In the 1980s architectural design expert Bill Hillier defined the term labyrinthine configuration or “maze-iness” of a place (a neighborhood, city, etc.) by how easy or accessible it was to circulate through it to reach the desired destination. He made a 0-10 point scale of increasing difficulty and identified Barbican Estate (London) as an example of maximum “maze-iness”, a complex of buildings built on several levels and featuring numerous entrances and corridors, which for many makes it a kind of concrete maze. To help visitors reach their destination, the routes are marked with colored lines on the ground and signs.

COVID MAY AFFECT OUR SPATIAL NAVIGATION SYSTEM

Having had the disease seems to cause a loss of ability to orient oneself in space.

Long COVID can cause neurological abnormalities such as brain fog characterized by memory problems, lack of mental clarity and an inability to concentrate.

A recent study published in March 2023 links having had long COVID with difficulties in spatial navigation and with the development of prosopagnosia or face blindness, a rare disorder of the visual system that prevents the recognition of familiar faces and which has been in the media because the famous actor Brad Pitt has admitted to suffering from it.

Localization difficulties affect the ability to locate a familiar place with respect to your current location. For example, the different sections of our supermarket (greengrocer's, butcher's, frozen food, etc.) or the parking space where the car is parked.

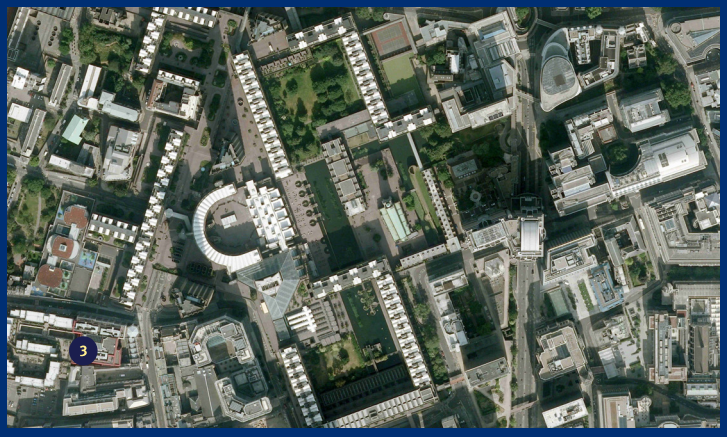
Have you had COVID? What about long COVID?
Do you know anyone who has had long COVID?
As a result of long COVID, have you/that person had or do you/that person have neurological problems?
If so, have you/that person noticed that it is more difficult to identify familiar faces?
And to locate oneself in space? For example, finding where one parked at the shopping center parking lot?

(*)If you would like to answer these same questions for us in a completely anonymous online survey, that takes only 1 or 2 minutes, capture this QR.

INSIDE THE LABYRINTH

1. Aerial view of an orderly urban neighborhood:
   The Eixample of Barcelona

2. Aerial view of a historic urban center:
   Sibiu, Romania



INSIDE THE LABYRINTH

3. Aerial view of a residential building complex:
Barbican Estate, City of London, United Kingdom

4. Aerial view of a village in a rural setting:
Carcassonne, France

MEMORABLE LABYRINTHS

***Labyrinth*: a virtual reality game that improves memory in the elderly.**

A recent study carried out in 2021[1] has confirmed that navigating virtual maze-like environments improves long-term memory in elderly individuals.

This opens the door to its future application to alleviate, slow and combat memory loss associated with aging and as a possible treatment to help with neuro-degenerative problems such as Alzheimer's[2] disease.

To reach this conclusion, the authors of the research developed the virtual reality game *Labyrinth* that immerses the individual in realistic new scenarios and environments.

(1) Wais, P. E., Arioli, M., Anguera-Singla, R. et al. (2021) *Sci Rep* 11, 2552

(2) Rubtcova, M. e Pavenkov, O. (2017) *International Conference on Inclusive Education-2017, University of South Australia-School of Education, October 27th-29th 2017*

MENTAL DISCONNECTION

One-way labyrinths are a great anti-stress therapy. And in Ancient Greece, they already knew it.

Another recent therapeutic application of labyrinths brings us back to their "origin". Since Antiquity and during the Middle Ages, labyrinths were understood above all as an area or a tool that invited meditation (and spirituality) when walking through them.

Nowadays, this use has been recovered and labyrinths are used to treat anxiety and stress. Specifically, small wall designs are used that must be traversed with the finger in order to achieve a state of mental relaxation. Full concentration on this task helps to free the mind from other worries, urgencies and anxieties.