Brain's GPS – not only for geographers

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Abstract
People have an innate ability to perceive and observe elements of the geographical environment, and interpret information coming from it as well as a sense of orientation in space. All this is affected by the state of the senses and personal knowledge. Cognitive processes, resources of concepts, knowledge of the environment and spatial imagination are essential. Some people show an environmental and visual-spatial intelligence, so such people may find it much easier to move around in space. Spatial skills can and must be constantly developed and improved, because they affect the quality of life. For decades scientific brain research has been conducted to discover its complex structure, thus explaining the process of learning the surroundings, development of spatial skills and functioning in the geographical environment. The discovery of the internal GPS in the brain of animals and humans turns out to be the most important study of the brain. Therefore not only a geographer knows space and knows how to move around it.

Keywords: geoinformation, GPS, spatial orientation, visual-spatial intelligence, brain.

Introduction

People perceive and observe the real world in the process of individual reception of reality, including certain elements of the geographical environment. The extent of the orientation in space and interpretation of the information coming from it depends on the state of the senses as well as personal knowledge. Every person, not only a geographer, has such skills. However, as geography is a chorological scientific discipline that studies the landscape of the Earth as well as its spatial environmental and socio-economic differentiation, it allows for a better understanding of the spatial variability of the human environment and explaining its causes. Does a geographer have better spatial skills and knows space better? In his book *The Little Prince* A. de Saint-Exupéry (2000) wrote:

And who is a geographer?
That is a sage who knows where to find seas, rivers, cities, mountains and deserts.

Geography is a discipline that goes beyond naming and locating specific geographical features. It does include the study of these elements, but it also deals with analysing, explaining and forecasting, and has huge educational values (Piotrowska 2005, 2006).

In an era of ICT and GIS we can ask another question: *Who is the man involved in geoinformation?* If you paraphrase the question of A. de Saint-Exupéry, the answer may be: *That is a sage who...* gathers, obtains, collects, processes, transmits, analyses and interprets geospatial data, which is consistent with the definition of geoinformation by Zwoliński (2009). The geospatial data is nothing more than information on individual geographic features, which is perceived by the human sensory systems and is the basis for learning geographical space. Boruń (1973) believes that the information is a level of ordering (or organising) the system. Młynarski (1979) writes that information is the most important component of each system, and its basic properties include the introduction of governance and order, and the ability to transfer it in space and time. As he further noted, each piece of information is processed by our knowledge and can lead to obtaining further information, or building new knowledge. At the same time it is the result of incoming stimuli and different information from the real world. Lisowski (2002), however, states that the information is the interpretation of the received signals (e.g. audio or optical), which describes the state and refers to some field of knowledge. According to him, the essence of information is to reduce uncertainty.

These obtained and received pieces of information about objects enable orientation in geographic space. The term *spatial orientation* is animals' innate ability to discern directions. Thus, spatial orientation is the ability of individuals to explore their environment in relation to the spatial and temporal conditions taking place in it. The main role is played here by the cognitive processes, knowledge of the body schema, the resource of concepts, knowledge about the environment, spatial imagination, etc. (Dictionary of Polish Language 2010). It is the ability to define and realise one's position in the terrain, as well as recognise it in a given situation. Therefore, it is closely related to visual perception (**Figure 1**).

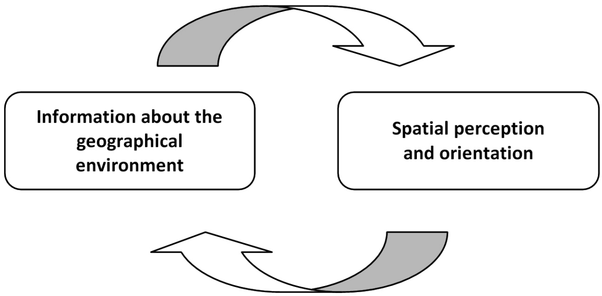

Figure 1. Model of the relationship between information and its reception and spatial orientation.
Source: own development

Referring to the Theory of Multiple Intelligence of Gardner (1983) which distinguishes 12 types of intelligence and remains the most important discovery of the social sciences of the 20th century, it is worth mentioning two of them: natural intelligence and visual-spatial intelligence. Some people are intelligent (sometimes specifically) in those terms. This innate ability can be both developed and improved, and the disciplines especially predestined to it are geography and geoinformation for which spatial orientation is one of the most important skills at all educational levels. This innate ability and perfected skill is used by people throughout their life, in different situations and contexts (Piotrowska 2011).

Spatial orientation: how to get to a destination?

The most basic questions related to spatial orientation include the following: *How do we locate ourselves in the terrain? How to get to a destination? How to find a geographical feature?* and *Does every person have the ability to orientate in the terrain?* Based on the research it can be concluded that spatial orientation ability depends on many factors, such as genes, experience and even sex. With regard to the latter condition, it is worth quoting Tomalski from the University of Warsaw, who states that *In the process of education boys more often than girls are encouraged to engage in games requiring good spatial orientation, and so later they are better in those terms* (Fiedorowicz 2013). In this perspective, it should be assumed that spatial orientation can actually be developed/learnt.

Various devices are used for proper orientation in space. The most primary and important scientific assistance for all, not only for the geographer, is a map. A map is the image of the Earth's surface or part of it, as shown on a plane, with the use of a proper cartographic projection, scale and using agreed symbols, allowing to read and interpret it. A map is still the basis of the knowledge and orientation in geographic space. According to Fiedorowicz (2013): *Most of us have lost the ability to "read" the road from the observation of nature – our ancestors were a lot better at their spatial skills. In contrast to the nomads, we cannot keep the direction of travel, and left in the unknown territory we walk in circles.*

As the author notes further, many animals, such as elephants, antelopes, or even ordinary ants, can wander from one place to another for several kilometers, keeping a selected direction of migration with no problems.

Few people, of course besides those who practice survival, can determine the cardinal directions on the basis of observations of the Sun or other stars and their positions towards the North Star. Geographical orientation in space is among the most important skills developed in geography classes and possible to apply throughout one's life (Piotrowska 2011). While the traditional ways of using the Sun and a watch, the North Star, and biological objects (trees, anthills) are still basic techniques, revolutionary advances have been made in this field.

The best-known instruments in use from before the era of technology is a compass (**Figures 2, 3** and **4**).

Figure 2. Liquid-filled compass.
Photo by Zbigniew Podgórski

Figure 3. East German compass with a mirror.
Photo by Stefan Kühn

Figure 4. Compass.
Source:
based on www.scholaris.pl

With the development of electronic technology and digital cartography, the instrument that allows orientation in space and determination of the route is a GPS receiver (**Figure 5**).

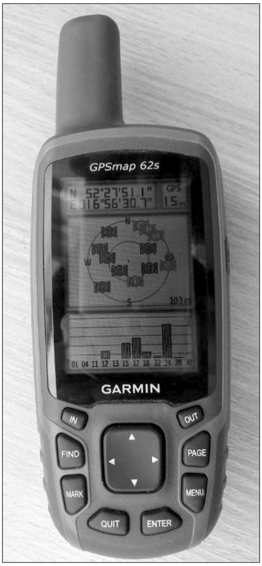

Figure 5. Garmin GPS receiver.
Photo by Iwona Piotrowska

The GPS (Global Positioning System, a US system of satellite navigation), consists of twenty four NAVSTAR satellites and ground stations. In Europe, a rival GALILEO system involving thirty satellites is being built, while in Russia there is work in progress on GLONASS. Today maps are GPS-adjusted, especially road and tourist ones.

The GPS-NAVSTAR (short for Global Positioning System – NAVigation Signal Timing and Ranging) is a satellite navigation system covering the entire globe. Its operation involves the measurement of the time it takes a radio signal from the satellites to reach a receiver. Knowing the velocity of an electromagnetic wave and the exact time of sending a signal, it is possible to calculate the distance between the receiver and the satellites. A GPS signal contains information about the positioning of satellites in the sky and about their theoretical path and deviations from it. The GPS receiver first updates this information in its memory and then uses it to establish its distance from the individual visible satellites.

The microprocessor in the receiver can calculate its geographical position (longitude, latitude and ellipsoidal elevation) and display it in a selected reference system as well as give the current GPS time with great accuracy. The GPS system is maintained and managed by the US Defence Department. In principle, everyone can avail themselves of its services if they possess a suitable GPS receiver. Its varieties are produced by independent commercial firms. Thanks to geostationary satellites placed in orbit round the Earth, it is possible to read the location of a point with an accuracy of a few metres.

Brain structure

Regardless of the devices, which help to determine the location or the route, can a man orient themselves in space? In search of the secret of perfect spatial orientation the researchers tested London taxi drivers, who daily roam in the jungle of 25 000 winding streets of the British capital (Fiedorowicz 2013). E. Maguire of the University College London conducted a study using magnetic resonance imaging and peered into the brains of taxi drivers and compared it with what is hidden under the skulls of their passengers. The research found that the taxi drivers had a more developed hippocampus, i.e. the structure related to, among others, remembering and learning processes.
It is interesting to look at the structure of the human brain, since here is the center of all cognitive processes, as well as spatial orientation (**Figure 6**).

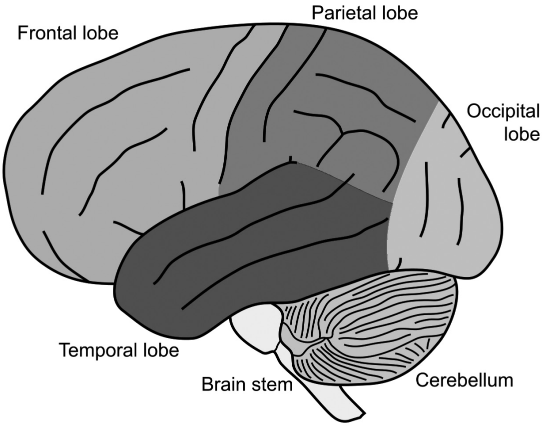

Figure 6. Human brain structure.
Source: based on en.wikipedia.org

The brain is built of approx. one trillion brain cells, which includes 100 billion active nerve cells and 900 billion "caring" cells that nourish, connect and protect nerve cells.

Individual lobes are responsible for the following processes:
a) frontal lobe – associated with motor activities as well as the higher mental functions, such as planning activities, adherence to ethical standards, analysis and control of emotional states, decision making and the ability to abstract thinking,
b) parietal lobe – responsible for spatial orientation, movement and motion perception, as well as temperature, pain and touch sensation,
c) occipital lobe – connected to the sight, it is responsible for vision and connotations associated with it, as well as colour and depth recognition,
d) temporal lobe – responsible for speech, hearing and understanding speech; it is important for verbal functions.

A specific role in the brain is played by the hippocampus – a small structure located in the temporal lobe of the cerebral cortex, an element of the limbic system primarily responsible for the memory.
The hippocampus plays an important role in transferring information from short-term memory (memory responsible for the storage of small details for a very short time, e.g. a dozen seconds) to long-term memory (i.e. persistent storage memory of theoretically unlimited capacity and storage time) and spatial orientation. The capacity of long-term memory is 1.4 petabytes, which corresponds to the information registered on 2 million CDs. The emergence of networks of neurons of increased conductivity is the basis of learning and memory. It has been found experimentally that damage to the hippocampus significantly impairs the ability of the animal to learn.

How do we obtain information and orient ourselves in space?

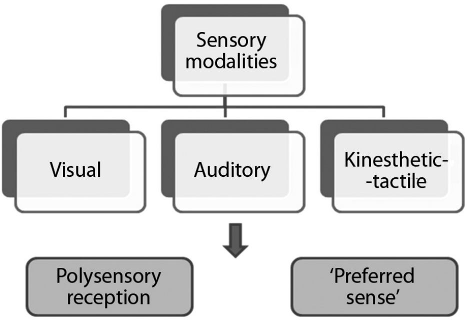

Figure 7. Representational systems by R. Bandler and J. Grinder.
Source: own study based on Taraszkiewicz M. & Rose C., 2006., *Atlas efektywnego uczenia (się)*, Vol. I, Transfer Learning sp. z o.o., Gdańsk.

According to R. Bandler and J. Grinder (after M. Taraszkiewicz, C. Rose, 2006) sensory representation systems can be delimited (**Figure 7**). These include the following sensory modalities: visual, auditory and kinesthetic-tactile. This means that the information from the environment is collected by the senses. Multisensory learning, called the Golden Rule of Comenius (teacher and educator of the 16/17 c.), with the primary sense preferred by a given person.

Since the middle of the twentieth century we have known that every second of human life the brain carries vast amount of information. It is estimated that human senses gather more than 11 million bits in one second. At any moment it rejects, in accordance with the Bennett's rule of logical depth, millions of bits in order to achieve a special state called 'consciousness'. According to M. Fiedorowicz (2013) it is a:

Mental place where the storage takes place is the working memory and its neural equivalent is the dorsolateral prefrontal cortex of the brain. Working memory of the prefrontal cortex is responsible for the ability to think and draw conclusions, manage large amounts of information in a quick and efficient way, and generate interesting ideas and effective strategies. Without working memory there is no fluid intelligence, allowing the mind to adapt to new, complex and challenging environments.

According to British researchers:

The human brain has specialised neurons responsible for memory and creation of spatial information. The existence of such neurons has been described so far only in rodents. A characteristic feature of these cells is that when the rat moves across the flat space neurons are energised in a geometrically regular manner: when applied to a map of the surface the obtained image is a grid comprised of triangles. The discovery of these unique neurons some time ago gave rise to the hypothesis that rodents have the ability to create virtual maps, so that to better orient themselves in their territory, and remember new locations in unfamiliar surroundings (Fiedorowicz 2013; http://tinyurl.com/zkkq62h).

To demonstrate this in relation to people Riepe at the University of Ulm, Germany, conducted an interesting experiment based on the fact that the participants had to find a way out of the maze in the shortest possible time. As the result, he discovered that men took an average of 2 minutes and 22 seconds to get out of the trap, while women needed 3 minutes and 16 seconds. This means that in both sexes the brain worked differently (Fiedorowicz 2013). In men the left part of the hippocampus was especially active, where cerebral map of the area probably develops, gradually supplemented with new information. On the other hand, in female brains part of the cerebral cortex, which manages visual memory, got activated. The experiment allowed to prove that in practice women when choosing a route orient themselves primarily by landmarks, while men use the directions and distances (Fiedorowicz 2013).

Brain grid

Special studies on spatial orientation in animals were conducted by John O'Keefe at the University College London and two researchers at the Norwegian Institute of Science and Technology in Trondheim, May-Britt Moser and Edvard Moser. In 1971 O'Keefe discovered that some cells were activated depending on location. He has found that these ‘place cells’, which are located in the hippocampus, form the internal map of the surroundings. In contrast, in 2005 Moser and Moser found that cells close to the hippocampus – In the entorhinal cortex, were activated when the tested rodent was passing through certain areas. These areas formed a regular grid shape consisting of hexagons, and each of the cells in a hexagon reacted according to a different spatial pattern.

Therefore, the grid cells and other cells of the entorhinal cortex which recognise the orientation of the head and room boundaries form a network with the ‘place cells’ in the hippocampus. These so-called grid cells form the internal navigation system, which tells the animal where it is, where it was and which way to go forward. Therefore, this system is a positioning system, an internal brain GPS. The system responsible for determining the position in the human brain is constructed similarly to that of other animals. The effects of the research of M. Moser and E. Moser, published in December 2012, *represent a real breakthrough in understanding the sense of spatial orientation* (http://tinyurl.com/z8xpd49; http://tinyurl.com/gkptc52).

In 2014 all three researchers, O'Keefe, Moser and Moser received the Nobel Prize in Physiology for the discovery of structures in the brain that act as our internal GPS and are responsible for the orientation and the ability to navigate in space (**Figure 8** and **9**).

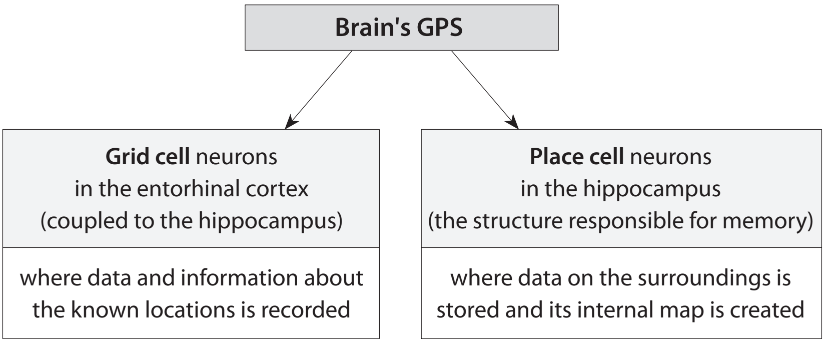

Figure 8. GPS in the brain – grid cells and place cells.
Source: own development based on http://tinyurl.com/j5l7mtm

In support of its decision, the members of the Nobel Committee wrote:

Figure 9. May-Britt Moser (Norway), John O'Keefe (USA) and Edvard Moser (Norway), after the Nobel Prize ceremony in 2014.
Source: Norwegian University of Science and Technology website nntu.edu

They made it clear which neurons and how store information in the brain about where we are, which is the fastest way to get home. […] How do we know where we are? How can we find our way from one place to another? And how do we store this information, so as the next time we follow the same route, we can find it immediately? This year's Nobel laureates have discovered the brain positioning system, 'the inner GPS', which allows us to orient ourselves in space (http://tinyurl.com/z8xpd49).

As Fiedorowicz wrote (2013): *the discovery of grid cells in a human will answer the question of where we currently are and how we remember where we have been so far.* This statement did not take a long time to wait for confirmation because brain research is progressing. In 2010 another study was conducted by the team of Jacobs of Drexel University in Philadelphia and Kahan of the University of Pennsylvania. They confirmed that the same grid cells exist in the human brain (an article on the research was published in the journal 'Nature Neuroscience' on 5 August 2013). Further studies enabled the discovery of place cells and grid cells in a human brain. It can be argued that every person in their brain has their own internal GPS. Cerebral navigation, our internal GPS, processes information transmitted by the senses, especially sight, onto detailed maps of the world around us. This allows the orientation in space, including geographical space.

Conclusions

The ability to observe the natural environment, imagination and spatial orientation is important for everyone, not only for geographers. Each person should be able to observe the surroundings and navigate through it. Modern man locates their position using GPS receivers. However, the ability to use their own internal GPS is also important. Research conducted for decades enable the study of very complex structures in the brain, and thus explain the process of learning the surroundings, spatial orientation, as well as learning and functioning in the geographical environment.

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