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Macro model of the injury of brain functional regions

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Macro model of the injury of brain functional regions

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Abstract. A lot of studies are related to brain activity. Researchers are trying to structure all available information with a purpose to analyse and predict different diseases, their mechanism. One of the methods that can be easily used in the medical sphere is topological modelling. It allows displaying any diagnosis or process in the form of a graph. This form is convenient and considered to analyse the causal-consequence links between graph nodes representing symptoms, different states of the body, etc. This article focusses at the process of building a stroke topological model that gathers knowledge of how stroke can hurt certain brain functional regions, and what consequences can cause the damage to these regions. The model is formed in 2 steps, increasing its level of detailing, i.e. by specifying brain regions.

1. Introduction

Topological modelling is one of the approaches to formalising knowledge of the problem provided by experts. In medicine, the topological model generally represents the pathogenesis of the disease, a mechanism of the development and expression of the disease [1]. Graph model nodes represent problems from the given diagnosis at different levels of the body. Since the human organism acts as a whole, all changes are connected between themselves with the causal-consequence relationships - graph edges.

The volume of knowledge, particularly in the medical field, is therefore very large and, in order to structure it, the knowledge acquired in the model-building process is divided into 3 levels:

- Level A: knowledge of predisposing factors;
- Level B: knowledge of changes in organ systems;
- Level C – knowledge of the symptoms of the disease.

When it comes to a particular problem - the effects of stroke on brain regions - then knowledge on 3 levels can be divided as follows:

- Level A — predisposing Factors of Stroke;
- Level B - brain functional areas affected by stroke;
- Level C – the effects of brain injury.

The knowledge of all three levels needs to be summarized in order to create a brain-topological model.

2. Brain structure

The structure of the brain needs to be studied initially. The brain is covered by a cortex. It's the outer layer that gives the brain the typical wrinkled look. The cortex is divided lengthwise in two hemispheres of the brain. Traditionally, each hemisphere is divided into four lobes: frontal, parietal, temporal and occipital. To understand why each disease affects a patient's behaviour differently, we need to know the basic principles of brain organization.

The first principle is the separation of functions by hemisphere – lateralization [2]. The brain is physically divided into two hemispheres: left and right. Despite their external similarities and active interactions provided by a large number of special fibres, functional asymmetry in brain work is quite clearly traceable. The right hemisphere copes better with different functions related to artisanal creative work, and the left for most people is associated with abstract thinking, symbolic action and rationality.

The second principle is also related to the distribution of functions across different areas of the brain. Although the body works in general and many of the highest functions of a human being are supported by coordinated work in different areas, the “division of work” of the brain cortex can be made quite clearly between the regions.

2.1. The Brain Lobes

Figure 1 shows the structural distribution of the brain in larger areas – lobe [3]. There are important brain centres in each of the lobe, responsible for the various important functions of the body.

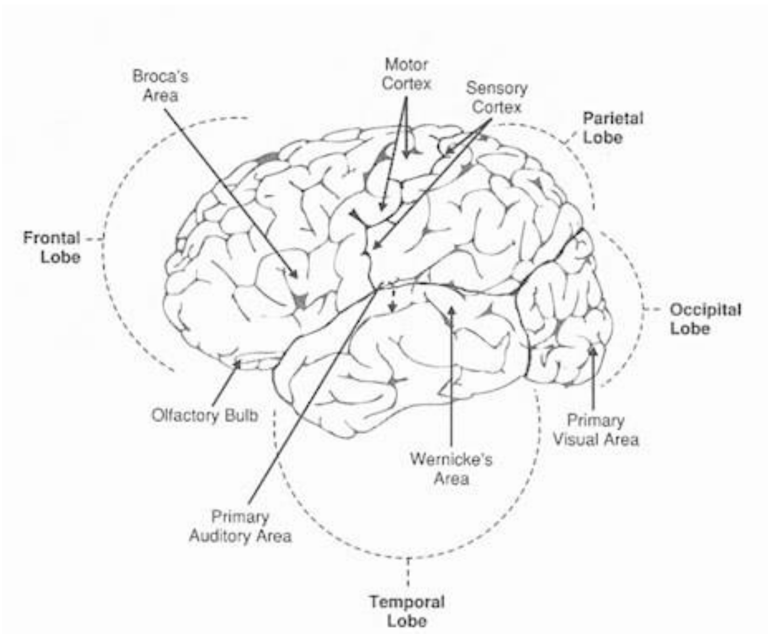


Figure 1. The brain lobes.

Frontal lobe is the largest lobe in the brain. So that it also has the greatest risk of being injured because it is located in the front of the braincase and is large. This lobe is a part of a number of functions: memory, decision-making, emotion and behavioural control.

The temporal lobe is behind the ears and is the second largest lobe. It is most commonly associated with hearing information processing and memory coding. It is considered that the temporal lobe (left and right hemispheres) also plays a major role in the processing of emotion, language and certain aspects of visual perception [4].

The parietal lobe is immediately behind the frontal lobe. It handles sensory information from different parts of the body. It contains a primary sensor cortex that controls feelings such as pain, heat or cold, etc.

The occipital lobe is the centre of our visual perception system. Visual information is being processed in this region of the brain. The information from human's eyes comes here and is being processed [5].

The fifth lobe is located deep in the cortex of the brain. It is a limbic part of the system that receives information from many regions of the brain, including thalamus, amygdala and cortex.

2.2. The brain functional regions

Of course, outlined brain structure – splitting into the lobes – is very "rude". The brain is a complex organ involved in all functions of the human body, so it should be addressed to a more detailed structure, observing the linking of brain areas to specific functions.

One of the variations is provided by the authors of the Brainnetome Atlas project [6], which summarizes the most important brain structures in one atlas. The authors release 7 large brain structures:

- frontal lobe;
- parietal lobe;
- occipital lobe;
- temporal lobe;
- insular lobe;
- limbic lobe;
- subcortical nuclei.

Each of these regions is divided into the more detailed functional areas summarized in table 1.

Table1. Brain functional areas.

Frontal Lobe	Temporal Lobe	Parietal Lobe	Insular Lobe	Limbic Lobe	Occipital Lobe	Subcortical Nuclei
Superior frontal gyrus	Superior temporal gyrus	Superior parietal lobule	Insular Gyrus	Cingulate Gyrus	Medio ventral occipital cortex	Amygdala
Middle frontal gyrus	Middle temporal gyrus	Inferior parietal lobule			Lateral occipital cortex	Hippocampus
Inferior frontal gyrus	Inferior temporal gyrus	Precuneus				Basal Ganglia
Orbital gyrus	Fusiform gyrus	Postcentral gyrus				Thalamus
Precentral gyrus	Parahippocampal gyrus					
Paracentral Lobule	Posterior superior temporal sulcus					

It should be noted that the areas covered by the Brainnetome Atlas project are divided into more detailed structures, but since this division is enough to link all human functions to the regions in the topological model, let us stay on this structure.

Each of these areas participates in the performance of several functions of the organism.

Knowledge of the functions of different regions was acquired through extensive literature observing and analysis. An excerpt from this is shown in table 2 [7].

Table 2. Summary of the functions of brain areas.

Area	Functions
Superior frontal gyrus	´ self-awareness ´ sensor system coordination ´ motor tasks

	´ memory
	´ attention
	´ cognitive processes
	´ psychological functions
Middle frontal gyrus	´ memory
	´ planning action
	´ eye movements
	´ reading
	´ writing
Inferior frontal gyrus	´ language processing
	´ making a speech
	´ recognizing objects
	´ reading
	´ movement control

Each of the areas described above may be injured for a variety of reasons, i.e. stroke. By pooling several sources of literature, the effects of injury or damage occurring in various dysfunctions were identified for each region. The knowledge fragment is shown in table 3 [8].

Table 3. Effects of damage to functional regions.

Functional region	Consequences of damage
Amygdala	Fear recognition disorder
	Depression and gloom
	Learning and memorizing problems
	Emotional sensitivity
	Memory disorders
Hippocampus	Memory problems (even loss)
	Memorizing, long-term memory problems
	Spatial disorientation
	Depression
	Psychiatric disorders
	Inability to interpret feelings
Thalamus	Inability to secure information
	Problems with operational functions (troubleshooting, logic, scheduling)
	Memory disorders
	Attention disorder
	Somnolence
	Insomnia
	Coma
	Temporary lack of movement
	Visual field loss
Basal Ganglia	Delayed movements
	Difficult speech
	Word finding problems
	Movement disorders
	Tremor
	Spasm
	Increased muscle tightness
	Difficulty in holding balance
	Difficulty in walking
	Visual problems

3. Nodes and edges of the topological model

Now that all the necessary information has been collected, we can start making a topological model. The model should be developed in several steps, gradually increasing the level of detail, i.e. increasing the number of nodes at different levels of the model.

In the first stage, the model is created at a macro level, it means that the effects of the stroke mechanism on large brain structures – lobes and subcortical regions are shown. Consequently, there are 11 nodes at level B:

- B1 – frontal lobe,
- B2 – temporal lobe,
- B3 – parietal lobe,
- B4 – occipital lobe,
- B5 – insular lobe,
- B6 – limbic lobe
- B7 – hypothalamus,
- B8 – thalamus,
- B9 – basal ganglia,
- B10 – hippocampus,
- B11 – amygdala.

If we are talking about level A, it is necessary to identify the factors that can cause damage to each region. The following factors are 19:

- A1 – arterial thrombosis,
- A2 – head injury,
- A3 – increased blood pressure,
- A4 – high cholesterol,
- A5 – diabetes,
- A6 – smoking,
- A7 – previous stroke/infarction,
- A8 – heart disorders,
- A9 —head surgery,
- A10 – food problems, diseases,
- A11 – aneurysm,
- A12 – immune diseases,
- A13 – vascular disorders,
- A14 — epilepsy,
- A15 – emotional load,
- A16 — atherosclerosis,
- A17 — hyperlipidaemia,
- A18 – passive, sedentary lifestyle,
- A19 – alcohol use.

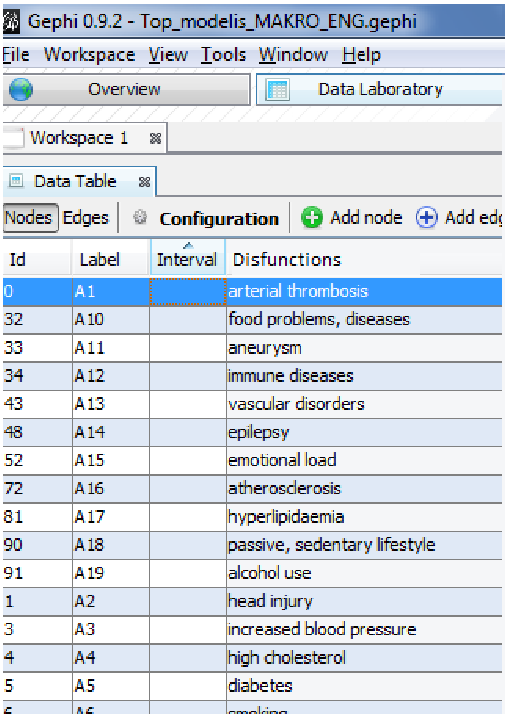
The biggest amount of nodes is at level C because they describe the various potential consequences of the brain areas injury that may result in a disorder of some functions or even complete dysfunction. The number of nodes at level C is 67, some of them:

- C1 - inability to memorize information,
- C2 – memory disorder,
- C3 – logic disorders,
- C4 – attention disorders,
- C5 – difficulties in the planning of action,
- C6 – somnolence,
- C7 – insomnia,
- C8 – coma,
- C9 – apathy,
- C10 – words finding problems,
- C11 – movement disorders,
- C12 – loss of visual field,
- C13 — reduction of body sensitivity,
- C14 – pain perception disorder,

4. Creating the graph in Gephi

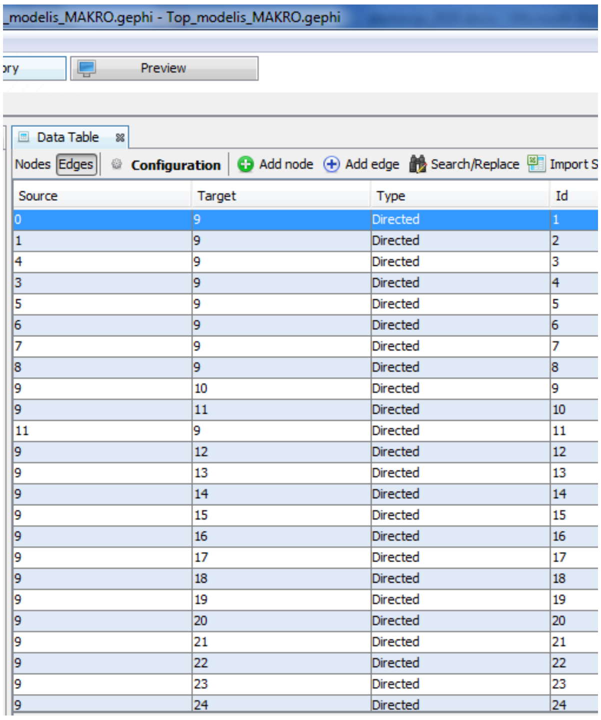
Now all nodes can be combined into a single model. It was done in Gephi software suitable for working with graphs. All nodes were entered in a program with names and transcripts (figure 2).

The next step is to make connections between the nodes. In the topological model, the levels are linked to each other – nodes from level A are definitely connected to level B nodes and level B is connected to level C. The edges between levels A and B and between levels B and C are created based on sources of literature. There are also edges between level B nodes – between brain regions. Information on the existence or absence of these edges is provided by the Brainnetome Atlas project connections matrix. The edges are also entered in the program (figure 3).



Id	Label	Interval	Disfunctions
0	A1		arterial thrombosis
32	A10		food problems, diseases
33	A11		aneurysm
34	A12		immune diseases
43	A13		vascular disorders
48	A14		epilepsy
52	A15		emotional load
72	A16		atherosclerosis
81	A17		hyperlipidaemia
90	A18		passive, sedentary lifestyle
91	A19		alcohol use
1	A2		head injury
3	A3		increased blood pressure
4	A4		high cholesterol
5	A5		diabetes

Figure 2. List of model nodes in the program.



Source	Target	Type	Id
0	9	Directed	1
1	9	Directed	2
4	9	Directed	3
3	9	Directed	4
5	9	Directed	5
6	9	Directed	6
7	9	Directed	7
8	9	Directed	8
9	10	Directed	9
9	11	Directed	10
11	9	Directed	11
9	12	Directed	12
9	13	Directed	13
9	14	Directed	14
9	15	Directed	15
9	16	Directed	16
9	17	Directed	17
9	18	Directed	18
9	19	Directed	19
9	20	Directed	20
9	21	Directed	21
9	22	Directed	22
9	23	Directed	23
9	24	Directed	24

Figure 3. List of connections between nodes in the program.

When the nodes and edges are entered in the program, an appropriate graph is created, which can be configured, for example, change nodes colour, size, placement, turn on/off node markings, etc. It is shown in figure 4.

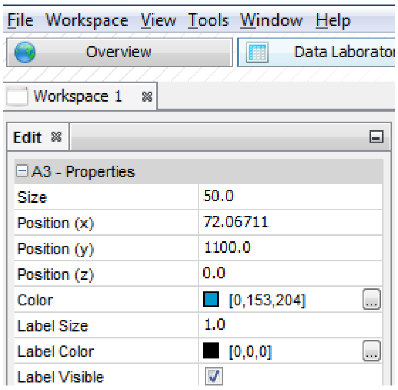


Figure 4. Configuration of the node parameters.

As a result, we get a brain-connected macro topological model (figure 5).

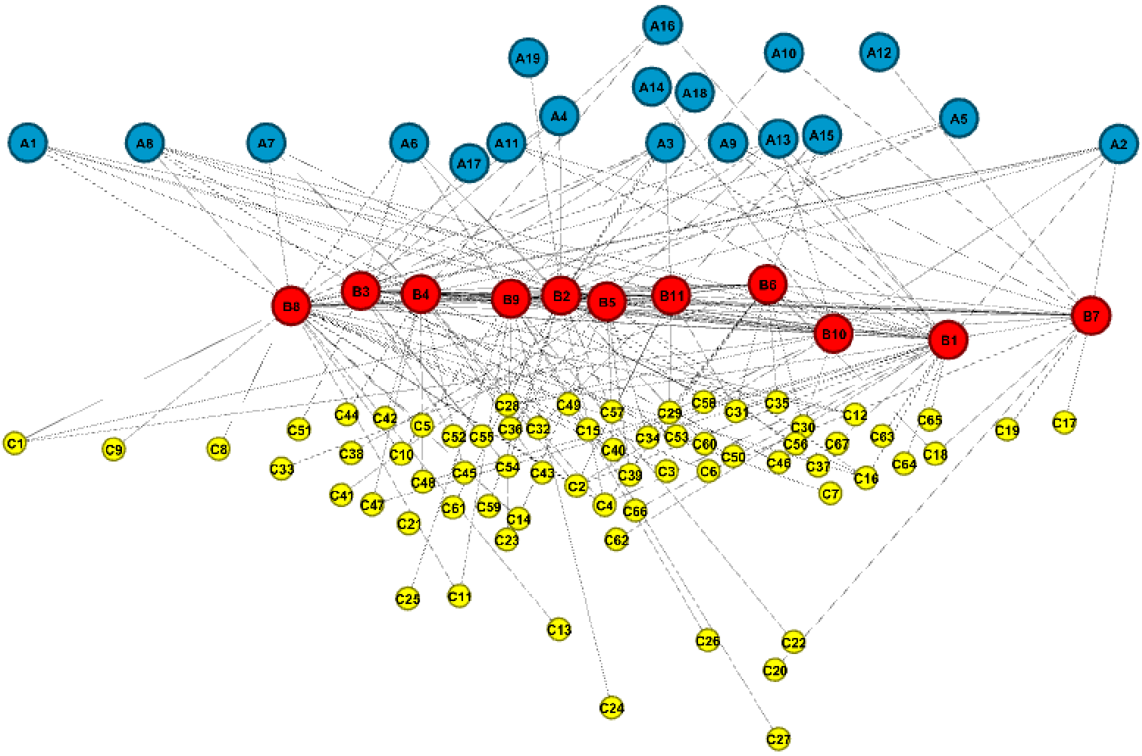


Figure 5. Macro model of brain connections.

5. Conslusion

Of course, such a model is too rude to be used in forecasting the effects of stroke. So it's necessary to detail it. The next stage of designing a model is to extend it with multiple nodes. At level B, there will be already 24 nodes showing the functional areas of the brain.

In the second stage of model formation, level A remains constant, only the number and nature of the connections are changed. Nodes of the level C – the consequences of damage –for each lobe were in the first stage of modelling. Accordingly, in the second stage, when level B changes to more than one node, level C is almost unchanged as the effects of damage to small functional regions are nearly entirely repeated as a consequence of the damage to the large lobe of these regions. Exceptions may only appear in some places if one of the smaller regions are involved in a specific function.

The next step is to find the weights of the nodes and edges of the model by exploring how one region can affect another, as well as the prognosis of the effects of stroke and the probability of damaging different regions, but this will already be described in the next article.

References

[1] Osis J, Grundspenkis J and Markovics Z 2012 *Sarežģītu heterogēnu sistēmu topoloģiskā modelēšana: teorija un lietojumi* (Rīga: RTU)
[2] Karolis V R, Corbetta M and Thiebaut de Schotten M 2019 The architecture of functional lateralisation and its relationship to callosal connectivity in the human brain *Nat Commun* **10** 1417
[3] Ackerman S 1992 *Discovering the Brain* (Washington: National Academies Press)
[4] Squire L R, Stark C E and Clark R E 2004 The medial temporal lobe *Annual Review of Neuroscience* **27**
[5] Schacter D L, Gilbert D L and Wegner D M 2009 *Psychology* (New York: Worth Publishers)
[6] Fan L *et al* 2016 The Human Brainnetome Atlas: A New Brain Atlas Based on Connectional Architecture *Cerebral Cortex* **26(8)** 3508-26
[7] Goldberg I, Harel M and Malach R 2006 When the brain loses its self: prefrontal inactivation during sensorimotor processing *Neuron* **50(2)** 329-39
[8] Japee S, Holiday K, Satyshur M D, Mukai I and Ungerleider L G 2015 A role of right middle frontal gyrus in reorienting of attention: a case study *Front Syst Neurosci*. **9** 23
[9] Greenlee J D *et al* 2007 Functional connections within the human inferior frontal gyrus *The Journal of Comparative Neurology* **503(4)** 550-9
[10] Swanson L W and Petrovich G D 1998 What is the amygdala? *Trends in Neurosciences* **21(8)** 323-31
[11] Aggleton J P and Passingham R E 1981 Syndrome produced by lesions of the amygdala in monkeys (Macaca mulatta) *Journal of Comparative and Physiological Psychology* **95(6)** 961-77
[12] Amaral D and Lavenex P 2007 *The hippocampus book (first ed.)* ed Anderson P, Morris R, Amaral, Bliss T and O'Keefe J (New York: Oxford University Press) p 37
[13] DeLong M and Wichmann T 2017 Update on models of basal ganglia function and dysfunction *Parkinsonism & Related Disorders* **15**
[14] Steriade M and Llinás R R 1988 The Functional States of the Thalamus and the Associated Neuronal Interplay *Physiological Reviews* **68(3)** 649-742
[15] Hikosaka O, Takikawa Y and Kawagoe R 2000 Role of the basal ganglia in the control of purposive saccadic eye movements *Physiological Reviews* **80(3)** 953-78