A generalized net model of the human body excretory system

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Abstract. The Generalized Nets (GN) have been proved as a successful tool for modelling of parallel processes. Up to now they have been used to describe different human body systems. In the present paper, GN is going to be applied for first time for the detailed description of human body excretory system.

Keywords: Excretory System, Generalized Nets, Human body

1 Introduction

The kidneys are a pair of bean-shaped organs tasked with excreting waste products and excess water in order to maintain the body's electrolyte and fluid balance. This is achieved by means of blood filtration. Kidneys are supplied by renal arteries that branch directly from the abdominal aorta. Renal arteries divide gradually, leading to a glomerular capillary plexus. The functioning unit of

the kidney is called the glomerulus. Afferent and efferent arterioles carry blood into and out of the glomerulus, respectively. In a normal physiological condition, 20% of the cardiac output flows through the 2.5-3 million glomerular capillary plexus [6].

The process of glomerular filtration is called renal ultrafiltration. The force of hydrostatic pressure in the glomerulus is the driving force that thrusts filtrate out of the capillaries and into the openings, or "fenesterations", of the nephron. During the process filterable blood elements, such as water and nitrogenous waste, will move towards the inside of the glomerulus, and nonfilterable components, such as cells and proteins, will exit via the efferent arteriole, and enter the bloodstream [8]. Filtration depends not only on the size of the molecule but also on its electrical charge. The proteins of the glomerular basement membrane carry a negative charge which repels negatively charged protein molecules [10]. The filterable components accumulate in the glomerulus to form the glomerular filtrate.

Glomerular Filtration Rate (GFR) is the rate of filtered fluid through the kidneys per unit time. It is controlled by three factors [9]:

(1) the difference in hydrostatic and oncotic pressure,
(2) the renal plasma flow, and
(3) the permeability of the glomerular membrane.

For a young healthy man, the GFR value is 180 l/24 h or 125 ml/min [7].

A typical adult has a Blood Volume (BV) of approximately 5 l. Plasma volume comprises about 55% of the BV , or approximately 3 l. Renal Blood Flow (RBF) measures at about 1.1 l/min. Renal Plasma Flow (RBF) is therefore calculated as follows: 0.55 l/min $\times$ 1.1 l/min = 605 ml/min. This means that for every 605 ml of plasma entering the glomeruli through afferent arterioles every minute, 125 ml (20%) are filtered and the remaining 480 ml pass through the efferent arterioles and back into the bloodstream.

Assessment of GFR is essential for determining renal function. The GFR rate is determined by the water permeability of its membrane, the surface area and by the Net Filtration Pressure (NFP). As such, the filtration rate is calculated by water permeability $\times$ area $\times$ NFP. Due to the fact that it is very difficult to determine the area of the entire capillary bed, an indicator called the filtration coefficient K_f is used, which is derived from the water permeability and the filtration area.

NFP itself is an algebraic sum of hydrostatic and osmotic pressures driven by protein-oncotic or colloid-osmotic pressures. There are 4 pressures that counteract: 2 hydrostatic and 2 oncotic. GFR is not a constant and shows considerable variability in various physiological conditions and diseases. The main reason for GFR decline in various diseases [5] is not due to an alteration in these parameters, but rather to decrease of number of functioning nephrons and, therefore, to decrease of the glomerular surface K_f.

The Generalized Nets (GN; see [1–3]) are a tool for modelling of parallel processes, extending Petri Nets and their other modifications. GN have numerous successful applications in different scientific areas, i.e. medicine, ecology, artificial

intelligence, and many others. Up to now GN have been used to describe different human body systems. In the present paper, GN is going to be applied for first time for the detailed description of human body excretory system.

2 The generalized net model

The GN model described the human body excretory system is presented in Fig. 1. The model contains 8 transitions, 16 places and 11 types of tokens. The transitions Z_1, Z_2, Z_5, Z_6, Z_7 represent the following human body systems and organs together with their ongoing processes:

Z_1 – Cardiovascular System (CVS);
Z_2 – kidneys;
Z_5 – bladder;
Z_6 – Nervous System (NS);
Z_7 – Muscle System (MS).

In the present model, aforementioned systems and organs are given in a simplified form. For the purposes of further research they might be described in much more detailed form.

The types of tokens, their meaning and characteristics are described as follows:

β – CVS, current status;
κ – kidneys, current status;
ω – bladder, quantity of urine;
ν – NS, current status;
μ – MS, current status;
α – blood, quantity;
γ – Primary Ultra Filtrated (PUF) blood that enters efferent artery;
δ – reabsorbed products from PUF that return in the blood;
ζ – a signal from bladder to NS for contraction;
θ – urine;
λ – a signal from NS to MS for contraction.

GN model transitions are successively represented as follows:

$$Z_1 = \langle \{l_2, l_5, l_8\}, \{l_1, l_2\}, \begin{array}{c|cc} & l_1 & l_2 \\ \hline l_2 & true & true \\ l_5 & false & true \\ l_8 & false & true \end{array} \rangle.$$

At each time-step, tokens from places l_5 and l_8 enter place l_2 and unite with token β that obtains the aforementioned characteristic. The token β splits to two tokens – the same token β and a token α that enters place l_1 with a characteristic:

"blood, perfusion volume".

$$Z_2 = \langle \{l_1, l_4\}, \{l_3, l_4\}, \begin{array}{c|cc} & l_3 & l_4 \\ \hline l_1 & false & true \\ l_4 & true & true \end{array} \rangle.$$

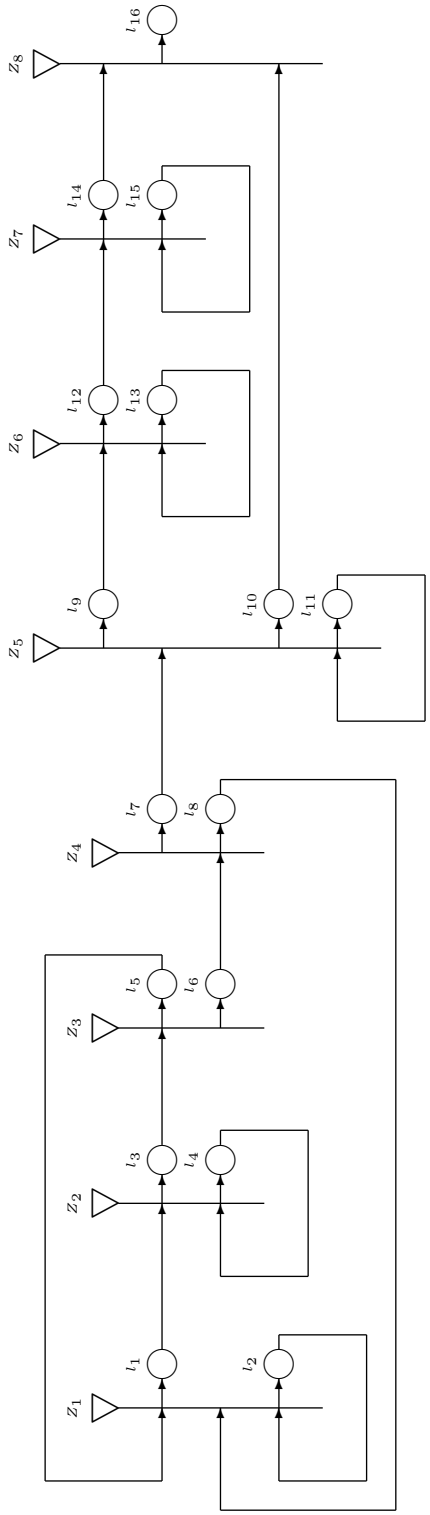

Fig. 1. GN model of the human body excretory system

At each time-step, the token α from place l_1 enters place l_4 and unites with token κ that obtains the aforementioned characteristic. The token κ splits into two tokens – the same token κ and a token α that enters place l_3 without a new characteristic.

$$Z_3 = \langle \{l_3\}, \{l_5, l_6\}, \begin{array}{c|cc} & l_5 & l_6 \\ \hline l_3 & true & true \end{array} \rangle.$$

At each time-step, the token α from place l_3 splits to two tokens – the same token α that enters place l_6 with a characteristic

"filtrated blood"

and a token γ that enters place l_5 with a characteristic

"PUF that enters afferent artery".

$$Z_4 = \langle \{l_6\}, \{l_7, l_8\}, \begin{array}{c|cc} & l_7 & l_8 \\ \hline l_6 & true & true \end{array} \rangle.$$

At each time-step, the token α from place l_6 splits to two tokens – the same token α that enters place l_7 with a characteristic

"the rest products of PUF that enter renal papila"

and a token δ that enters place l_8 with a characteristic

"reabsorb products from PUF that return in the blood system".

$$Z_5 = \langle \{l_7, l_{11}\}, \{l_9, l_{10}, l_{11}\}, \begin{array}{c|ccc} & l_9 & l_{10} & l_{11} \\ \hline l_7 & false & false & true \\ l_{11} & W_{11,9} & W_{11,10} & true \end{array} \rangle,$$

where
$W_{11,9}$ = "there is enough quantity of urine in the bladder",
$W_{11,10}$ = "MS is relaxed".

At each time-step, the token α from place l_7 enters place l_{11} and unites with token ω that obtains the aforementioned characteristic.

When the predicate $W_{11,9}$ becomes *true*, the token ω splits to two tokens – the same token ω without a new characteristic and a token ζ that enters place l_9 with a characteristic:

"signal from stretch receptors to NS

that there is enough quantity of urine in the bladder".

When the predicate $W_{11,10}$ becomes *true*, the token ω splits to two tokens – the same token ω without a new characteristic and a token θ that enters place l_{10} with a characteristic:

"the urine is passed from the bladder to the urethra".

$$Z_6 = \langle \{l_9, l_{13}\}, \{l_{12}, l_{13}\}, \begin{array}{c|cc} & l_{12} & l_{13} \\ \hline l_9 & false & true \\ l_{13} & W_{13,12} & true \end{array} \rangle,$$

where
$W_{13,12}$ = "signal from bladder that there is enough quantity of urine in it".

When the token ζ from place l_9 enters place l_{13}, it unites with token ν that obtains the aforementioned characteristic. When the predicate $W_{13,12}$ becomes *true*, the token ν splits to two tokens – the same token ν and a token λ that enters place l_{12} with a characteristic:

"signal to MS for contraction".

$$Z_7 = \langle \{l_{12}, l_{15}\}, \{l_{14}, l_{15}\}, \begin{array}{c|cc} & l_{14} & l_{15} \\ \hline l_{12} & false & true \\ l_{15} & W_{15,14} & true \end{array} \rangle,$$

where
$W_{15,14}$ = "contraction of the detrusor muscle".

When the token λ from place l_{12} enters place l_{15}, it unites with token μ that obtains the aforementioned characteristic. When $W_{15,14}$ becomes *true*, the token μ splits to two tokens – the same token μ and a token λ that enters place l_{14} with a characteristic:

"signal from MS for contraction".

$$Z_8 = \langle \{l_{10}, l_{14}\}, \{l_{16}\}, \begin{array}{c|c} & l_{16} \\ \hline l_{10} & true \\ l_{14} & true \end{array} \rangle.$$

The token θ from place l_{10} and the token λ from place l_{14} are united in place l_{16} in a token θ with a characteristic:

"final urine; quantity".

3 Conclusion

GN model of human body excretory system is here developed for first time in a form more detailed than the GN model presented in [4]. As the main systems and organs are presented in a simplified form, in future, the model might be

worked out in more details. Also, it may be included as a subset of the human body GN model (see [4]). It can be used for simulating of some situations for which there is enough information with a purpose to assist in decision making process, and for students training.

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