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Generalized Nets as Tools for Modelling of Biological and Medical Processes

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Abstract: *Short remarks on Generalized Net (GN) theory are given. Some applications of GNs in biology and medicine are discussed.*

Keywords*: Biology, Generalized net, Medicine.*

On the concept of Generalized net

The concept of a *Generalized Net* (GN) is described in the books [3, 6].

GNs are defined in a way that is principally different from the ways of defining the other types of Petri nets [13].

Let us first give some informal remarks concerning GN notations. A GN is shown in Fig. 1. Its places are marked with O. Each part of the net which looks like the one shown in Fig. 2, is called *transition* (more precisely a graphic structure of the transition). Transition's conditions are denoted by |. GNs, like other nets, contain tokens which transfer from place to place. Every token enters the net with an initial characteristic. During each transfer, the token receives new characteristics. So, they "collect" their "*history*" and in some sense they transform in individuals. This is the first essential difference with the other types of Petri nets.

Every GN-place has at most one arc entering and at most one arc leaving it. The places with no entering arcs are called *input places* for the net (l_1, l_2 in Fig. 1) and those with no leaving arcs are called *output places* (l_{14} and l_{15} in Fig. 1).

The *input places* are always at the transition's left, and the *output places* are always at the transition's right. Every place has at most one input and at most one output arc.

When tokens enter the input places of a transition, it becomes *potentially fire able* and at the moment of their transfer towards the transition's output places, it is being fired.

The transition becomes active at a given time-moment and is active up to another predefined moment.

Another basic difference between GNs and the ordinary Petri nets is that here transitions are objects of a more complex nature. A transition may contain *m* input and *n* output places where $m, n \geq 1$.

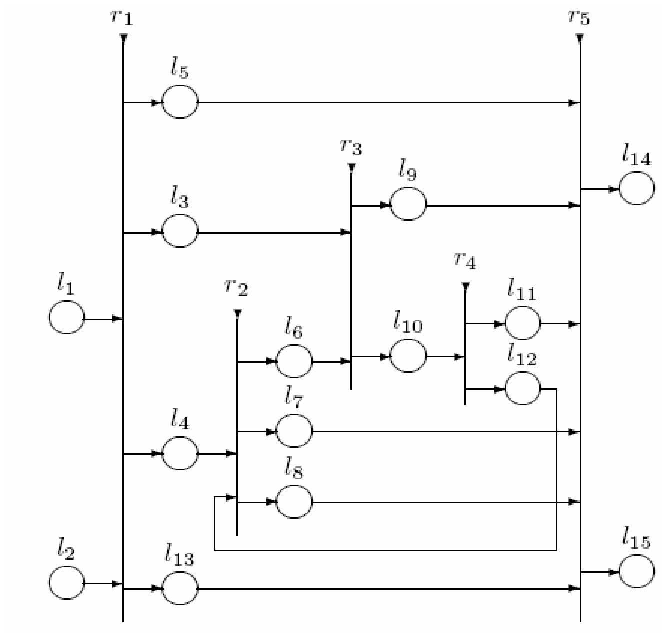

Fig. 1

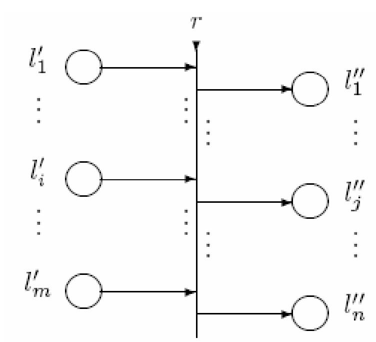

Fig. 2

The third basic difference is related to the time during which the GN functions. It *can be* determined from some global time-scale and in this case the net is not invariant about the time-parameters.

In the present form of the GN-definition, time is discrete. It increases with discrete steps. We can see the status of the GN-model in each current time-moment.

Some notations:

- $N = \{0, 1, 2, \ldots\} \cup \{\infty\}$;
- $pr_i X$ is the i-th projection of the n-dimensional set, where $n \in N$, $n \geq 1$ and $1 \leq k \leq n$.

More generally, for a given n-dimensional set $X (n \geq 2)$

$$pr_{i_1, i_2, \ldots, i_k} X = \prod_{j=1}^{k} pr_{i_j} X$$

$(1 \leq i_j \leq n,\ 1 \leq j \leq k,\ i_{j'} \leq i_{j''} \text{ for } j' \neq j'')$;

- card(X) is the cardinality of set X.

Formally, every transition is described by a seven-tuple:

$Z = \langle L', L'', t_1, t_2, r, M, \square \rangle$,

where:

(a) L' and L'' are finite, non-empty sets of places (the transition's input and output places, respectively); for the transition in Fig. 2 these are

$L' = \{ l'_1, l'_2, \ldots, l'_m \}$

and

$L'' = \{ l''_1, l''_2, \ldots, l''_n \}$;

(b) t_1 is the current time-moment of the transition's firing;

(c) t_2 is the current value of the duration of its active state;

(d) r is the transition's *condition* determining which tokens will transfer from the transition's inputs to its outputs. Parameter r has the form of an Index Matrix (IM, see, e.g., [2, 3, 5, 6]):

$$r = \begin{array}{c|ccccc} & l''_1 & \ldots & l''_j & \ldots & l''_n \\ \hline l'_1 & & & & & \\ \vdots & & & r_{i,j} & & \\ l'_i & & & (r_{i,j} \text{ – predicate}) & & \\ \vdots & & & (1 \le i \le m,\ 1 \le j \le n) & & \\ l'_m & & & & & \end{array}$$

where $r_{i,j}$ is the predicate which gives the condition for transfer from the i-th input place to the j-th output place. When $r_{i,j}$ has truth-value "*true*", then a token from the i-th input place can be transferred to the j-th output place; otherwise, this is impossible;

(e) M is an IM of the capacities of transition's arcs:

$$M = \begin{array}{c|ccccc} & l''_1 & \ldots & l''_j & \ldots & l''_n \\ \hline l'_1 & & & & & \\ \vdots & & & m_{i,j} & & \\ l'_i & & & (m_{i,j} \ge 0 \text{ – natural number or } \infty) & & \\ \vdots & & & (1 \le i \le m,\ 1 \le j \le n) & & \\ l'_m & & & & & \end{array}$$

(f) $\square$ is called transition type and it is an object having a form similar to a Boolean expression. It may contain as variables the symbols that serve as labels for a transition's input places, and it is an expression built up from variables and the Boolean connectives $\wedge$ and $\vee$ determining the following conditions:

- $\wedge(l_{i_1}, l_{i_2}, \ldots, l_{i_u})$ – every place $l_{i_1}, l_{i_2}, \ldots, l_{i_u}$ must contain at least one token,
- $\vee(l_{i_1}, l_{i_2}, \ldots, l_{i_u})$ – there must be at least one token in all places $l_{i_1}, l_{i_2}, \ldots, l_{i_u}$, where $\{ l_{i_1}, l_{i_2}, \ldots, l_{i_u} \} \subset L'$.

When the value of a type (calculated as a Boolean expression) is "*true*", the transition can become active, otherwise it cannot.

The ordered four-tuple

$E = \langle\langle A, \pi_A, \pi_L, c, f, \theta_1, \theta_2\rangle, \langle K, \pi_K, \theta_K\rangle, \langle T, t^o, t^*\rangle, \langle X, \Phi, b\rangle\rangle$
is called a *Generalized Net* (GN) if:

(a) A is a set of transitions (see above);

(b) π_A is a function giving the priorities of the transitions, i.e., π_A: $A \to N$;

(c) π_L is a function giving the priorities of the places, i.e., π_L: $L \to N$, where
$L = pr_1A \cup pr_2A$

Obviously, L is the set of all GN-places;

(d) c is a function giving the capacities of the places, i.e., c: $L \to N$;

(e) f is a function which calculates the truth values of the predicates of the transition's conditions (for the (ordinary) GNs, described in this section, function f obtain values "false" or "true", or values from set {0, 1}. If P is the set of the predicates used in a given model, then we can define f as f: P $\to$ {0, 1};

(f) θ_1 is a function giving the next time-moment for which a given transition Z can be activated, i.e., $\theta_1(t) = t'$, where $pr_3Z = t$, $t' \in [T, T + t^*]$ and $t \leq t'$. The value of this function is calculated at the moment when the transition terminates its functioning;

(g) θ_2 is a function giving the duration of the active state of a given transition Z, i.e., $\theta_2(t) = t'$, where $pr_4Z = t \in [T, T + t^*]$ and $t' \geq 0$. The value of this function is calculated at the moment when the transition starts functioning;

(h) K is the set of the GN's tokens. In some cases, it is convenient to consider this set in the form
$K = \bigcup_{l \in Q^I} K_l$,
where K_l is the set of tokens which enter the net from place l, and Q^I is the set of all input places of the net;

(i) π_K is a function giving the priorities of the tokens, i.e., π_K: $K \to N$;

(j) θ_K is a function giving the time-moment when a given token can enter the net, i.e., $\theta_K(\alpha) = t$, where $\alpha \in K$ and $t \in [T, T + t^*]$;

(k) T is the time-moment when the GN starts functioning. This moment is determined with respect to a fixed (global) time-scale;

(l) t^o is an elementary time-step, related to the fixed (global) time-scale;

(m) t^* is the duration of the GN functioning;

(n) In all publications on GNs [3] it is defined that X is the set of all initial characteristics that the tokens can receive when they enter the net. In [6], for a first time another interpretation of X will be introduced: X is a function which assigns initial characteristics to every token when it enters input places of the net;

(o) Φ is the characteristic function which assigns new characteristics to every token when it makes a transfer from an input to an output place of a given transition;

(p) b is a function giving the maximum number of characteristics a given token can receive, i.e., b: $K \to N$.

For example, if $b(\alpha) = 1$ for any token α, then this token will enter the net with some initial characteristic (marked as its zero-characteristic) and subsequently it will keep only its current characteristic. When $b(\alpha) = \infty$, token α will keep all its characteristics. When $b(\alpha) = k < \infty$, except its zero-characteristic, token α will keep its last k characteristics (characteristics older than the last k will be "forgotten"). Hence, in general, every token α has $b(\alpha)+1$ characteristics when it leaves the net.

We must note that this definition is intentionally not fully formalized. If we fully formalize the transition conditions and the characteristic functions of the GNs, the applicability of GNs would obviously decrease.

A given GN may not have some of the above components. In these cases, an asterisk will be written in place of every missing component. The GNs of this kind generate a special class called reduced GNs.

The static structure of a given GN is determined by the elements of the set $pr_{1,2,6,7}A$, i.e., the static structure of a GN is determined by the collection of the following elements for each transition: the input and output places, the index matrix of the arcs and the transition type. The dynamical character of the net is due to the GN's tokens and the transitions' conditions (pr_5A), the temporal character comes from the components T, t^o, t^* and from the elements of the set $pr_{3,4}A$. Finally, the components Φ, X and b play the role of a memory in the GN.

Various functions are also related to these four GN components: the functions π_A, π_L, c to the static structure; f, π_K to the dynamical elements; θ_1, θ_2 and θ_K to the temporal components.

A variety of different types of GN-extensions are defined and each of them is proved [3, 6] to be a conservative extension of the ordinary GNs. The basic types of GN-extensions are:

- Intuitionistic fuzzy GNs of types 1, 2, 3, and 4;
- Colour GNs;
- GNs with interval activation time;
- GNs with complex structure;
- GNs with global memory;
- GNs with optimization components;
- GNs with additional clocks;
- GNs with stop-conditions;
- Opposite GNs;
- Generalized net with tokens duration of "life";
- GNs with tokens possessing enhanced memory capabilities;
- Generalized nets in which the tokens obtain variables as characteristics;
- Generalized nets with three-dimensional structure;

and others.

The algebraic aspect of the GN theory is the oldest one. In its frames different operations and relations over transitions of GNs, and operations and relations over GNs are defined.

The idea of defining operators over the set of GNs dates back to 1982 [3]. It is an essential extension of the Valk's idea from [14].

Now, the operator aspect has an important place in the theory of GNs. Six types of operators are defined in its framework. Every operator assigns to a given GN a new GN with some desired properties. The defined groups of operators are:

- global (G –) operators;
- local (P –) operators;
- hierarchical (H –) operators;
- reducing (R –) operators;
- extending (O –) operators;
- dynamical (D –) operators.

The *global operators* transform, according to a definite procedure, an entire given net or all its components of a given type. There are operators that change: the form and structure of the transitions, temporal components of the net; the duration of its functioning, the set of tokens, the set of the initial characteristics; the characteristic function of the net; the evaluation function, or other net's functions.

The second type of operators are *local operators*. They transform single components of some of the transitions of a given GN. There are 3 types of them:

- temporal, that change temporal components of a given transition;
- matrix, that change some of the index matrices of a given transition;
- other operators: they alter the transition's type, the capacity of some of the places in the net, the characteristic function of an output place, the evaluation function associated with the transition condition predicates of the given transition.

The third type of operators are the *hierarchical operators*. They are of 6 different types and fall into two groups by their way of action:

- expanding,
- shrinking;

a given GN, and by their object of action – into three groups:

- acting upon or giving as a result of their work a place,
- acting upon or giving as a result of their work a transition,
- acting upon or giving as a result of their work a subnet.

The next (fourth) group of operators defined over GNs produces a new, reduced GN from a given net. They would allow the construction of elements of the classes of reduced GNs. To find the place of a given Petri net modification among the classes of reduced GNs, it must be compared to some reduced GN obtained by an operator of this type. These operators are called *reducing operators*.

Finally, the operators from the last-sixth-group are related to the ways of the GN functioning so they are called *dynamical operators*. They are the following:

- operators that determine the procedure of evaluating the transition condition predicates;
- operators governing tokens splitting: one that allows and one that prohibits splitting, respectively; and operators governing the union of tokens having a common predecessor: allowing and prohibiting;
- operators that determine the strategies of the tokens transfer: one at a time vs. in packs;
- operators related to the ways of evaluating the transition condition predicates: predicate checking; expert estimations of predicate values; predicates depending on a solution to an optimization (e.g., transportation) problem;
- operators used to change the direction of the tokens transfer.

The operators of different types, as well as the other that can be defined, have an important theoretical and practical value. On the one hand, they help the properties and the behaviour of GNs to be studied, and on the other hand, facilitate the modelling of many real processes. Information on the research about GNs can be found in [1, 11].

Examples of GN-models of biological and medical processes

Here we shall give a series of examples illustrating the process of development of a GN-model. The GNs that we will construct here are reduced ones. The present models have independent sense. Part of them are based on [4].

Let us start with the GN-interpretation of the system “environment – organism” (Fig. 3), following [4].

Here we shall construct two separate types of GN-models and we shall show their development with complication of the modelled biological process.

The first interpretation is shown in Fig. 4 and the second one – in Fig. 5. The places which interpret equal objects are marked by equal signs. Place *E* in both GNs corresponds to the “environment” and place *O* – to the “organism”. Place *l* is an additional one, which is necessary for the GN-correctness. In the first model the relation “environment – organism” is described by the GN-transitions Z_1 and Z_2. The GN will contain one token, which will circulate through places *E* and *O*, obtaining as current characteristics the evaluation of the status of the environment and of the organism (by some criteria). The second model also contains the same two transitions, but now their sense is detected at determining of the result of the same relation. This result can be accounted as the current characteristic of the token in place *l*. This token will split into two tokens which will enter places *E* and *O*, obtaining characteristics as above and after that they will unite in one token in place *l*.

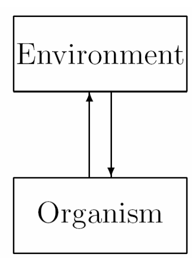

Fig. 3

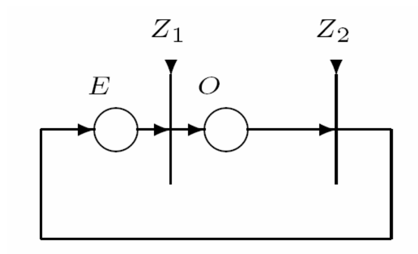

Fig. 4

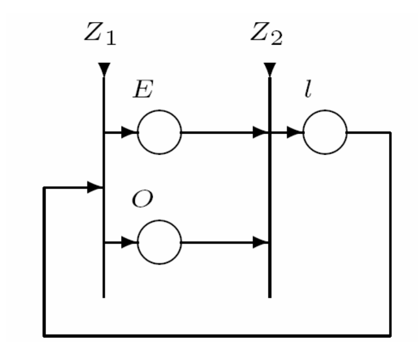

Fig. 5

Additional factors are added in Fig. 6 to the model from Fig. 3. These factors are marked in the GN-interpretations from Figs. 7 and 8 by place *A* in which enters a token with initial characteristic the values of these additional factors. In the first model the new token will unite with the interior token in place O. The same situation will occur in the second model, but now the form of the first transition condition is more complex:

$$Z_1 = <\{A, l\}, \{E, O\}, \begin{array}{c|cc} & E & O \\ \hline A & false & true \\ l & true & true \end{array}>.$$

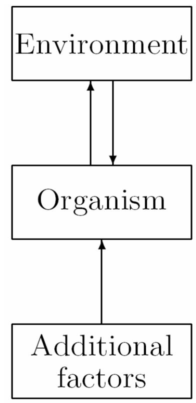

Fig. 6

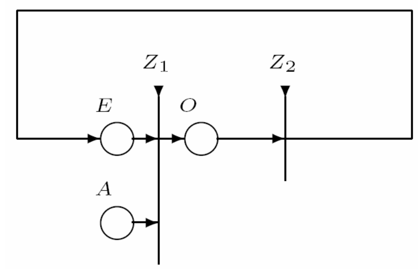

Fig. 7

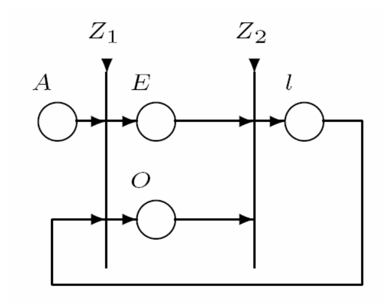

Fig. 8

The next step of complication of the model in [4] is related to the process of environment parameters accounting (without their control – see Fig. 9). The values of these environment parameters are marked in the GN-interpretation from Figs. 10 and 11 by the token characteristic, which will obtain the token entering place P from place E. This token is a result of splitting the token from place E to two separate tokens. In both cases place P is an output place for the net and the token's characteristic is used for collecting statistical data for the modelled process, which will be calculated after finishing the simulation.

The form of the first transition of the first GN-model now is:

$$Z_1 = <\{E, A\}, \{O, P\}, \begin{array}{c|cc} & O & P \\ \hline E & true & true \\ A & true & false \end{array}>,$$

and the form of the second transition of the second GN-model is:

$$Z_2 = <\{E, O\}, \{P, l\}, \begin{array}{c|cc} & P & l \\ \hline E & true & true \\ O & false & true \end{array}>.$$

The concept of feedback is among the most important ones in the cybernetics. It appears in the models from [4] in the form from Fig. 12 and it is represented in the two GN-interpretations with the forms of Figs. 13 and 14, respectively. In both cases, the new (third) transition is added to the GNs. Also, in the two cases, the token's characteristic in place *A* is determined on the base of the previous token's characteristic, obtained in place *P*. Therefore, the relation "environment – organism" now has two separate forms: "direct" and "indirect" one.

The first of them is represented by the token's characteristic in place *O* for the first type of GN-models, which is based on the previous token's characteristic (in place *E*); and by the token's characteristic in place *O* for the second type of GN-models, which is based on the token's characteristics in places *E* and *l* (if the token obtains any characteristic in the latter place).

The new (indirect) token's characteristic is obtained in place *E* on the base of the token's characteristic obtained sequentially in places *P*, *A* and *O* for the first GN-model and in places *P*, *A*, *O* and *l* for the second GN-model.

Of course, the feedback is related to the control of the process.

The model from Fig. 12 can be generalized in the form of Fig. 15.

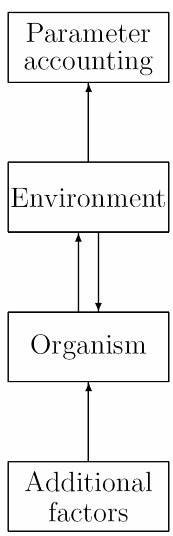

Fig. 9

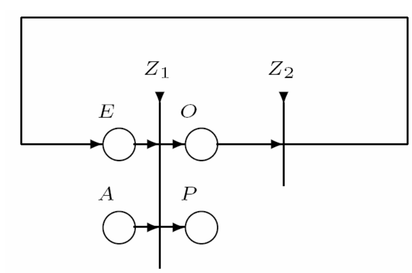

Fig. 10

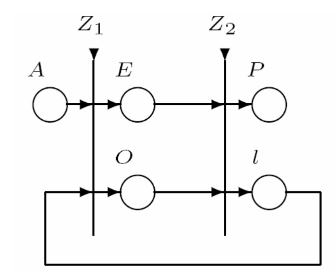

Fig. 11

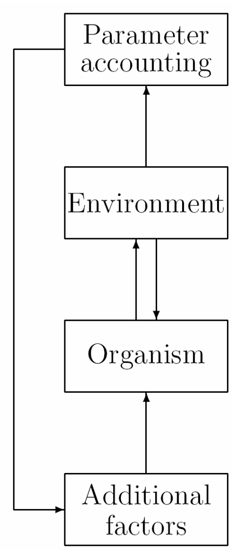

Fig. 12

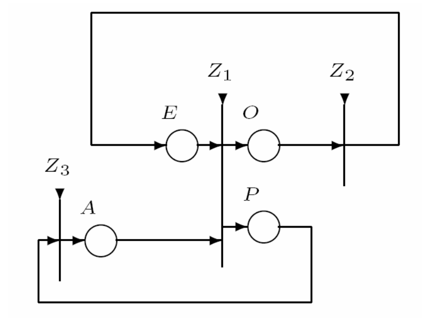

Fig. 13

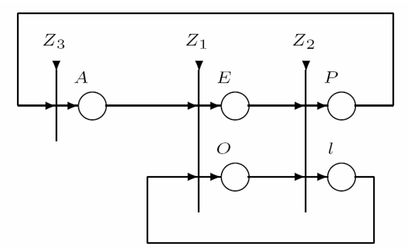

Fig. 14

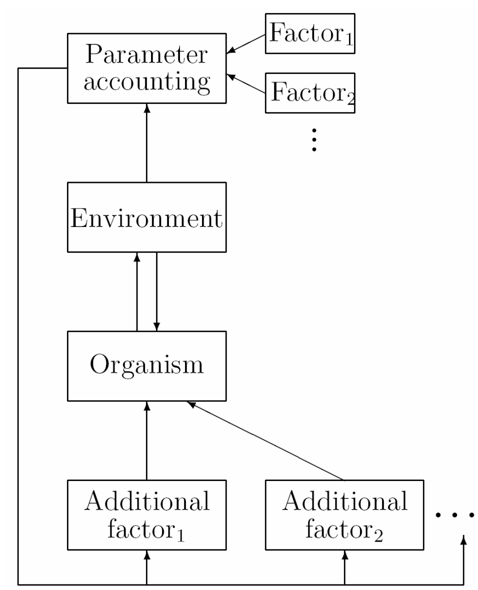

Fig. 15

Now there are exterior factors F_1, F_2, ... acting on the environment and having an influence on the process of environment parameters accounting. Also, the additional parameters can be of different types (in the GN-interpretations they are marked with A_1, A_2,... – see Figs. 16-17).

The first GN-model must contain one additional (fictive) place l and the second one – one more such place *m*.

Finally, the model from Fig. 15 can be generalized in the form of Fig. 18. Now the role of the Intellect (of the Organism) is drowned. In the GN-interpretations in Figs. 19-20 (that are extensions of the GNs from Figs. 16-17) it is marked with place *I*.

The constructed GN-models use only a part of the possible GN-components, i.e., these models are reduced ones. For example, we do not use the temporal components of the transitions. We can add these components and in result we shall have the possibility to account the effects during the model time. These time-parameters can be as constants, as well as values of complex functions (which will be interpreted by functions Θ_1 and Θ_2). We can also add in the GN-models other parameters, e.g., place- and arc-capacities (which correspond to the capacities of the sensor and motive channels); place-, transition- and token-priorities (which correspond to the orders of the influences); global time-components (which will help to construct more complex GN-models, which will be compositions of simpler GN-models from the above discussed types) and others. Really, if we have a set of GN-models (from the first and/or from the second type) we can construct larger GN-models, which are a union of these models. The global time components will help to determine the causal relations among the separate sub-GNs.

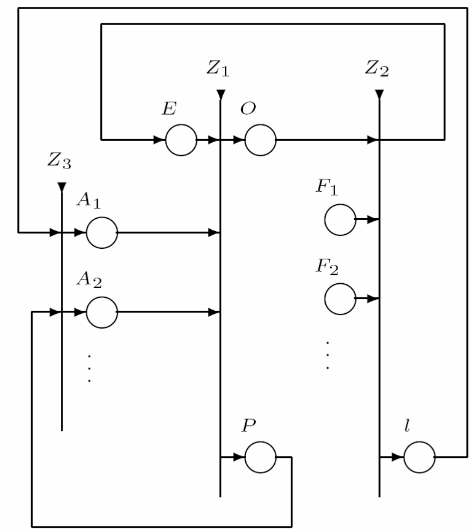

Fig. 16

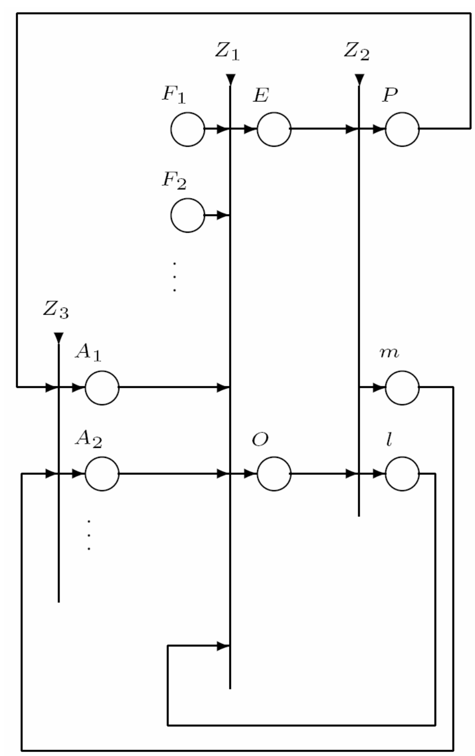

Fig. 17

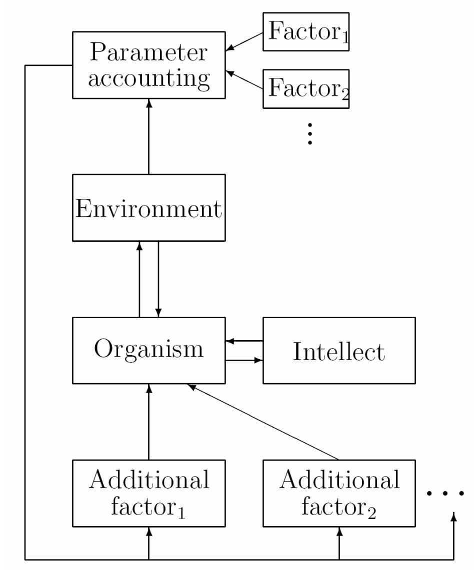

Fig. 18

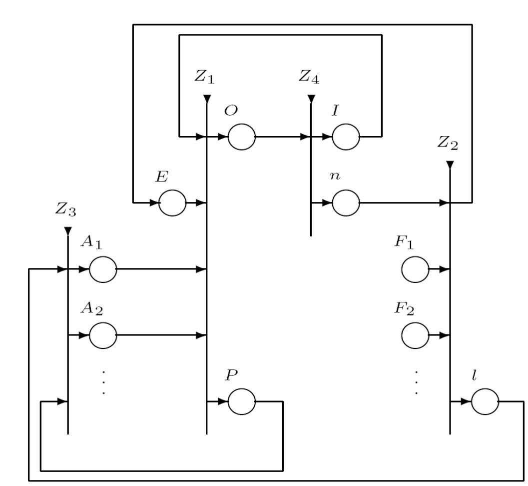

Fig. 19

The already constructed GN-models of biological processes can be changed adaptively, using different types of operators, defined over the GNs. The hierarchical operators can play very important role in constructing complex hierarchical models. For example, the human body is a very complex system and the process of its GN-modelling will be very interesting and important. Up to now, all models related to the human body are based on analytical mathematical means. In the GN-models the existing models can be used for determining of some of the tokens characteristics and for calculating the truth-values of some of the transition condition predicates. But the apparatus of the GNs gives the possibility for us to work not only with analytical and statistical mathematical means, but also with elements of the mathematical logic. For example, the GNs give us the possibility to describe in an implicit form the logical conditions that determine the order of application of the other separate mathematical tools. This will make the models more detailed.

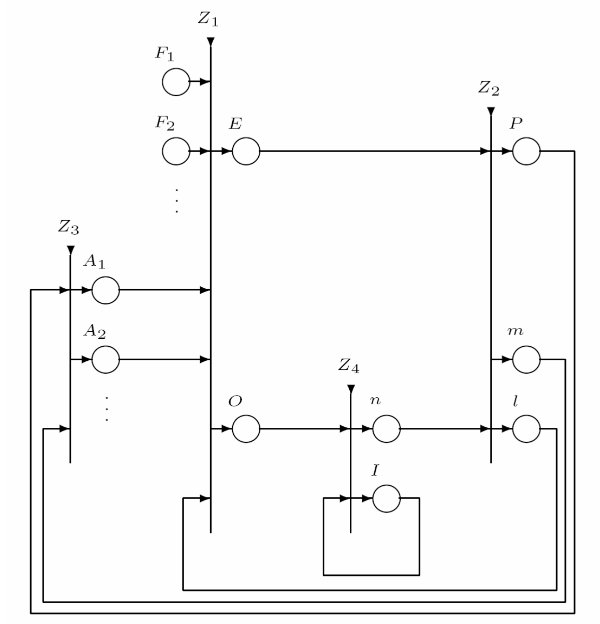

Fig. 20

Now, we shall discuss these models.

Firstly, a GN-model of the human body will be used for investigating the behaviour of the separate systems and the relations between them. In the framework of such a model various biological processes at various levels can be studied.

For instance, in the input position of the GN-model corresponding to “mouth” a token enters with an initial characteristic “food (chemical composition, quantity, etc.)”. This leads to the emergence of new tokens with characteristics “saliva”, “gastric juice”, etc. Replacing some of the characteristic functions of transition condition predicates with random functions of the corresponding kind in the GN-model, we can simulate processes related to acceptance, digestion and excretion of food. On the other hand, the initial characteristic of the token might be “medicine” or “poison” instead of “food” and the processes would flow in a different way. Therefore the GN-model of a human body would be useful for studying the behaviour of individual organs and systems, with no need of actual experiments. Of course, the values of the random functions built in the model will be subject of various modifications in order to obtain a better approximation of reality.

Another application of such a GN-model would be prediction of various processes in the human organism and suggesting possible preventing measures. For example, while our monograph [12] was in press, the authors realized that the GN-model of pancreas functioning described there could be used for the purposes of prediction. It is known that patients with advanced diabetes must receive insulin several times a day, after which they can accept certain foods while they must abstain from others. In the GN-model of pancreas functioning, the following situation could be modelled: a token enters with an initial characteristic “food of a certain kind” (which is strongly desired by the patient, independently from whether it is allowed or not). The process of pancreas functioning at different moments of injecting insulin with different quantities of it is investigated (for this purpose, a GN with varying tokens' characteristics could be used). Thus we would answer the question: “When and how much insulin should be injected to the patient so that he might be able to accept the desired food”. It must be immediately noted that the technical implementation of such an idea is by no means difficult. Moreover, a patient with no serious illnesses bar diabetes should not all need the overall GN-model of the whole human body – the subnet reflecting the work of the pancreas and several other subnets related to it would suffice.

Thirdly, the so developed GN-model will be naturally linkable to the GN-models of the processes of medical diagnostic. The latter include: collecting information about the patient (quantitative observations – blood, urine, blood pressure, etc., as well as qualitative observations). This information is put in as initial characteristics of the tokens belonging to the GN-model of the human body; within the frames of it, the functioning of the system of organs of the particular patient is simulated. The results of the simulation are supplied back to the diagnostic model to be used for a more complete description of the processes flowing in the patient's body.

It must be noted that the above described top-down approach for modelling the functioning of the human body organs and systems may be combined with Ivan Dimitrov's "Informational Theory of Diseases" [9] and its GN interpretation [8].

Now, following [10], we will construct an abstract GN that will describe the structure of the system "object – interior/exterior environment" and its relationships.

The GN on Fig. 21 has three types of tokens – α-, β- and γ-tokens.

Place l_1 stays for the interior environment. It contains token α^* with an initial characteristic "*current status of the interior environment*". This token will stay in place l_1 for the whole time of the GN-functioning. In some moments it will split to two tokens – the same token α^* (that continues staying in l_1, and token α_{cu} that will represent the signals from the interior environment to the object. Here *cu* is the current number of the signal. For brevity, we shall write below α instead of α_{cu}.

Place l_2 represents the exterior environment. It contains token β^* with an initial characteristic "*current status of the exterior environment*". This token, similarly to the above one, will stay in place l_2 during the GN-functioning. In some moments it will split to two or three tokens – the same token β^* (that in l_2), token β'_{cu} that will represent the signals from the exterior environment to the object as whole, and token β''_{cu} that will represent energetic resources from the exterior environment necessary for the object. Here *cu* is again the current number and again, for brevity, we shall write below β' and β'' instead of β'_{cu} and β''_{cu}.

Place l_{13} stays for the object memory. It contains token γ^* with an initial characteristic "*current status of the object memory*". This token, similarly to those above, will stay only in place l_{13} for the whole time of the GN-functioning. In some moments it will split to two tokens – the same token γ^* (that in l_{13}) and token γ'_{cu} that will represent the signals from the memory to the object component for a decision making, representing by place l_{12}. As above, for brevity, below we shall write γ' instead of γ'_{cu}.

In some moments other tokens, generated by the object, will enter places l_1 and l_2 and will unite with tokens α^* and β^*, respectively. They symbolize the object effects over the interior and exterior environments.

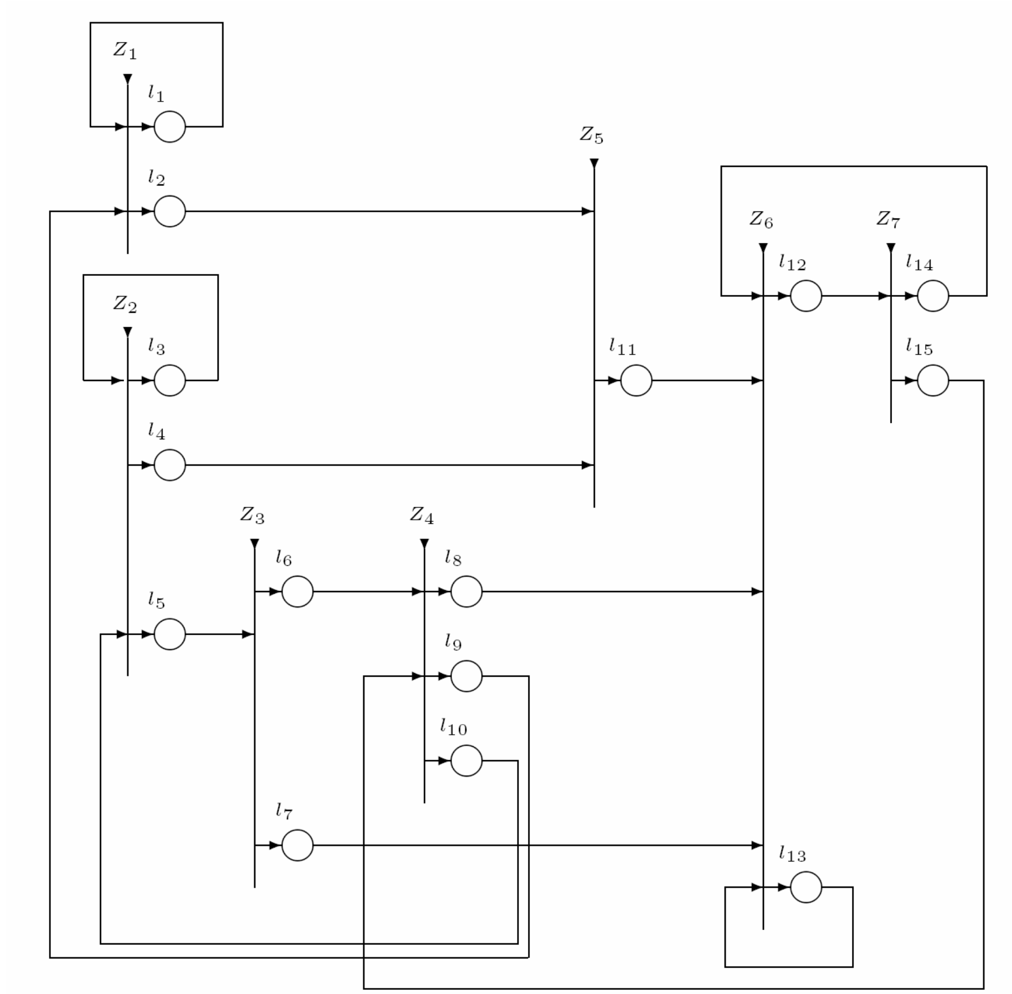

Fig. 21

$$Z_1 = <\{l_1, l_{10}\}, \{l_1, l_2\}, \quad \begin{array}{c|cc} & l_1 & l_2 \\ \hline l_1 & true & W_{1,2} \\ l_{10} & true & false \end{array} >,$$

where
$W_{1,2}$ = "the interior environment signal to the object is higher than a given level".

If predicate $W_{1,2}$ = true, then token $\alpha*$ splits to tokens $\alpha*$ and α, as we discussed above, and the new token α will obtain the characteristic "*parameters of the interior environment signal to the object*".

$$Z_2 = <\{l_3, l_{11}\}, \{l_3, l_4, l_5\}, \quad \begin{array}{c|ccc} & l_3 & l_4 & l_5 \\ \hline l_3 & true & W_{3,4} & W_{3,5} \\ l_{11} & true & false & false \end{array} >,$$

where
$W_{3,4}$ = "the exterior environment signal to the object is higher that a given level";
$W_{3,5}$ = "the object would like/must receive energy resources from the exterior environment".

Token $\beta*$ can split to two ($\beta*$, and β' or β'') or three ($\beta*$, β' and β'') tokens. Token $\beta*$ obtains the above mentioned characteristic, token β' obtains a characteristic "*parameters of* *the exterior environment signal to the object*", and token β'' obtains a characteristic "*parameters of the energy resources from the exterior environment for the object*".

We must note that words "would like/must" show that the object can obtain the energy resources from the exterior environment in a result of purposeful activities (for example, we – the people – obtain energy resources from the food, water, etc.), but the object can obtain some energy resources without its desire (for example, electric or sun shock).

Z_3 = <{l_5}, {l_6, l_7},

	l_6	l_7
l_5	*true*	*true*

>.

Token β'' splits to two tokens β_1'' and β_2'' with characteristics "*parameters of the energy resources from the exterior environment for the object effectors*" and "*parameters of the energy resources from the exterior environment for the object memory*".

Z_4 = <{l_6, l_{15}}, {l_8, l_9, l_{10}},

	l_8	l_9	l_{10}
l_6	*true*	*false*	*false*
l_{15}	*false*	$W_{15,9}$	$W_{15,10}$

>,

where

$W_{15,9}$ = "there is a command from the processor for an effect to the interior environment";

$W_{15,10}$ = "there is a command from the processor for an effect to the exterior environment".

Token β' enters place l_8 with a characteristic "*parameters of the used energy resources from the exterior environment by the effectors*".

Token γ'' (it will be described below) can enter place l_9 or l_{10} with respect to its current characteristic, or it can split to two tokens entering both these places. In place l_9 this token obtains the characteristic "*object effect over the interior environment*", while in place l_{10} it obtains the characteristic "*object effect over the exterior environment*".

Z_5 = <{l_2, l_4}, {l_{11}},

	l_{11}
l_2	*true*
l_4	*true*

>.

Tokens α and β' enter place l_{11} without any characteristic.

Z_6 = <{l_7, l_8, l_{11}, l_{13}, l_{14}}, {l_{12}, l_{13}},

	l_{12}	l_{13}
l_7	*false*	*true*
l_8	*false*	*true*
l_{11}	*false*	*true*
l_{13}	$W_{13,12}$	*true*
l_{14}	*false*	*true*

>,

where $W_{13,12}$ = "it is necessity to reach some solution".

The tokens from places l_7, l_8, l_{10} and l_{14} enter place l_{13} and unite with token γ staying there. It obtains the characteristic, mentioned above. If predicate $W_{13,12}$ = true, then token γ splits to two tokens – γ that continues staying in place l_{13} and γ' that enters place l_{12} with the characteristic "*decision making for the current problem*". This problem can be generated in a result of an effect from interior and/or exterior environment, as well as in a result of a reminiscence in the object memory.

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

Token γ' splits to two tokens γ_1' and γ_2' with characteristics "*the solution that must be memorized*" and "*command to the effectors for effects over the interior or exterior environment*".

So described GN-model represents the functioning of an abstract system, having memory, effectors and receptors and its relations with its interior and exterior environment.

The above described GN-model can be used for simulation, investigation and control of relationships "object – environment".

The present paper is included in the book of Vihren Chakarov, Anthony Shannon, Joseph Sorsich (1939-2002) and the author [7] as Chapter 1.

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