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Detection of Emergent Situations in Complex Systems by violations of structural invariants on Algebras of Transformations

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ABSTRACT

In this paper we will investigate emergent situations in complex systems represented by algebras of transformations. Though algebras of transformations seem to be rather distanced from a modeled complex system we show that it is representation very effective and for our application very appropriate. The paper continues in recent published works where the detection of an emergent situation was done by indication of violence of so called structural invariants. In this paper is used only one type of structural invariant – Matroid and Matroid Bases (M, BM) investigating the influence of their violation to interacting elements (components) in so called basic group (compartment). A simple calculus for the emergent situation appearance computation is introduced. The application of the presented approach and computation method is demonstrated in cases of discovery of diseases (diseases of cardio-vascular system and diabetes of second type) where the violence of structural invariant indicates the emergence of disease and in case of possible collapse of the selected ecosystem.

Keywords: emergent situation; structural invariants; matroid bases; Ramsey numbers; ECG signals; diabetes; ecosystem.

1 INTRODUCTION

The paper continues in topics and technologies introduced in papers [1], [2] and [3]. Especially paper [1] is needed for the effective reading and the understanding this paper. Theoretical field of the paper is narrowed in work with transformation algebras and matroid bases, application area is focused to detection of diseases of complex systems.

Similarly as in paper [1] we start here with 4 working hypotheses:

Hypothesis 1(H1): The emergent phenomenon is induced by a sharp change of complex system structure (“jump on the structure”) that comes from outside of this system. ♦

Hypothesis 2(H2): In case that we accept H1, the eventuality of an emergent phenomenon appearance may be detected as a sharp violence of complex system structure registered as the violence of Structural Invariants respectively. ♦

Note 1.1: In sections 4 – 6 will be illustrated various examples of violence of Structural Invariants. In case that the observed complex system (or its properties) is (are) described as a Matroid and its Bases, one of such violence can be represented as an extension of some Basis. Hypothesis 3(H3): One of possibilities how to represent detection of appearance of emergent situation by extension of a matroid basis is to anticipate the increase of number of interacting elements in so called basic group (compartment). ♦

Hypothesis 4(H4): In order to attain an emergent phenomenon (by an extension of a matroid basis) the complex system increases the number of elements (transformations, properties, processes) in basic group (compartment) by a minimum number of elements (transformations, properties, processes). ♦

Notes to organization of the paper

In Section 2 there are introduced some works that are relevant to the topic of our paper. The description of the theory and computation method are introduced in section 3. In Sections 4, 5 and 6 are case studies for application of the method for diseases of cardio-vascular system, for diabetes of second type and for a possible collapse of the selected ecosystem.

2 SOME RELATED WORKS

The proposed paper is associated especially with results published in works [1], [2] and [3]. In these papers is presented as well theoretical material for computing with emergent situations as application of the developed method in phenomena of macro-world (10^{-2}m ÷ 10^{2}m) and also in phenomena of micro-world (10^{-10}m ÷ 10^{-15}m). General background for conceptual constructions of emergent phenomena and for computing with objects of emergent phenomena reflected from the opposite side (than in this paper) are published in [4] a [5]. For the first part of the method application related to detection of diseases of cardio-vascular system are relevant papers [8], [9], [10], [11] and [12]. Works [8], [9], [11] introduce the deployment of modern diagnostic methods using neural networks and sophisticated transformations. The direct relation of paper [10], that uses discriminant analysis, to our paper is very easily illustrated. Similar reasoning could be realized for approaches with neural networks – however with more complicated conceptual constructions.

Works [13], [14] and [15] open the problems of the detection of an emergent phenomenon that leads to diabetes of second type (hyperglycemia) and to consequent complications (e.g., in field of podiatry). The success of application of our method depends - as in the case of diseases of cardio-vascular system – on the level of the description of the modeled complex system. (details in work [1]). The lower number of elements has the considered matroid the better is constructible a needed emergent phenomenon (of course – without a self-organizing phenomenon). From the other side – the higher is the number of elements of matroid (in our case – the higher number of transformations), the more "precise" is the model of the system. Work [16] forms the background for application of our method in the field of ecosystems. Except the conceptual level of the system description that has already been discussed is open again the problem of number of the carrier of the matroid and its influence to stability of the considered complex system. The application of the method for the considered ecosystem (Trebon basin in South Bohemia, Czech Republic) is easy to deploy it for the super ecosystem of the planet and compare the results with existing results acquired from quantitative models (e.g., [17]). A (small) common negative point of all cited works (including this proposed paper) is an absence of a chaotic phase and self-organizing phenomenon from expression (3.2).

3. VIOLENCE OF STRUCTURAL INVARIANTS ON ALGEBRAS OF TRANSFORMATIONS

Computations with Matroids and Ramsey Numbers

The concept and classes of emergent situations were introduced, e.g., in paper [1]. Here let us remind essential knowledge from [1] concerning matroids.

Matroid has the following pleasant properties:

- It is possible to construct it for each set of elements (carrier of the system) when we have the relation of independence or when they are given independent sets.
- If the relation of independence exists it is easy (in most cases) to associate it with a semantic content (according to real conditions).
- Matroid is usually introduced as the following structure

$$M = \langle X, IND, \{N_1, N_2, \ldots, N_n\} \rangle = \langle X, B \rangle, \qquad (3.1)$$

where X is the ground set of elements (carrier), IND is a relation of independence, $N_1, N_2, \ldots, N_n$ are independent sets and B is a set of matroid bases. Matroid bases are maximum (according to cardinality) independence sets.

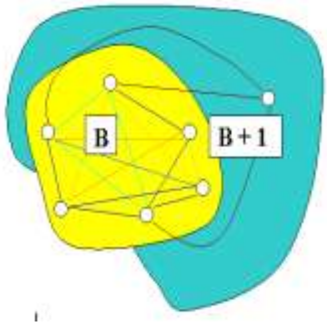

Fig. 3.1: Extension of a matroid basis by one element

The violence of this SI is considered (in this paper) as an extension of a matroid basis at least by one element (and it will be considered as an indicator of emergent situation appearance).
In case that relation IND is considered as a binary relation it is possible to use the following consequences:
The bases (**B**) will be constructed as perfect sub-graphs (in perfect graph on X).
The independent (B) and dependent elements in the perfect graph are easy constructed by coloring the edges by two colors and the formalism of Ramsey numbers – R(#**B**, #Y)) – is offered to be used.
The extension of one of bases (**B**) by one element is illustrated in Fig 3.1. The perfect graph in Fig.3.1 has six nodes and 15 (brown) edges. Coloring the edges by green and blue colors, there appears at least one perfect sub-graph with 3 nodes and 3 edges (basis **B**) – for example the green one. For extension of **B** by one element (into **B+1** with 4 nodes) we need to add at least 3 elements (that are invisible here).
Historical note: Till now there are known only some Ramsey numbers (RNs), e.g.: R(3, 3) = 6, R(3, 4) = 9, R(3, 5) = 14, R(3, 6) = 18, .., R(3, 15) = [73, 78], …, R(4, 4) = 18, R(4, 11) = [96, 191], …, R(6, 10) = [177, 1171], …, R(10, 10) = [798, 23 556], …, R(19, 19) ≥ 17 885. The brackets [., .] denote intervals of integer numbers. (In computations in Sections 4, 5 and 6 will be used known table quantities from [7].)
Note 3.1: According to hypothesis H 4 (from the Introduction) the system selects as optimal those Ramsey numbers for which is needed to add the minimum elements for the extension of basis by one element.

Example 3.1.1: #X = 1600. (#**B** = 11 for #X ≥ 1597) and for one element extension of Basis (#**B** = 12 for #X ≥ 1637) is needed to add at least 40 elements.

Theoretical Background of the Method

In this paper we will work with the following simple scheme:

$$G1 \rightarrow (G1 \oplus X) \rightarrow \text{Chaotic phase} \rightarrow \text{Emergent phenomenon} \rightarrow \text{Self-organizing process} \rightarrow G2, \qquad (3.2)$$

where G1, G2 are algebras of transformations that characterize complex system in situations of balances and X is a set of transformations that extends (reduces) kernel part of G1. (In case that is used matroid approach the kernel part will be the basis of the matroid.) Symbol ⊕ has no specific significance and depends on a real case of method application.
The goal of our effort is to estimate the number of elements in X (using techniques introduced in 3.1) and the algebra G2 that is formed as a result of the change of G1.

In paper [1] were discussed problems of "chaotic phases" and "self-organizing processes" that need more detailed investigation however not necessarily introduced here.

For the description of the discussed complex systems will be applied state models. Transformations transfer the system from one state to another state and the only problem is to detect a possible appearance of an emergent situation. For it is used a common decision rule:

$$(\text{IF } (\#X \geq \min \Delta\, f(RN))) \Rightarrow (\text{THEN } (PAES)), \qquad (3.3)$$

where "min Δ f(RN)" is a minimal difference between further and actual Ramsey number and PAES is "a possible appearance of an emergent situation". (Detail explanation is in examples in Sections 4, 5 and 6.)

4. DETECTION OF DISEASES OF CARDIO-VASCULAR SYSTEM

One of very important information about the health of human heart is ECG diagram. In Fig. 4.1 is illustrated how the part of so called PQRST complex correspond to states in one cycle of the heart activity. In our state approach description we see 6 transformations that realize this cycle:

$$\tau_U(U(k-1)) \rightarrow P(k) \rightarrow \tau_P(P(k)) \rightarrow Q(k) \rightarrow \tau_Q(Q(k)) \rightarrow R(k) \rightarrow \tau_R(R(k)) \rightarrow S(k) \rightarrow \tau_S(S(k)) \rightarrow T(k) \rightarrow \tau_T(T(k)) \rightarrow U(k), \quad (4.1)$$

where P, Q, R, S, T, U are phases (states) of ECG signal (according to Fig.4.1) and τ_P, τ_Q, τ_R, τ_S, τ_T, τ_U are transformations. Without a loss of generality we consider about a composition algebra

$$A = \langle \{ \tau_P, \tau_Q, \tau_R, \tau_S, \tau_T, \tau_U \}, o \rangle, \quad (4.2)$$

where "o" is a symbol for the composition of transformations. Expression (4.1) illustrates transformation activities as, e.g.,

$$P(k) = \tau_U(U(k-1)), Q(k) = \tau_P(P(k)), R(k) = \tau_P(Q(k)), S(k) = \tau_R o \tau_Q(Q(k)), \ldots, U(k) = \tau_T o \tau_S o \tau_R(R(k)) = \tau_T(\tau_S(\tau_R(R(k))), \ldots \quad (4.3)$$

Within the framework of our theory we suppose that individual diseases of heart are presented in ECG diagram as a composition of deform transformations τ_*, τ_+, τ_{**}, …that modify (deform) of parts of ECG diagram of a healthy man. The result of application of our theory is the estimation how many of such transformation induce the emergence of a disease. We consider the carrier of algebra A as a carrier of a matroid M. Considering hypotheses H1 – H4 from the beginning of the paper and the principles introduced in 3.1 and 3.2 we search for a minimal Ramsey number that could extend the basis of the actual matroid M. According to Ramsey theory – matroid M has three element bases – R(#B1,#B2) = 6 = R(3,3), [7]. For the extension of basis of this matroid we need at least 3 elements – R(3, 4) = 9, [7].

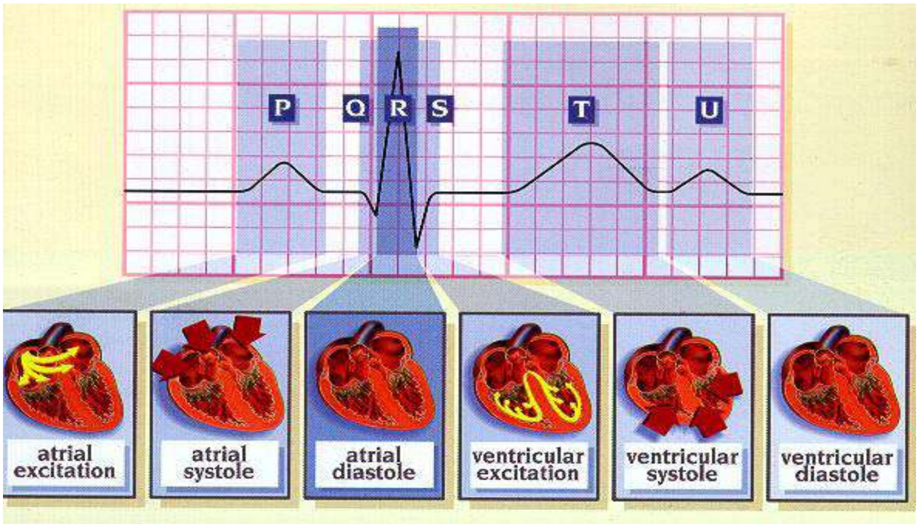

Fig. 4.1 Phases P, Q, R, S, T, U of ECG signal (source [12]).

For illustration let us consider three deform transformations:

- τ_{Q+} … deform phase Q,
- τ_{R+} … deform phase R,
- τ_{S+} … deform phase S.

Considering the influence of these transformations into ECG diagram of a healthy man we obtain basic conditions for heart disease called "Left Bundle Branch Block (LBBB)". By the same way is possible to consider about another heart diseases. In work [10] have been published results of investigation of cardiac arrhythmia diagnosis using discriminant analysis on ECG signals. Translating the method from [10] into our terminology and context – the authors used 9 transformations (τ_i) describing ECG signal and deforming transformations of the type of linear shifts (τ_d):

$$I = 1, \ldots, 9, \; \tau_i: PQRST \rightarrow R^1, \tau_i(PQRST) = x_i, \; \tau_d(x_i) = \alpha_d x_i + \beta_d, \alpha_d, \beta_d \in R^1 \quad (4.4)$$

Basis for matroid with 9 elements has 3 or 4 elements. Further Ramsey number providing extension of this matroid basis by at least one element is 14. According to results published in [10] all discovered diseases needed at least 5 deforming transformation applied for ECG signal of a healthy man.
There have been tested the following hearth diseases:

LBBB – (Left Bundle Branch Block),
RBBB (Right Bundle Branch Block),
VPC (Ventricular Premature Contraction),
APC (Atrial Premature Complex).

5 DETECTION OF DIABETES OF SECOND TYPE

Diabetes is one of very much extended disease of our age and especially the causes of its establishment in human organism are still puzzles for medicine. We present here a simplified scheme of control of sugar level in blood and show the emergence of the disease as a violence of structural invariant (M, MB) on an algebra of transformations. The presented results point out two important factors for healing methods used against to diabetes nowadays:

- In case of controlling blood sugar level by a feedback algorithm there are sufficient at least three deform transformation for the emergence of the disease.
- The blood sugar level is controlled by another principle than feedback principle and the “insulin strategy” only avoids the problem.

In figure 5.1 is a general scheme of feedback control expressed not by data flows but as a state diagram. There are used the following states and transformations:

- NS … neutral state (in classical mechanic like terminology it is a balance state),
- MS … measurement state,
- RS … regulation state,
- τ_{Di} … disturbances transformation of an influence i,
- τ_{Δ} … transformation for the transfer of error Δ,
- τ_{+}, τ_{-} … transformation for compensation error (+Δ), (-Δ),
- $\tau_{\Delta 0}$ … transformation for the transfer of zero error Δ..

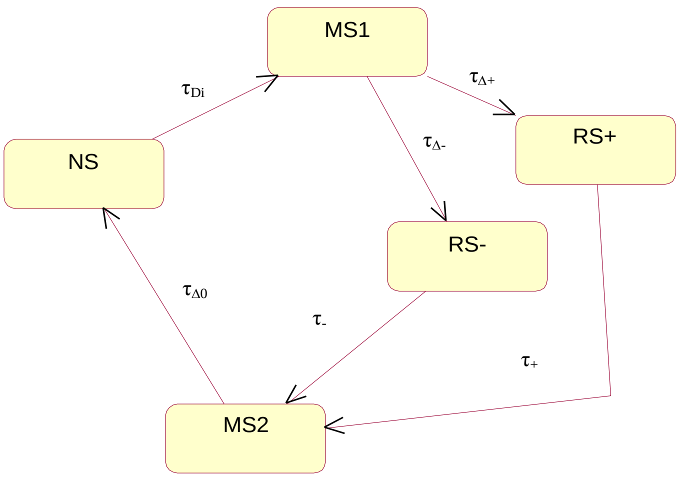

Fig.5.1 Scheme of feedback control expressed by transformation.

For the case of diabetes we adapt scheme from Fig.5.1 into the form illustrated in Fig.5.2 with the following states and transformations:

- NS … neutral state, in which the control error is near to zero. (Control error is usually considered (guided by a classical medicine) as a difference between the actual quantity of glycemic quotient and the required quantity of this quotient.)
- MS1 … measurement state indicating positive or negative control errors – (+Δ), (-Δ),
- RS_{+}, RS_{-} … regulation states for compensation of positive or negative control errors,

- MS2 … measurement state indicating zero control error after control action,
- τ_{Dfood} … transformation expressing influence of received food on the level of blood sugar,
- $\tau_{Dmuscle}$ … transformation expressing influence of muscle activities on the level of blood sugar,
- τ_{Dliver} … transformation expressing influence of liver activities on the level of blood sugar,
- τ_{Dload} … transformation expressing influence of an actual load of organism on the level of blood sugar,
- τ_{Dfat} … transformation expressing influence of operation with fat reserves on the level of blood sugar,
- τ_{Dglyc} … transformation expressing influence of glycolysis (the production of sugar by organism from non sugar matters),
- $\tau_{Dothers}$ … transformation expressing influence of other factors (e.g., hormones) on the level of blood sugar,
- $\tau_{+\Delta}, \tau_{-\Delta}$ … transformation for the transfer of errors $(+\Delta)$,$(-\Delta)$,
- τ_{+}, τ_{-} … transformation for compensation error $(+\Delta)$, $(-\Delta)$.
- $\tau_{\Delta 0}$ … transformation for the transfer of zero error Δ..

Note 5.1: The considered system is staying in states waiting for a transformation that moves it into a next state. (E.g., it stays in NS waiting for some disturbance τ_{Di}. The activities that go inside the states are not emphasized here.)

Now we apply the theory from section 3.
The number of transformations in scheme 5.2 is 12 (counting each disturbance transformation as an individual transformation). Basis of matroid with 12 elements is 3 or 4. For extension of basis by at least one element is sufficient to add to set of transformations at least 2 elements (R(3,5) = 14). One alternative is to consider the following extending transformations:
- τ_{TD} … transformation expressing influence of time delay in transfer lines (i.e., in composition with transformations $\tau_{+\Delta}, \tau_{-\Delta}$ and $\tau_{\Delta 0}$),
- τ_{setup} … transformation expressing influence of faulty set up of required quantity of glycemic quotient,

and eventually
- τ_{sensor} … transformation expressing influence of fault function of sensor for measurement of the level blood sugar.

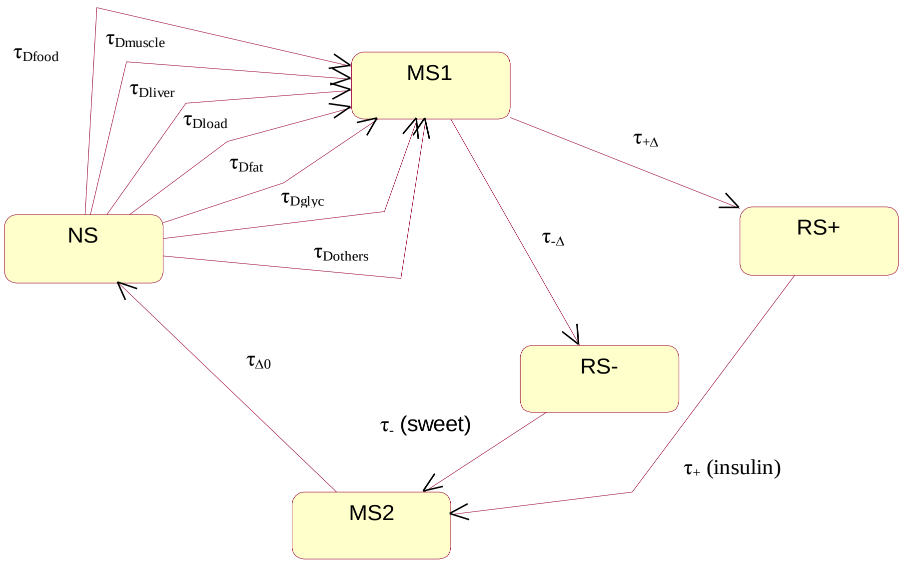

Fig. 5.2: Scheme of feedback control of the level of blood sugar

In case that we count all disturbance transformation as one transformation we have only 6 transformations and R(3, 3) = 6. The nearest Ramsey number is 9. So that the considerations about the character of extending transformations introduced above are valid. As a conclusion – no comments for nowadays applied medicine methods.

6 DETECTION OF A POSSIBLE COLLAPSE OF AN ECOSYSTEM

In paper [16] has been modeled the situation of the violence of so called Short Water Cycle in a selected ecosystem (Trebon basin in South Bohemia, Czech Republic). The Short Water Cycle (SWC) refers to the behavior of the local ecosystem (e.g., the Trebon region), in which the volume of water that comes into the ecosystem is evaporated and falls back into this system. In the Trebon ecosystem, the evaporated water rises quickly inside the transport zone and does not have time to recondense before it is transported outside the ecosystem to the distant mountains, where it condenses spontaneously in the rising air streams. (Due to the enormous volumes of vapor that are transported, the condensation is very dynamic and sometimes leads to torrential downpours).

The ecosystem was described (for the conditions of the violence of SWC) by 19 states – Tab. 6.1.
Note 6.1: The number of states could be substantially larger however after a few experiments we recognized that substantially larger number of states do not bring substantially greater amount of information. In the introduced set of states has been discovered (with help of a qualified expert) the set of transformations – Tab. 6.2. Now we apply the theory from section 3. The number of transformations in Tab.6.2 is **141**. Using Ramsey numbers from [7] we find a few possible results for basis of matroid with 141 elements: $\#B \in \{4, 5, 7, 10, 14\}$. ($R(4, 10) \in [80, 149]$, $R(4, 14) \in [141, 349]$, $R(5, 7) \in [80, 143]$,
$R(5, 10) \in [141, 442]$.)

The minimal number of transformations that is necessary to add to X (in order to attain an emergence phenomenon by extension of the matroid basis by one element) is **12** ($R(4, 14) \in [141, 349]$, $R(4, 15) \in [153, 417]$. We may find in Tab. 6.2, additional transformations (τ_{ai}), not discovered still, that could be really dangerous for the ecosystem:

τ_{a1} = S1→ S14, S15, τ_{a2} = S1→ S15, τ_{a3} = S2→ S14, τ_{a4} = S2→ S15, τ_{a5} = S1→ S16, τ_{a6} = S14→ S18, τ_{a7} = S12→ S19,

τ_{a8} = S5→ S11, τ_{a9} = S11→ S6, τ_{a10} = S3→ S11, τ_{a11} = S3→ S14, τ_{a12} = S12→ S7.

Table 6.1: States of the modeled ecosystem

Field of observation	Content of the state
Name of the state	
Air humidity and water	
S1	Low local humidity
S2	Medium local humidity
S3	High local humidity
S4	Local fog
S5	Regional fog (covering an area greater than 20 km2)
S6	High volume of water absorbed in the soil
S7	Local floods
S8	Violation of the small water cycle (SWC)
Weather	
S9	Rain
S10	Snow
S11	Longtime local dry atmosphere, (arid soil)
S12	Semi-clear weather
S13	Very cloudy weather and overcast
S14	Strong wind
S15	Storm
Evaporation	
S16	High evaporation (nearly no water goes back into the ecosystem)
S17	Medium evaporation – (some of the evaporated water returns back)
S18	Low evaporation
S19	Diminished evapotranspiration

The description of the introduced ecosystem by 19 states represents rather an approximation of a state model. The needed number of states could be for about 100 (and as a consequence in induces for about …of transformations). Nevertheless even in our case has already been seen that the higher number of elements in the carrier of transformation algebra brings

- higher variability of emergent phenomenon (here registered only by a change and by a number of elements in the matroid basis),
- higher number of elements that are necessary to add to matroid carrier for the extension of matroid basis. The second item could be understood as a reason why the standard ecosystems are relatively stable and sufficiently distanced from collapse situations.

Table 6.2 Qualitative matrix of transformations

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19
S1	1	1	0	0	0	0	*	*	*	*	1	*	*	*	*	1	1	1	1
S2	0	1	1	1	0	0	*	0	1	0	0	0	1	*	0	0	1	1	0
S3	0	1	1	1	1	1	1	0	*	*	0	*	*	*	*	1	1	0	0
S4	0	0	1	1	1	*	*	*	1	1	0	1	1	*	0	0	1	1	0
S5	0	1	1	1	1	*	*	0	1	1	0	1	1	*	1	0	0	1	0
S6	0	1	1	1	0	1	1	0	*	*	0	1	1	*	*	0	1	1	0
S7	0	1	1	1	0	1	1	0	1	0	0	1	1	1	1	0	0	1	0
S8	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0	1	0	0	1
S9	0	1	1	1	1	1	1	0	1	1	0	1	0	1	1	1	0	1	0
S10	0	0	0	0	0	1	0	0	1	1	0	1	1	0	0	0	0	1	0
S11	1	0	0	0	0	0	0	1	0	0	1	0	1	0	0	0	0	0	1
S12	*	*	*	0	0	1	*	*	1	1	0	1	1	0	0	0	1	1	0
S13	*	*	*	0	0	*	*	0	0	0	0	1	1	1	*	0	1	1	0
S14	*	*	*	0	0	*	*	*	*	*	0	1	1	1	1	1	0	0	0
S15	0	0	1	1	0	0	1	0	1	0	0	0	0	0	1	0	0	1	0
S16	1	1	0	0	0	0	0	1	0	0	1	1	0	*	1	1	1	0	1
S17	1	1	0	1	1	1	0	0	1	1	0	1	0	*	1	0	1	1	0
S18	1	0	0	0	0	0	*	1	0	0	1	1	0	*	1	0	0	1	0
S19	1	0	0	0	0	0	0	1	0	0	1	*	*	*	*	1	0	0	1

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CONCLUSIONS

In continuation of paper [1] there is applied in this paper the detection method for an emergent situation appearance. The method introduced in [1] is reduced here only for computation with numbers of matroid bases (without relations to the power of emergent phenomena). The proposed method provides only a necessary condition for emergent situation appearance. The sufficient condition depends on self-organizing process that forms an external view of emergent situation (and it is not discussed here). The practical deployment and usage of the method is focused to the detection of appearance of diseases in complex systems (considered as special emergent phenomena). The results of application of the detection method demonstrate the possibility of a sharp simplification of diagnostic methods (even in the phase of a preliminary diagnosis).

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