Structure and symmetries in complex networks

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Contents

I Summary of Professional Accomplishment

A Name and surname

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B Academic degrees

Ph.D. in physics, 2003, Faculty of Physics and Nuclear Techniques AGH
M.Sc., 1999, Faculty of Physics and Nuclear Techniques AGH

C Information about previous employment in scientific establishments

- since 1.10.2005 adjunct, Faculty of Physics and Applied Computer Science, AGH University of Science and Technology
- 1.10.2003 - 30.09.2005 teaching assistant, Faculty of Physics and Applied Computer Science, AGH University of Science and Technology (until 2004 Faculty of Physics and Nuclear Techniques)
- 1.10.1999-30.09.2003 PhD studies, Faculty of Physics and Nuclear Techniques, AGH University of Science and Technology

D Indication of the scientific achievement constituting the author's significant contribution to the development of the given scientific discipline

D.1 Title of the scientific achievement

Pursuant to Article 16(2) of the Act of March 14, 2003 on university degrees and university title in arts (Journal of Laws No 65, item 595, as amended), I would like to present the cycle of 8 scientific publications entitled:

Structure and symmetries in complex networks

D.2 Summary of Professional Accomplishment

a. Krawczyk M.J., "Differential equations as a tool for community identification", Physical Review E 77 (2008) 065701(R), IF: 2.508

b. Krawczyk M.J., "Application of the differential equations method for identifying communities in sparse networks", Computer Physics Communications 181 (2010) 1702, IF: 2.3

c. Krawczyk M.J., "Topology of the space of periodic ground states in the antiferromagnetic Ising and Potts models in selected spatial structures", Physics Letters A 374, (2010) 2510, IF: 1.963

d. Krawczyk M.J., "Symmetry induced compression of discrete phase space", Physica A 390 (2011) 2181, IF: 1.373

e. Krawczyk M.J., "Static and dynamic properties of discrete systems with compresses state space; A polymer chain as an example", The European Physical Journal B 86 (2013) 246, IF: 1.463

f. Krawczyk M.J., "Symmetry-driven compression of the set of states of a Hubbard ring", Journal of Magnetism and Magnetic Materials, 349 (2014) 63, IF: 2.002

g. Krawczyk M.J., "New aspects of symmetry of elementary cellular automata", Chaos, Solitons and Fractals 78 (2015) 86, IF: 1.448

h. Krawczyk M.J., "Communities and classes in symmetric fractals", International Journal of Modern Physics C 26 (2015) 1550025, IF: 1.125

The total impact factor of these papers is: 14.182

E Description of the scientific objectives of the achievement with discussion of the obtained results and their possible developments and applications

E.1 Introduction

E.2 Detailed discussion of all the publications that are the basis of the proposal

E.3 Introduction

My research concerns the investigation of the structure and properties of complex systems. At the beginning of the research I dealt with the problem of community detection in networks, next I concentrated on the analysis of the network symmetries.

E.3.1 Communities in networks

Communities in networks are important in many areas, such as biology, sociology or economy, where an existence of communities reflects a real structure of the network. Proper indication of communities is not an easy task, as there is no formal definition of the community, data are often noisy and also because of the computational complexity. The commonly used definition of the community says that a community is a set of nodes which are more densely connected to each other than to the remaining nodes of the network [1, 2]. The method of community detection proposed by us [3–5] is based on the evolution of the elements of the connectivity matrix in accordance with an equation:

$$\frac{dA_{ij}}{dt} = G(A_{ij}) \sum_{k \neq i,j} (A_{ik}A_{kj} - \beta) \tag{1}$$

where: A_{ij} is an element of the connectivity matrix, $G(x) = \Theta(x)\Theta(1-x)$ is a function which keeps the values of the connectivity matrix elements in a given range $[0, 1]$ and β is a parameter which indicates the lower limit of statistically meaningful values of products of weights of two links between nodes.
The proposed formalism of community detection originates from the concept of an application of differential equations for an analysis of the Heider balance, proposed in [6]. It was shown, that the evolution of the connectivity matrix, where weights of links may be positive or negative, leads to the stationary state with a division into two groups. In [7] it was shown, that the proposed method of the analysis of social systems leads for all initial conditions to an unambiguous division, which

is not always possible in the case of formerly used models. However, the specific character of the Heider problem was that a path via two subsequent links between communities strengthened the connection inside the community. This effect is not present in equations (1), which allows to obtain more than two communities.
An application of the equation (1) to the connectivity matrix leads to changes of the weights of particular links in time. Some of the values will decrease while others will increase, which causes a separation of the significant links from among all links of the network. As a result, during the evolution of the connectivity matrix one successively obtains different divisions of the nodes into communities. As the values of some weights become equal to zero we obtain groups of nodes which are connected with each other, while there is no connection between different groups. Obviously the question remains, which from the obtained divisions reflects the real structure of the analysed network. To answer this question we calculate, for each obtained division, the value of the *modularity* [1, 8], defined as:

$$Q = \frac{1}{m}\sum_{ij}\left[w_{ij} - \frac{k_i k_j}{m}\right]\delta(c_i, c_j)$$

where: $w_{ij} \in [0, 1]$ is a weight of the connection between nodes i and j, $k_i \sum_j w_{ij}$ is a weighted degree of the node, $m = \sum_{ij} w_{ij}$ and

$$\delta(c_i, c_j) = \begin{cases} 1, & \text{if } i \text{ and } j \text{ belong to the same community,} \\ 0 & \text{otherwise.} \end{cases}$$

The value of the modularity is close to zero for random networks and it takes values significantly different from zero in the case of networks, the structure of which is not a random one. We take this into account to accept from among all obtained divisions of the connectivity matrix the one for which the value of the modularity is maximal. One must remember that the modularity must refer to the analysed network, so it is calculated for the original connectivity matrix and current division of the network. The obtained division reflects the community structure of a given network. It should be mentioned, that the dependence of the modularity to the subsequently obtained divisions is not monotonous.

E.3.2 Network symmetries

A common problem which arises when we analyse complex networks is their large size, which leads to computational difficulties connected both with the computer memory and the time of calculations. Because of that, on the subsequent stage of the research I have concentrated on the analysis of the network symmetry which enables an indication of nodes similar in respect of their topological properties in

network, which in turn allows to represent the system via classes of nodes [11–17]. The class of a node is specified by its degree (in- and out-) and by classes of the neighbouring nodes. The degree of a node is the number of other nodes in the network, connected with this node. In the case of directed graphs we distinguish the degree which arises from edges going to a given node and the one from edges going from this node. In the case of weighted graphs, when we determine classes of nodes we must also take into account the weights of particular edges. A slightly similar formalism was proposed in [18], where nodes equivalence could however concern different relations between nodes, and not the local symmetry of the network.
The algorithm of classes identification goes as follows: At the first step a list of nearest neighbours of each node is constructed. In general we construct two lists: the list of neighbours for ingoing edges and the list of neighbours for outgoing edges. In the case of the undirected graph both lists are identical. For weighted graphs both lists besides the nodes numbers cover also the weights of particular edges. The nodes are marked by different symbols in accordance with the lengths of the lists and the weights in particular lists. Then, the numbers in the lists of neighbours are replaced by the symbols just assigned. In the case when symbols in the list if neighbours for nodes which are marked by the same symbol are not the same, they must be further distinguished. The procedure is repeated until the lists of neighbourhood for all nodes with the same symbol are also the same. At the end, each node has assigned a given class. To conclude, a class is defined as a set of nodes, which have the same number of neighbours, which belong to the same classes.

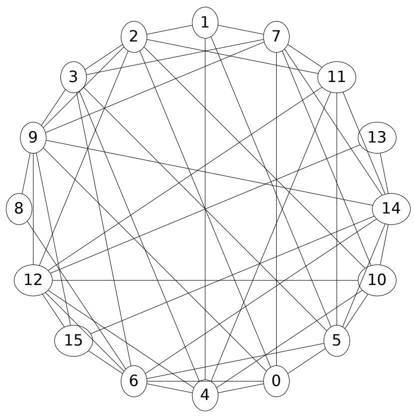


Figure 1: Example of an undirected and unweighted graph.

Here is an example of the application of this procedure. For the undirected and unweighted graph shown in Fig.1, the procedure of classes identification is presented in Tab.1. For each node its degree k is determined, and then to all nodes with the same degree the same symbol is assigned (third column in Tab.1). Next, a list of neighbours for each node is constructed, and in the place of the node number an appropriate symbol is written (fourth column in Tab.1). After the first iteration of classes identification procedure, it is seen that the lists of neighbours for nodes marked by the same symbol are the same, with an exception of nodes marked by the symbol B. In one case the node marked by the symbol B has neighbours marked by the symbol D (second row in Tab.1) and in the other (last row) the neighbours are marked by the symbol E. This situation causes that nodes decorated by the symbol B must be further distinguished. In Tab.1 it is visible in the SECOND ITERATION, where to each symbol a digit is added: to the symbol B two different digits are added for their distinction, and for the remaining - one digit. In the analysed example, this is sufficient for proper classes identification. As the result, we obtained that the original system of 16 nodes may be reduced to the system of 6 classes. Detailed description of the algorithm for all possible cases was presented in [17].

		FIRST ITERATION										SECOND ITERATION								
No	*k*	*class*	*classes of neighbouring nodes*								*class*	*classes of neighbouring nodes*								
0	6	C	D	D	D	D	E	E			C1	D1	D1	D1	D1	E1	E1		
1	4	B	D	D	D	D					B1	D1	D1	D1	D1				
2	7	D	B	C	C	C	C	E	E		D1	B1	C1	C1	C1	C1	E1	E1	
3	6	C	D	D	D	D	E	E			C1	D1	D1	D1	D1	E1	E1		
4	7	D	B	C	C	C	C	E	E		D1	B1	C1	C1	C1	C1	E1	E1	
5	7	D	B	C	C	C	C	E	E		D1	B1	C1	C1	C1	C1	E1	E1	
6	8	E	A	B	C	C	D	D	E	E	E1	A1	B2	C1	C1	D1	D1	E1	E1
7	7	D	B	C	C	C	C	E	E		D1	B1	C1	C1	C1	C1	E1	E1	
8	2	A	E	E							A1	E1	E1						
9	8	E	A	B	C	C	D	D	E	E	E1	A1	B2	C1	C1	D1	D1	E1	E1
10	6	C	D	D	D	D	E	E			C1	D1	D1	D1	D1	E1	E1		
11	6	C	D	D	D	D	E	E			C1	D1	D1	D1	D1	E1	E1		
12	8	E	A	B	C	C	D	D	E	E	E1	A1	B2	C1	C1	D1	D1	E1	E1
13	2	A	E	E							A1	E1	E1						
14	8	E	A	B	C	C	D	D	E	E	E1	A1	B2	C1	C1	D1	D1	E1	E1
15	4	B	E	E	E	E					B2	E1	E1	E1	E1				

Table 1: Classes identification procedure for an example of undirected and unweighted graph presented in Fig.1, where No is a node number and k its degree.

Although during the classes identification procedure we take into account directly only nearest neighbours of each node, the proposed method takes into account also their further neighbourhood. The reason is that the class of a node depends on its nearest neighbours, whose classes as well depend on their nearest neighbours, and so on.
The existence of classes is related to the symmetry of the analysed system. The applied procedure of classes identification allows for a reduction of the size of analysed systems, by the construction of the network of classes.

In my papers I have shown applications of the method of classes identification to different discrete systems. It was the analysis of the state space of classical systems, such as spins networks [11, 12], roundabout [12] or possible conformations of a polymer chain placed in a gel medium [13], and the quantum system represented by the Hubbard ring [14]. In all these cases it was necessary to indicate the space of allowed states of the analysed system. The states may be then treated as nodes of some network. An edge between particular nodes means a possibility of the transformation of the system from one state into another in some elementary process. Such systems are known as Kripke structures [19]. In the obtained network classes of nodes may be indicated. The method has been also used for the classification of the elementary cellular automata [15] and for an analysis of self-similar, symmetric fractals [16].

It was also shown that in the stationary state, the probabilities of states which form a given class are the same, which means that the probability of a given class is equal to the product of the probability of a state which belongs to a given class and the number of states which form this class. This equality allows to analyse some properties of the system for the reduced graph of classes instead of the larger graph of states. The possibility of the reduction of the size of the analysed system is a significant simplification in the case of analysis of real systems. The method may be applied to any network.

E.4 Detailed discussion of the publications (a-h) that are the basis of the proposal

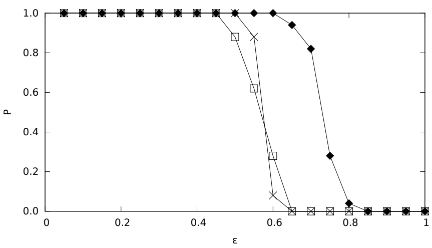
a. Krawczyk M.J., "Differential equations as a tool for community identification", Physical Review E 77 (2008) 065701(R)

All algorithms of community detection applied to any network return results where all nodes of the network are divided into communities. On the other hand, when we apply those algorithms to a network which reflects relations between elements of a real system, usually we have no knowledge to say if the obtained result is a proper one. Because of that it is useful to test algorithms using artificial networks, the structure of which is known.
In the presented paper we apply the community detection method which is based on a set of differential equations (1). The method was applied to artificial networks with their communities structure known a priori. The networks were generated as follows: At the beginning a network consists of

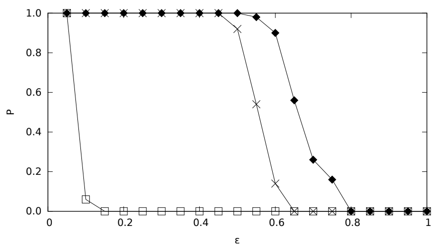
a given number of fully connected, equally or differently sized communities, mutually exclusive. A connectivity matrix for such a network is a symmetric one, and its element value A_{ij} equals 1, if nodes i and j belong to the same community, otherwise it is equal to 0. Next, some noise was added to A_{ij}, i.e. each matrix element equal to 1 was reduced by a random number from the range $[0, \epsilon]$ and a random number from the same range was added to each matrix element equal to 0. The question I address is the maximal value of the noise amplitude ϵ which still allows for the reconstruction of the communities structure of the analysed network. The results of the proposed method were compared with the results obtained from the commonly used method proposed by Newman [9].
The result is a relation of a percentage of properly reproduced networks to the noise amplitude. The obtained results show that the method proposed by us allows for the reconstruction of the network structure in a wide range of noise values and returns similar results to the one obtained with the application of the Newman algorithm; our results are even better in the case when communities differ largely in size. The obtained results are shown in Fig.2.

b. Krawczyk M.J., "Application of the differential equations method for identifying communities in sparse networks", Computer Physics Communications 181 (2010) 1702

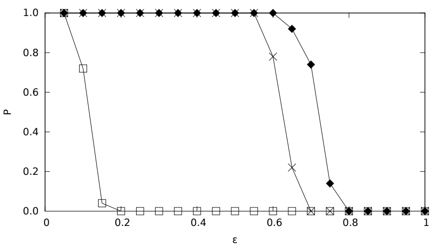
This work is a continuation of the paper described above [4]. While in the former paper fully connected graphs have been analysed, here I concentrate on more sparse graphs. This correction is important, as absence of some links is observed in numerous real networks. The analysed networks were generated in an analogous way to the described earlier, but now after the construction of the network which consists of a given number of fully connected communities, a part of edges was removed with a given probability pz. Next, the noise is added in the same way as was done for fully connected graphs. In the paper, our results obtained for the method of community detection proposed by us [3] are compared with two other algorithms: the Newman algorithm [9] which consist in successive joining of nodes into communities and the algorithm proposed in [10] where the set of all nodes is successively divided into communities; at each time step a division is made of existing communities into two parts. Similarly to the previously discussed paper for the case of fully connected clusters, also in the case of more sparse networks the obtained results are as good, or even better, as the results obtained for other algorithms. These results are presented graphically in Fig.3.



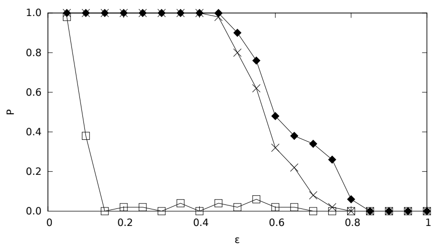
(a) $N = 110$, communities of 50, 48 and 12 nodes



(b) $N = 130$, communities of 22, 34, 11, 10 and 53 nodes

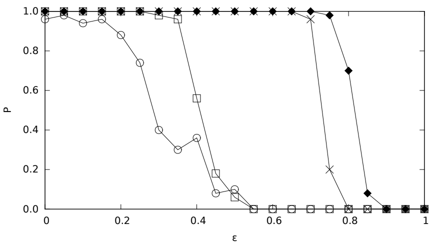


(c) $N = 130$, communities of 19, 60, 45 and 6 nodes

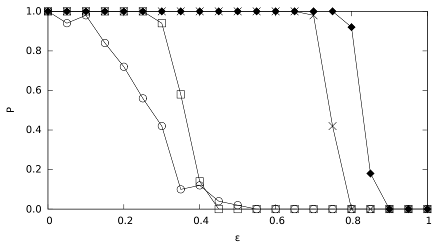


(d) $N = 110$, communities of 18, 22, 30, 38 and 2 nodes

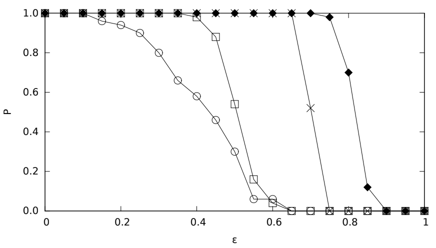
Figure 2: Results for communities of different sizes. Symbols meaning: $\square$ - Newman algorithm , $\times$ - Eq. 1 with $\beta = 0.25$, ♦ - Eq. 1 with $\beta = 0.4$ [4].



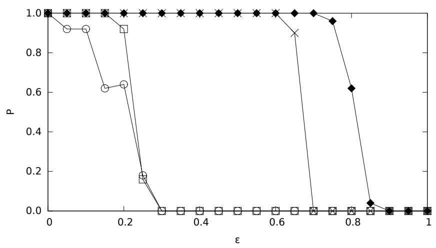
(a) communities of 165, 93 and 42 nodes, $pz = 1/3$



(b) communities of 175, 75 and 50 nodes, $pz = 1/3$



(c) communities of 148, 117 and 35 nodes, $pz = 1/4$



(d) communities of 191, 74 and 35 nodes, $pz = 1/4$

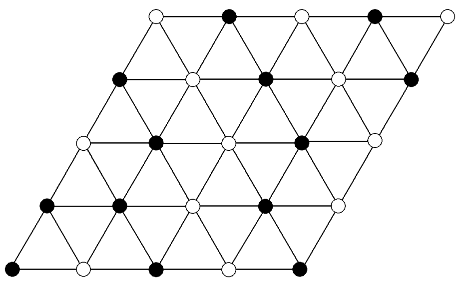
Figure 3: Results for the network of $N = 300$ nodes, communities of different sizes. Symbols meaning: $\circ$ - Duch & Arenas method, $\square$ - Newman algorithm, $\times$ - Eq. 1 with $\beta = 0.25$, ♦ - Eq. 1 with $\beta = 0.4$ [5].

c. Krawczyk M.J., "Topology of the space of periodic ground states in the antiferromagnetic Ising and Potts models in selected spatial structures", Physics Letters A 374, (2010) 2510

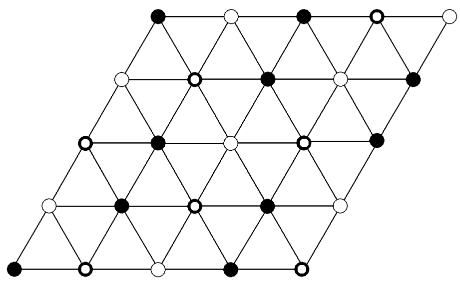
The present paper is devoted to the analysis of the topology of ground states space of three selected spins systems with the antiferromagnetic interaction in the Ising [20] and Potts [21] (for three possible spin orientations) models with periodic boundary conditions. The analysed systems are: the triangular lattice, the Archimedean $(3, 12^2)$ lattice and the cubic Laves C15 lattice. An important limitation in respect of the size of analysed systems is that the number of possible spins configurations for the system of the size N grows as 2^N for the Ising model and as 3^N for the Potts model (for assumed three possible spin orientations). In each case, possible spins configurations are treated as nodes of a graph. We also define an elementary process, which is a change of orientation of one spin, which transforms one state of the system into another. Those one-spin transitions between states are seen as edges of the analysed graph. The quantities investigated are the state energy and the multiplicity of ground states. The calculations required a indication of possible transitions between ground states. For the ground states, also their classes were indicated (where class is a concept defined by us to indicate equivalence of states, discussed in Section E.3.2).

In the case of the Archimedean network, a system which consists of one unit cell is analysed. For this system, in the case of the Ising model, there are 2^6 different spins configurations. Energy of the ground state of the system is equal to -5 (in the units of the exchange energy) and is obtained for six configurations. In the case of triangular lattice, systems which consist of 16 and 25 nodes are analysed. Their energy of the ground state equals -16 (90 states) and -25 (3630 states), respectively. In this systems each node has six nearest neighbours and one third of edges is frustrated. The obtained result shows that for each triangle there is one frustrated edge, although spins configurations which lead to the ground state are not trivial. An exemplary spin configuration equivalent to a ground state is shown in Fig.4a. In the case of the Laves network, the ground state with energy -16 is realised by 90 from among 2^{16} possible states of the system.

In the Potts model with three possible spin orientations, the structure with three nearest neighbours for the Archimedean network leads to the ground state energy equal zero (absence of frustration). This energy is obtained for 12 spins configurations. For the triangular network, the value of the ground state energy depends on the size of the system. Thus if a linear size of the network is a multiplicity of three, there is no frustrated edges in the system and the energy of the ground states equals zero, while in another case this energy will be higher. For the system which consists of 9 spins energy of the ground state is equal to zero, as expected and is fulfilled by 6 spins configurations, while for $N = 16$ and 25 energy is equal to 6 (288 states) and 7 (450 states), respectively. Similarly to the case of the Ising model, spins configurations which lead to the ground state are not trivial (Fig.4b). For the last analysed network, i.e. the Laves structure, the ground state of energy $N/2 = 8$ is realised by 90936 from among 3^{16} possible spins configurations. In these states one for each six edges is frustrated, which gives $N/2$ frustrated edges in one elementary cell.



(a) Ising model (two possible spin orientations)



(b) Potts model (three possible spin orientations)

Figure 4: Example of a ground state spin configuration for a triangular network of $N = 25$ [11].

One-spin transitions between two ground states which do not cause increases of energy of the state are possible in the case of the triangular lattice in the Ising model and the Laves network in the Potts model. In the first case all ground states can be divided to three subsets, and inside each of them the change of the orientation of one spin transforms a given state into another state which belongs to the same subset. Inside each of these subsets there are states which are their mirror reflections. The obtained result indicates an existence of a 'constant of motion', with different value for each of the three subsets. They are also a manifestation of the threefold symmetry of the system, related to the symmetry of the triangular lattice. This issue is discussed further in the paper [12].

In the case of the Laves network one-spin transitions which preserve energy of the system are possible between all ground states; this means that the network is connected.

If transitions between states are possible, it is natural to ask how many ground states can be obtained as a result of a change of the orientation of one spin from particular configurations which realise ground states. In the language of networks we ask about degree of particular nodes. As our aim is to select states which demonstrate the same topological properties, besides the number of possible transitions also properties will be important of nearest neighbours of particular nodes. Classes indication was made for two systems in which one-spin transitions between ground states are possible. For the triangular lattice of size $N = 25$ in the Ising model the ground state is realised by 3630 different spins configurations. In this case 12 classes are obtained. For the Laves network in the Potts model the ground state is realized by 90936 configurations which reduce to 28 classes. As can be seen in both cases, and especially in the second, the reduction of the system size is really significant. It is a manifestation of a strong symmetry of analysed networks.

d. Krawczyk M.J., "Symmetry induced compression of discrete phase space", Physica A 390 (2011) 2181

This work is the systematization of the concept of classes of states, which has been introduced in the previous work [11]. Such classes can be indicated in any system which is characterized by a finite number of discrete states and for which an elementary process which transforms one state of the system into another can be defined. If there is also a topological symmetry, the identification of classes of states allows for the reduction of the system size and for its representation in an equivalent form as a graph of classes, where each node represents the class of states, instead of original graph of states. In general, both graphs are weighted. For both system representations, i.e. as a graph of states and as a graph of classes, the transition matrix can be constructed [25]. Its elements express the probabilities of particular transitions between states, or between classes of states. The calculation of the eigenpair for which the eigenvalue is equal to 1 for the transition matrix of the graph of states allows for the indication of probabilities of particular states in the stationary state. In the discussed paper, I shown that for the correctly indicated classes of states the following equality is true: $p_{state}N_s = p_{class}$, where p_{state} - an element of the normalised main eigenvector which expresses probability of a given state, N_s - number of states which form a given class and p_{class} - an element of the normalised main eigenvector which expresses probability of a given class. This relation between the mentioned probabilities allows for the analysis of actually considered system as the graph of classes instead of the original graph of states. As this graph can be much smaller, it is very advantageous in the case of large systems. An application of this property is presented in the paper [13].

In the paper, two different systems were analysed: the triangular network of spins in the Ising and Potts model, and a simple traffic system of the roundabout with three access and three exit roads.

Triangular network of spins

In the previous paper [11] I have shown that in the case of the Ising model for the triangular network of the size $N = 25$ there are three mutually isolated subsets of ground states in which it is possible to transform one state into another as a result of the change of the orientation of one spin. In the currently discussed paper I have shown that in each of these subsets one of the axes of the system is different. It may be shown by calculation of the correlation function of spins with its nearest neighbours along each axes for all ground states. This function is given by the expression: $w_i =< \sigma_{-1i}\sigma_0 + \sigma_0\sigma_{1i} >$, where σ_0 denotes spin of a given node, σ_{1i} and σ_{-1i} spins of neighbouring nodes along one of the three axes i of the system. The obtained values are the same for all ground states and are equal to $-0.6, 0.2, -0.6$, the difference between three subsets of states is seen as a different order of values which specify one of the system axes.

The threefold symmetry of the system is also seen in the structure of classes of ground states. It manifests in a noticeable difference of the density of characteristic motives of spins arrangement described in [22]. It is seen in the number of motives shown in Fig.5 which can be oriented along one of the three axes of the system.

When the size of the triangular network is enlarged to $N = 36$, the threefold symmetry is lost. In this case, about 7% of ground states are isolated. For the remaining states it is possible to transform one state into another in one-spin processes.

Roundabout

As it was mentioned above, the second of analysed systems was a roundabout with three access roads and three exit roads. For simplicity, it is assumed that maximally two vehicles can occupy each road at the same time. Transitions

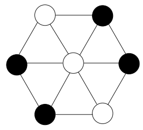


Figure 5: Motives oriented along one of a system axes [12].

between particular states, understood as possible configurations of roads occupation, are connected with the displacement of the one vehicle from an access road to an exit road (provided that it is not already occupied by two vehicles), arrival of a vehicle on a partially occupied access road or leaving the system by a vehicle which is situated on an exit road. An example of possible transitions is presented in Fig.6 (figure unpublished).

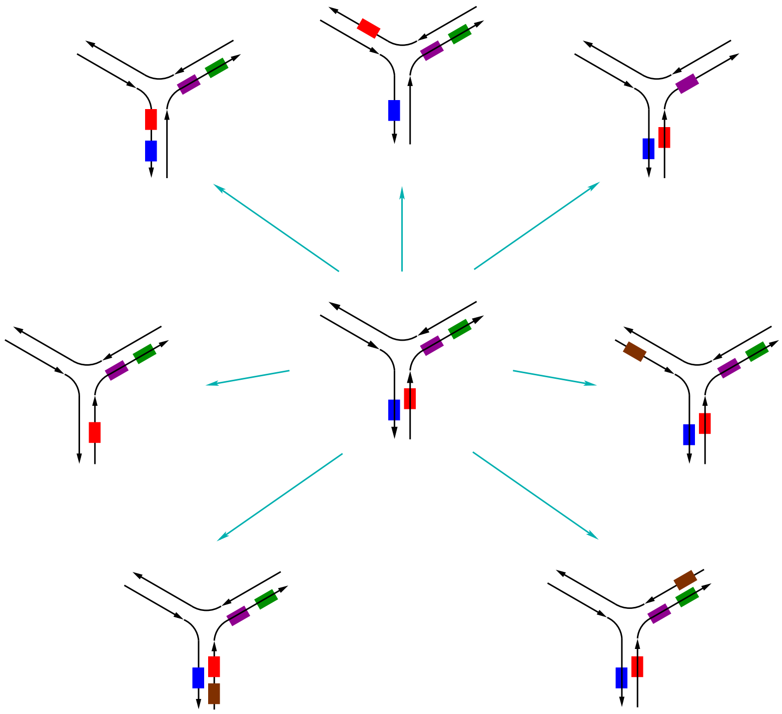


Figure 6: Possible transitions for example state of roundabout (unpublished illustration of the paper [12]).

It was shown in the paper that a significant reduction of the system size is possible when it is represented by classes of states. The initial number $3^6 = 729$ of possible states of the system is reduced to 55 classes. For this system also communities are identified by means of the differential equation method (discussed earlier). As it was shown, the states with fully occupied and completely empty roads are present form separate communities. Also, the symmetry between states with occupied and empty roads is present in the community structure.

e. Krawczyk M.J., "Static and dynamic properties of discrete systems with compressed state space; A polymer chain as an example", The European Physical Journal B 86 (2013) 246

In this paper the state space was analysed, formed by possible conformations of the circular polymer chain in the repton model [23, 24]. The states of the system are represented here by nodes of a network, while its edges are equivalent to changes of positions of one repton, with preservation of the continuity of the molecule. Three cases have been considered: of a free molecule, of a molecule which moves in a medium with regular structure, and of a molecule in an external electric field. The last case is significantly different, as in the case when the energy of external field is higher than the thermal energy, some conformations will effectively play the role of traps. In the case without external field, the probabilities of particular transitions are the same, whereas in field they depend on the external field energy to the thermal energy ratio ε and on the angle between the field direction and the direction of the repton displacement. The stationary distribution of probabilities of particular states can be estimated as asymptotic values from the Master Equations for sufficiently long time [25]:

$$\frac{dM_i(t)}{dt} = \sum_{j \in S_i} M_j(t) w_{j \to i}(\varepsilon) - \sum_{j \in S_i} M_i(t) w_{i \to j}(\varepsilon) \tag{2}$$

where $M_i(t)$ is the probability of the state i, the summing goes through neighbours of node i with probability w of a transition between given nodes, calculated for a given field value. The equations allow also for an estimation of the time needed for a molecule to achieve trap conformation and the time needed for its release. During our calculations, we generalized the *exact enumeration* method [26] for the case of weighted networks.

The *exact enumeration* method allows for an estimation of probabilities of particular states of the system as dependent on time. This is done by an evolution of a record of the size equal to the number of states, where the values of probabilities for trap states are kept equal to 0 and for the remaining states - at the beginning - to 1. Then, the evolution of probabilities for states which are not trap states is made, where in each time step the value assigned to each state is equally divided into all its neighbours. This means that the new value for each state is a sum of fractions of probabilities obtained from states which can be transformed to a given state. The procedure is not appropriate for direct application in our case, as it assumes the equality of weights of all transitions. In our case the weights are different, and therefore new values of the probabilities of states are obtained by means of the Master Equations (2). The modified method takes into account different weights and different time scales of particular transitions.

In the case of weak field, the probabilities of particular states are of the same order. The situation changes of course in the case of strong field, where the probabilities of particular states are strongly different. In particular in the case when trap conformations are possible, after some time the whole probability concentrates in these states. Both for the graph of states and the graph of classes, the times of the trap conformation achievement and trap conformation release (if it is possible because of the external field value) were found numerically with an application of the modified version of the *exact enumeration* method and the set of the Master Equations. The results are presented in Fig.7. In the case of weak fields $\varepsilon \leq 0.1$ and for strong fields $\varepsilon > 5$ time needed to obtain the trap conformation varies with field only slightly. In the case of weak field this time is long, as expected, because of thermal noise. Between the two plateaux, this time decreases. The time of release from trap conformations is very short for $\varepsilon < 1$, for higher values of the field the curve increases quickly. A qualitative accordance is obtained of the results for the graph of states and the graph of classes. The difference of the results is due to the change of the system size.

Another issue analysed in the presented paper is the dependence of the number of states on the presence of gel medium and an external field. In all cases, the obtained number of classes is lower then the number of states of the system. Yet, as a result of partial symmetry breaking by the field, the reduction of the system size is lower than in the case without external field.

The character of the polymer chain displacement in the porous medium in the presence of an external field depends on the length of the molecule, the medium density and the field value. Using the method proposed in the paper it is possible to estimate important parameters of the molecule motion, such as the velocity and the diffusion coefficient. The obtained field dependence of the velocity is different for different field directions. In the case when trap conformations are possible, the velocity increases for $\varepsilon \leq 2$ and then decreases as $\exp(-\alpha\varepsilon)$ with $\alpha \approx 0.5$. When there is no trap

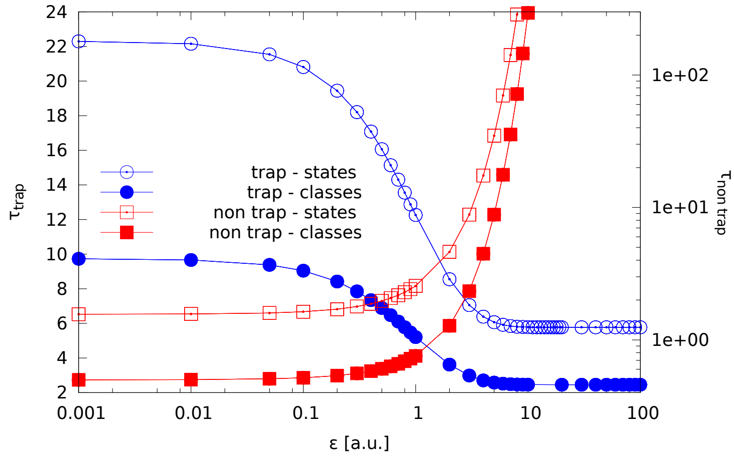


Figure 7: Fig. 9. Time of enrichment the trap state τ_{trap} (left hand side vertical axis) and time of escape from the trap $\tau_{non\ trap}$ (right hand side vertical axis) as a function of ε. The empty symbols refer to the states network, while the full one to the classes network [13].

conformations, for small field the velocity increases up to $\varepsilon \leq 5$ and then a plateau is obtained. Further, for $\varepsilon < 0.1$ the value of the diffusion coefficient is very small and approximately constant, then it increases linearly up to $\varepsilon\ approx 3$, where it achieves a maximal value. Next, up to $\varepsilon = 10$ the curve decreases to zero, which does not change for higher fields. The obtained result is consistent with the relation for the velocity for the case when trap conformations are allowed : both, the velocity and the diffusion coefficient decrease to zero in the same range of the field.

f. Krawczyk M.J., "Symmetry-driven compression of the set of states of a Hubbard ring", Journal of Magnetism and Magnetic Materials, 349 (2014) 63

In the paper, classes of states were identified for a quantum system, which is the Hubbard ring, i.e. one-dimensional cyclic chain of atoms. In the single-band Hubbard model in the atomic limit, each atom has maximally two electrons, because of the Pauli exclusion principle. For the ring of a given length it is possible to indicate the state space, which consists of all possible configurations of atoms occupation. Then, the states may be seen as nodes of a network, edges of which are indicated by the process of electron hopping between neighbouring atoms and changes of orientation of a single spin (spin flip). It should be noted that the frequency of the hopping is different than the frequency of spin flips [29]. In our model, this is included as different weights of particular edges of the network. The obtained network is symmetric: if a given process transforms state A to state B, the reverse process transforms state B to state A, and amplitudes of transitions in both directions are the same. When determining the number of classes, four variants were analysed: the full state space, the full state space without states which are mirror reflections of other states, the space of ground states also with and without mirror reflections. In the latter two variants, atoms are occupied by at most one electron. In each of the analysed variants the obtained graph is undirected and weighted, which influences the procedure of the classes identification. The obtained results reflect the symmetry due to the band filling. In Fig.8 the number of classes in a function of the band filling is presented, while in Fig.9 the reduction of the system size in a function of the chain length in the case of the half-filled band is shown. For large systems the number of classes seems not to exceed 15 percent of the number of states.

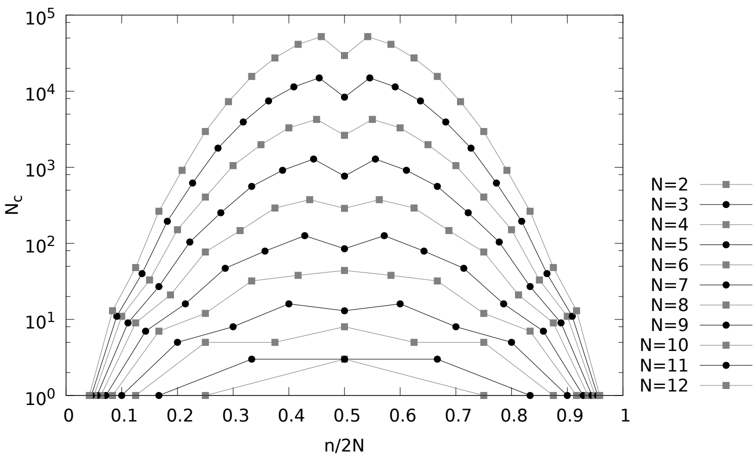


Figure 8: Number of classes N_c in a function of occupation ratio $n/2N$, where n - number of electrons, N - number of atoms [14].

g. Krawczyk M.J., "New aspects of symmetry of elementary cellular automata", Chaos, Solitons and Fractals 78 (2015) 86

In this paper the classification is presented of elementary cellular automata [27] with application of classes identification method. The analysed state space if formed by a set of all possible configurations of the system. Each cell of the automaton may be in one of two possible states $(0, 1)$, with periodic boundary conditions. The states are treated as nodes of a network.

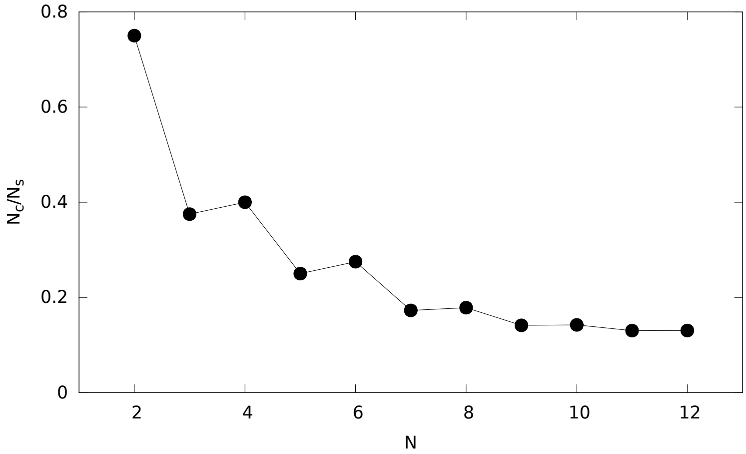


Figure 9: Reduction of the system size N_c/N_s in a function of a chain length in a case of half-full system [14].

Transitions between particular states result from the automaton rule. The analysed automata are deterministic, so each state can be transformed just to one state. However, particular states may be obtained from more then one state. This means that when classes are determined, one has to take into account both the list of ingoing neighbours and - in this case the one-element-list of outgoing neighbour. An example of the state space obtained for the automaton No 86 of size 4 is presented in Fig.10.

For 232 from among 256 automata, the obtained number of classes increases exponentially with the system size. The increase is however slower than the increase of the number of states and it is not faster then 1.7^N, while the number of states increases as 2^N, where N is the length of the lattice. The largest number of classes is obtained for the chaotic automaton No 30 (and three equivalent according to the Wolfram classification [28]), the second largest for the automaton No 110 (and three equivalent according to the Wolfram classification [28]) which is Turing complete. The reduction of the size of the state space is different for different automata and changes from one to even four orders of the magnitude.
For the remaining 24 automata a different, non-trivial character of the relation between the number of classes and the system size is observed. For example for the automata 90 and 165 it changes as shown in Fig.11.

The obtained results show that the relation of the number of classes to the

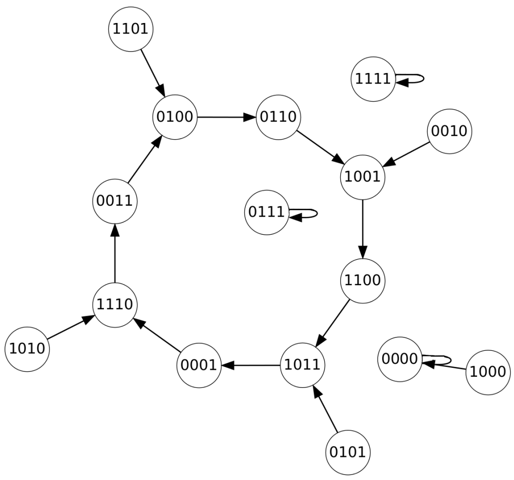


Figure 10: Graph of states obtained for the automaton No 86 of size $N = 4$ [15].

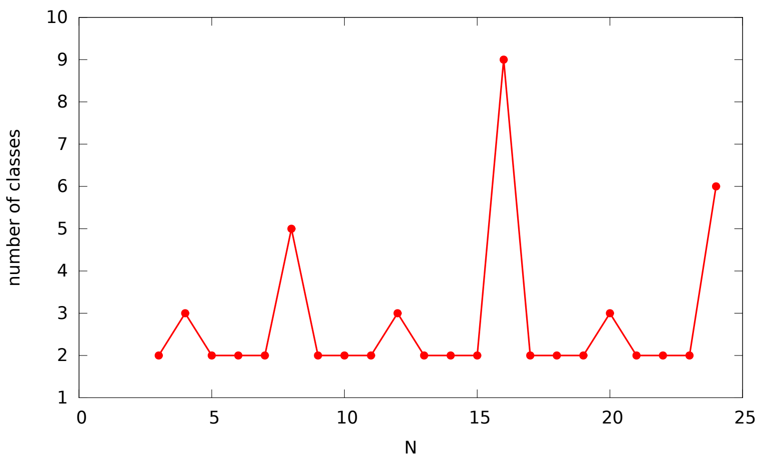


Figure 11: Number of classes in a function of the automaton length for automata No 90 and 165 [15].

length for automata classified by Wolfram as equivalent [28] is the same. What's more, taking into account this relation as a criterion of the change of the number of classes we state that the number of symmetry groups is equal to 80, i.e. of 8 less then results from the Wolfram classification [28]. The result suggests an existence of a symmetry of automata rule, different than described until now. However, the questions of its definition and of the confirmation in larger systems remain open.

h. Krawczyk M.J., "Communities and classes in symmetric fractals", International Journal of Modern Physics C 26 (2015) 1550025

This paper, on one hand, is a continuation of a series of papers on the analysis of systems exhibiting symmetry, and on the other hand it refers to the previous works on community detection in networks. In the paper I analysed symmetric and self-similar fractals, example of which are the Sierpinski triangle and the Koch curve. In the presented paper it was shown that an application of the differential equation method - proposed by us - of community detection allows to indicate nodes whose belonging to communities is ambiguous, i.e. for which an overlapping is observed. This means that the node may belong to more than one community. In Fig.12 communities found for the Sierpinski triangular network of size $N = 42$ are presented.

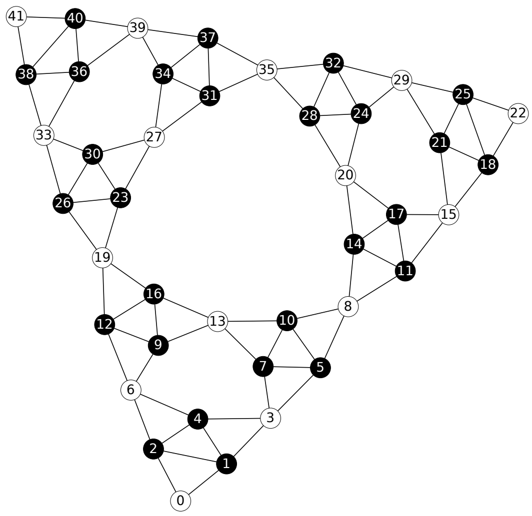


Figure 12: The Sierpinski triangular network with indication of communities for $N = 42$, here we have 9 communities of 3 nodes each (black nodes) and 15 communities of 1 node each (white nodes) [16].

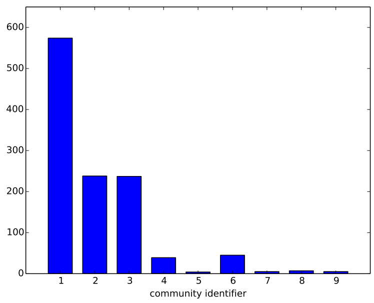
Here we have 9 communities of 3 nodes each (black nodes in the figure) and 15 communities of 1 node each (white nodes in the figure). Some of isolated nodes are the ones for which overlapping is observed. The procedure which clearly assigns nodes to communities in the case of symmetry must classify such nodes as singular communities. An application of the community detection procedure for the connectivity matrix slightly disturbed allows to indicate a community where a given node belongs to. The matrix elements are disturbed by addition of noise: a small value is subtracted from ones and a small value is added to zeros. After many repetitions of the procedure, a histogram can be constructed of the frequency of connection of a given node classified as singular with other communities. The histograms, for the Sierpinski triangle, are presented in Fig.13. Two highest bars in Fig.13b-13d reflect the same strength of the connection of appropriate nodes with two communities. For example for the node No 3 (Fig.13b) two bars of almost the same height correspond to communities $(1, 2, 4)$ and $(5, 7, 10)$ in Fig.12.

What's more, the obtained histograms reflect the community structure of the whole network; on the basis of the height of particular bars we are able to show, the way of the connection of particular communities with each other. An important result is also that if histograms obtained for two nodes are the same, those nodes belong to the same class.

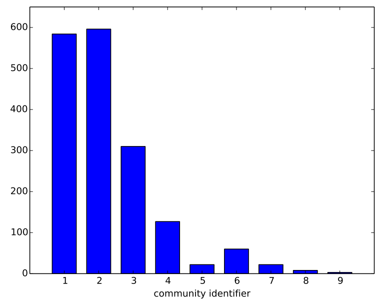
E.5 Summary

The proposed method of the community detection in networks [4, 5] may be applied to any graphs, i.e. weighted or unweighted networks, directed or undirected ones. As it was shown on the basis of model networks, its application allows for the proper indication of communities also in the case when these communities differ significantly in size; this may be a problem when other methods are applied [30]. The method works well with noisy data. The method allows also for indication of the overlapping nodes, i.e. in the situation when a node belongs to more than one community. For such nodes, having added a slight noise to the connectivity matrix, one can construct histograms which reflect the structure of their connections with communities observed in a given network [16].

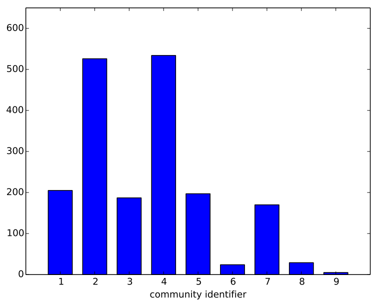
The reduction of the system size by classes of states indication is possible for any network which is characterised by some symmetry of its topology: in a nutshell, at least two nodes should have the same structure of their neighbourhood. The class of a node is determined by the number of its neighbours and weights of particular connections. We say that nodes belong to the same class if they have the same number of neighbours which belong to the same classes. In other words,



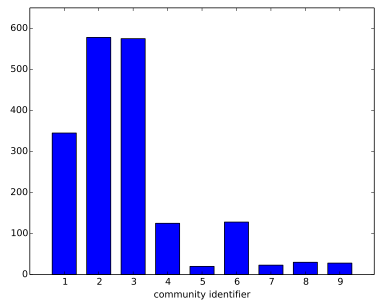
(a) Node number 0. Analogous histograms obtained for nodes 22 and 41.



(b) Node number 3. Analogous histograms obtained for nodes 6, 15, 29, 33 and 39.



(c) Node number 8. Analogous histograms obtained for nodes 19 and 35.



(d) Node number 13. Analogous histograms obtained for nodes 20 and 27.

Figure 13: Histograms of the frequency of the connections of a given node with original communities of the size different than one for the Sierpinski triangular network for $N = 42$ [16].

this means that lists of the neighbours of nodes which belong to the same classes must be the same. This condition is equivalent to taking into account not only the nearest neighbours of a given node, but also the neighbours of the neighbours, and so on. Likewise the originally analysed system is represented as a graph, also obtained classes of states may be represented in a form of a graph.
The proposed method of the indication of classes of states was applied to graphs which represent the state space of a given classical systems, such as the spins systems [11, 12], the roundabout [12] or conformations of the polymer molecule [13] and the quantum system, i.e. the Hubbard ring [14].

For all these systems, the time evolution can be presented as a random walk in the state space. In the stationary state, the probabilities of all states which form a given class are the same; this allows to analyse the properties of the system in its equivalent representation by means of classes. The existence of classes, as it was shown, results directly from the symmetry of the system. The class structure can be found for any values of parameters which describe processes which occur in the system. The structure of classes remains the same when these parameters are of different values. For example, the structure of the classes network for the polymer molecule, discussed in the paper [13], is the same in a wide range of the magnitude of the electric field.

In my papers I have shown that the method of classes finding may be useful also in the case of different graphs. With the use of this method, the classification of elementary cellular automata [15] and the reduction of networks obtained for symmetric fractals [16] was made. The same procedure was also applied for Boolean networks [17]. The method may also be a useful tool which allows for the analysis of a system in its equivalent form of classes representation, which for systems which manifest the topological symmetry is of a smaller size.

F Discussion of other scientific and research achievements

F.1 Before obtaining the PhD degree

During my PhD studies, under the scientific supervision of Prof. Krzysztof Kułakowski, I dealt with the issue of the displacement of a polymer chain in an agarose gel under influence of high electric fields. As a part of dissertation I performed a series of measurements of the velocity and the diffusion coefficient of DNA chains as a function of the external field strength. The results of experiments were presented in papers [31–34]. On different stages of the research we made experiments which cover a wide range of DNA chains lengths and the external field strengths. They allowed for the indication of the relation of the velocity and the diffusion coefficient to those parameters.

The experimental results were the basis for the analytical model of the gel electrophoresis in high fields, so called geometration [31–33, 35]. In the paper [31] we introduced the concept of a mean free path of the polymer chain between subsequent collisions with a gel fibres. This quantity was used for the correction of the expressions for the velocity and the diffusion coefficient in the case of high field, which is described as the geometration model, introduced in [36].
The paper [35] was a continuation of the previous paper with the addition of the possibility of two hookings of the molecule on the gel fibre.
In the paper [32] the set of differential equations was introduced to describe probabilities of multiple hookings of a chain with a fibres of a gel.
The analytical calculations introduced in two mentioned papers were summarised and used for the interpretation of the experimental results in the paper [33].

The computer simulations were made within the model of the gel electrophoresis proposed by us, and other models which describe displacements of the polymer chains in different ranges of the chain lengths and external field strengths. The obtained results were presented in papers [34, 37–40]. Particularly noteworthy are the papers [38] and [39] which were devoted to the presentation of the cellular automaton proposed by us, which enables a simulation of the electrophoresis in high fields. For the first of these it was a one-dimensional automaton, in the other – two-dimensional automaton. Performed simulations allowed for the quantitative reconstruction of the experimental results.

Some of the papers presented in this subsection [33,34,39,40] were printed after I have obtained the PhD degree, they are however the integral part of research made before its obtaining.

F.2 After obtaining the PhD degree

After obtaining the PhD degree my research was connected with biological topics for some time. At that time, some papers were written which concerned modelling of the formation of the polymer networks [41, 42] and PCR process [43]. In the case of the polymer networks a phase diagram was constructed, which presented the distribution of pore sizes as a function of the model parameters, such as the length and the number of chains. The obtained distribution is consistent with the percolation theory [44]. As regards of the paper about the polymerase chain reaction (PCR) [43] I made simulations, on a basis of our model, which reconstruct the experimental results [45] on the efficiency of the analysed process.

My interest in biology has also found an expression in a cooperation during realization of the grant of Polish Ministry of Science and Higher Education (2006-2009) „The use of modern functional genomics and bioinformatics for the characterization and modelling of biological processes of major importance in medicine and agriculture". The result of this cooperation is the paper [46] which concerns the research on genes important in depressive states expression in the specific brain areas under an influence of selected antidepressant drugs.

The next issue I worked with was analysis of properties of the Archimedean $(3, 12^2)$ network with the Ising anti-ferromagnetic bound [47]. The calculations concerned the temperature relation of the magnetic susceptibility and the specific heat. There were also identified some periodic ground states with non-zero density of frustrations. The results allowed to say that topological disorder or bounds disorder is not necessary for the existence of the spin glass phase.

Later, still working in the Prof. Krzysztof Kułakowski group, I made computer simulations of selected social processes. Among analysed problems, I can list modelling of communication systems [48–50], social behaviour [51–55] and analysis of the structure of social networks [56]. Some of this research was done as a part of the grant SOCIONICAL (2009-2013) – Complex Socio-Technical System in Ambient Intelligence realised as FP7.

In the paper [48] the spatio-temporal correlations of traffic for the motorway M-30 around Madrid was analysed. We shown that they are the shortest in the evening (from 6 p.m. to 8 p.m.) and are connected with large changes of the velocity of vehicles. This area is a border between different motion regimes.
The paper [49] concerns, in turn, the modelling of traffic by the cellular automaton. It was shown there that there is a phase transition in the parameters space of the model between phase of fluent motion and the jammed system. In the paper the method of classes of states was also used [11–17] to reduce the size of the analysed system.

The third of papers connected with modelling of communication systems [50] concerns correlations between people in crowd. It was shown that existence of the local order is connected with a collective behaviour. In other words, in the ordered phase of the motion an increase of the short-range spatial order is observed, while in the disordered phase spatial correlations are weaker and individuals move with different velocities.

The paper [51] was connected with the analysis of an optimal behaviour strategy of individuals in the emergency situation. As possible strategies of behaviour we used a selfish strategy, a passive strategy or a cooperation with other individuals. We have shown that communities appear in situation when individuals communicate with each other, taking joined actions. It was also shown that the dynamics of the communication depend on the level of tolerance of individuals. On the other hand, in the paper [52] the analysis of the division into communities of children of different ages belonging to the same class in the school and teachers on the bases of experimental data collected in schools in Mexico. Obtained results show how the division changes with the age in terms of gender of individuals belonging to a given group.
Another issue taken by us, discussed in the paper [53], is a typical waiting time in the queue if at its front another person may appear. Our analysis concerned the queue of people and the queue of cars. Obtained results show that the distribution of the waiting times is scale-free, which in particular means that very long times of waiting are possible.

The next paper of this series [54] was devoted to the problem of opinions dissemination under the Axelrod model [57] with the modification of the method of calculation of the probability of approval or rejection of a given fashion, on a bases of the number of neighbours with the same opinion. The modification leads to loss of the ordered phase observed in earlier papers, e.g. [58].

In the paper [55] the analysis was made of the so-called Simmel effect [59–61], which captures the efforts of lower classes to imitate elites and the aspirations of the latter to be original, on the basis of the analysis of the popularity of names in the USA. It was shown that the popularity of some feature (the name) which appears in the node with the high degree (which represents elites) causes a temporal increase or its popularity in other nodes, and later the feature gradually disappears.

Our analyses of social systems, as it was already mentioned, was also related with structure of social networks. In the paper [56] it was shown that the social network of LiveJournal is scale-free, clustered and assortative. Those features cause that it is similar to the line graph [62, 63] constructed for the scale-free network. The relation of the clustering coefficient to the node degree for both networks show the same character, which suggests that line graphs constructed on scale-free networks provide an appropriate representation of real social systems.

Papers which are part of the achievement are marked in bold.

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[47] Krawczyk M.J., Malarz K., Kawecka-Magiera B., Maksymowicz A.Z., Kułakowski K., "Spin glass properties of an Ising antiferromagnet on the Archimedean (3,122) lattice", Physical Review B 72 (2005) 24445

[48] Krawczyk M.J., Beltran Ruiz C., Kułakowski K., "Situations in traffic - how quickly they change", Central European Journal of Physics 9 (2011) 1452

[49] Krawczyk M.J., Kułakowski K., "Coarse-grained cellular automaton for traffic systems", International Journal of Modern Physics C 24 (2013) 1350011

[50] Gawroński P., Malarz K., Krawczyk M.J., Malinowski J., Kupczak A., Sikora W., Kułakowski K., Wąs J., Kantelhardt J., "Strategies in crowd and crowd structure", Acta Physica Polonica A 123 (2013) 522

[51] Krawczyk M.J., Malarz K., Korff R., Kułakowski K., "Communication and trust in the bounded confidence model", Lecture Notes in Artificial Intelligence 6421 (2010) 90

[52] Krawczyk M.J., del Castillo-Mussot M., Hernández-Ramírez E., Naumis G.G. and Kułakowski K., "Heider balance, asymmetric ties, and gender segregation", Physica A (2015) *w druku*

[53] Krawczyk M.J., Gronek P., Nawojczyk M. and Kułakowski K., "If Others Jump to the Queue Front, How Long I Will Wait?", Acta Physica Polonica A 127 (2015) 95

[54] Krawczyk M.J., Kułakowski K., "On a combinatorial aspect of fashion", Acta Physica Polonica A 123 (2013) 560

[55] Krawczyk M.J., Dydejczyk A., Kułakowski K., "The Simmel effect and babies' names", Physica A 395 (2014) 384

[56] Krawczyk M.J., Muchnik L., Mańka-Krasoń A., Kułakowski K., "Line graphs as social networks", Physica A 390 (2011) 2611

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[60] Pedone R., Conte R., "The Simmel effect: imitation and avoidance in social hierarchies", Lecture Notes in Artificial Intelligence 1979 (2000) 149

[61] Pedone R., Conte R., "Dynamics of status symbols and social complexity", Social Science Computer Review 19 (2001) 249

[62] Whitney H., "Congruent graphs and the connecivity of graphs", American Journal of Mathematics 54 (1932) 150

[63] Evans T.S., Lambiotte R., „Line graphs, link partitions and overlapping communities", Physical Review E 80 (2009) 016105

Małgorzata Krawczyk

II Academic activity including didactic achievements, research co-operation and popularization of science

G List of publications providing the basis of the achievement

I am the only author of subsequent papers.

1. Krawczyk M.J., "Differential equations as a tool for community identification", Physical Review E 77 (2008) 065701(R)

2. Krawczyk M.J., "Application of the differential equations method for identifying communities in sparse networks", Computer Physics Communications 181 (2010) 1702

3. Krawczyk M.J., "Topology of the space of periodic ground states in the antiferromagnetic Ising and Potts models in selected spatial structures", Physics Letters A 374, (2010) 2510

4. Krawczyk M.J., "Symmetry induced compression of discrete phase space", Physica A 390 (2011) 2181

5. Krawczyk M.J., "Static and dynamic properties of discrete systems with compresses state space; A polymer chain as an example", The European Physical Journal B 86 (2013) 246

6. Krawczyk M.J., "Symmetry-driven compression of the set of states of a Hubbard ring", Journal of Magnetism and Magnetic Materials, 349 (2014) 63

7. Krawczyk M.J., "New aspects of symmetry of elementary cellular automata", Chaos, Solitons and Fractals 78 (2015) 86

8. Krawczyk M.J., "Communities and classes in symmetric fractals", International Journal of Modern Physics C

H List of other scientific publications (not included into the achievement, as indicated in d.1) and bibliometric indicators

H.1 Publications in journals tracked by the Journal Citation Report (JCR)

- Krawczyk M.J., del Castillo-Mussot M., Hernández-Ramírez E., Naumis G.G. and Kułakowski K., "Heider balance, asymmetric ties, and gender segregation", Physica A (2015) *w druku*, IF: 1.732
  My contribution to this work was to make calculations regarding division of the social groups (classes in schools in Mexico) in terms of gender. My percentage contribution to this paper is 30%.

- Gawroński P., Krawczyk M.J. and Kułakowski K., "Emerging communities in networks - a flow of ties", Acta Physica Polonica B 46 (2015) 911, IF: 1.00
  My contribution to this work was to make simulations concerning the designation of communities. My percentage contribution to this paper is 30%.

- Krawczyk M.J., Gronek P., Nawojczyk M. and Kułakowski K., "If Others Jump to the Queue Front, How Long I Will Wait?", Acta Physica Polonica A 127 (2015) 95, IF: 0.604
  My contribution to this work was to implement program and carry out simulations for the model estimating waiting time in the queue if at its front people from outside appear. My percentage contribution to this paper is 60%.

- Krawczyk M.J., "Classes of states of discrete systems", International Journal of Modern Physics C (2015), in press, IF: 1.125
  My contribution to this work was to collect and summarise material which concerns nodes classes in networks with local symmetry presented in the former publications. Also in the paper, the method was applied for Boolean networks. I am the only author of this paper. I am the only author of this paper.

- Malarz K., Krawczyk M.J., Kułakowski K., "Influence of long-range interactions on strategy selection in crowd", Acta Physica Polonica B Proceedings Supplement 7 (2014) 371, IF: 0.531
  My contribution to this work consisted in discussion of the obtained results. My percentage contribution to this paper is 10%.

- Krawczyk M.J., Malinowski J., Kułakowski K., "Size dependence of the largest distance between random points", Acta Physica Polonica B Proceedings Supplement 7 (2014) 331, IF: 0.531
  My contribution to this work was to implement the program and carry out simulations for assumed model. My percentage contribution to this paper is 70%.

- Krawczyk M.J., Dydejczyk A., Kułakowski K., "The Simmel effect and babies' names", Physica A 395 (2014) 384, IF: 1.722
  My contribution to this work was to make simulations for proposed model. My percentage contribution to this paper is 60%.

- Krawczyk M.J., Kułakowski K., "Coarse-grained cellular automaton for traffic systems", International Journal of Modern Physics C 24 (2013) 1350011, IF: 1.125
  My contribution to this work was to work the plan of the real city and to make numerical simulations. I took part in the preparation of text of the paper. My percentage contribution to this paper is 70%.

- Krawczyk M.J., Kułakowski K., "On a combinatorial aspect of fashion", Acta Physica Polonica A 123 (2013) 560, IF: 0.531

My contribution to this work was to implement the computer program and carry out computer simulations for the proposed model. My percentage contribution to this paper is 70%.

- Gawroński P., Malarz K., Krawczyk M.J., Malinowski J., Kupczak A., Sikora W., Kułakowski K., Wąs J., Kantelhardt J., "Strategies in crowd and crowd structure", Acta Physica Polonica A 123 (2013) 522, IF: 0.531
  My contribution to this work was to analyse the character of the phase transition by means of the multi-fractal analysis. My percentage contribution to this paper is 10%.

- Gąska M., Kuśmider M., Solich J., Faron-Górecka A., Krawczyk M.J., Kułakowski K., Dziedzicka-Wasylewska M., "Analysis of region-specific changes in gene expression upon treatment with citalopram and desipramine reveals temporal dynamics in response to antidepressant drugs at the transcriptome level", Psychopharmacology 223 (2012) 281, IF: 4.077
  My contribution to this work was to carry out statistical analysis of the obtained experimental data. My percentage contribution to this paper is 10%.

- Krawczyk M.J., Beltran Ruiz C., Kułakowski K., "Situations in traffic - how quickly they change", Central European Journal of Physics 9 (2011) 1452, IF: 0.909
  My contribution to this work was to carry out experimental data. I took part in the preparation of text of the paper. My percentage contribution to this paper is 60%.

- Krawczyk M.J., Muchnik L., Mańka-Krasoń A., Kułakowski K., "Line graphs as social networks", Physica A 390 (2011) 2611, IF: 1.373
  My contribution to this work was to carry out the analysis of the properties of model network as to compare with properties of real network. My percentage contribution to this paper is 30%.

- Krawczyk M.J., Malarz K., Korff R., Kułakowski K., "Communication and trust in the bounded confidence model", Lecture Notes in Artificial Intelligence 6421 (2010) 90, IF: brak
  My contribution to this work was to analyse how communities structure depends on values of the model parameters. Also participate in the discussion of the obtained results. My percentage contribution to this paper is 30%.

- Krawczyk M.J., "Communities in Social Networks", IEEE Conference Proceeding ICBAKE 2009, IF: brak
  The aim of the paper was the comparison of the obtained communities fro

selected social networks with application of two different methods of communities indication. In the paper it was also shown that despite of the same character of the node degree distribution for all analysed networks the nodes play different roles in particular networks. I am the only author of this paper.

- Krawczyk M.J., Kułakowski K., "Formation of DNA networks - computer simulations", Acta Physica Polonica B 38 (2007) 1813, IF: 0.664
  My contribution to this work consisted in the implementation of the program and making simulations of the DNA network formation. I also participated in the results interpretation. My percentage contribution to this paper is 70%.

- Krawczyk M.J., Kułakowski K., "Pores in a two-dimensional network of DNA strands - computer simulation", Lecture Notes in Computer Science 42 (2006) 3889, IF: brak
  My contribution to this work consisted in the implementation of the program and making simulations of the DNA network formation. I also participated in the results interpretation. My percentage contribution to this paper is 70%.

- Paściak P., Krawczyk M.J., Gudowska-Nowak E., Kułakowski K., "Diffusion of DNA molecules in gel at high electric fields", Journal of Biological Physics 31 (2005) 365, IF: 1.371
  My contribution to this work consisted in making simulations of DNA displacement in high field. My percentage contribution to this paper is 20%.

- Krawczyk M.J., Kułakowski K., "Off-lattice simulation of the solid phase DNA amplification", Computer Physics Communications 170(2) (2005) 131, IF: 1.644
  My contribution to this work consisted in simulations of the efficiency of amplification of DNA. My percentage contribution to this paper is 70%.

- Krawczyk M.J., Malarz K., Kawecka-Magiera B., Maksymowicz A.Z., Kułakowski K., "Spin glass properties of an Ising antiferromagnet on the Archimedean (3,122) lattice", Physical Review B 72 (2005) 24445, IF: 3.185
  My contribution to this work consisted in the calculation of the specific heat and magnetic susceptibility for the analysed system. My percentage contribution to this paper isa 30%.

- Krawczyk M.J., Paściak P., Dydejczyk A., Kułakowski K., Dulak J., "Gel electrophoresis of DNA - new measurements and the repton model at high fields", Acta Physica Polonica B 36 (2005) 1653, IF: 0.807
  My contribution to this work consisted in the planning and performing the

experiment and analysis of its result. My percentage contribution to this paper is 30%.

- Krawczyk M.J., Kułakowski K., "High field electrophoresis - computer simulations", Computer Physics Communications 163 (2004) 172, IF: 1.515
  My contribution to this work was to implement the program and to carry out simulations. I also participated in the interpretation of the results. My percentage contribution to this paper is 70%.

- Krawczyk M.J., Dulak J., Paściak P., Kułakowski K., "Diffusion constant in gel electrophoresis at high fields", Electrophoresis 25 (2004) 789, IF: 3.743
  My contribution to this work was to participate in the planning, implementation, and development of the experiment. My percentage contribution to this paper is 40%.

- Paściak P., Krawczyk M.J., Kopeć M., Dulak J., Kułakowski K., "Gel electrophoresis at high fields", Acta Physica Polonica B 34 (2003) 3533, IF: 0.752
  My contribution to this work was to carry out the experiment and to analyse its results. My percentage contribution to this paper is 40%.

- Krawczyk M.J., Kułakowski K., Maksymowicz A.Z., "New cellular automaton designed to simulate geometration in gel electrophoresis", Computer Physics Communications 147 (2002) 354, IF: 1.204
  My contribution to this work was to carry out numerical simulations for the proposed cellular automaton and I also participate in the discussion of the obtained results. My percentage contribution to this paper is 60%.

- Krawczyk M.J., Kułakowski K., "How geometration reduces the velocity of DNA in gel electrophoresis", Theory in Biosciences 121 (2002) 231, IF: 0.705
  My contribution to this work was to carry out numerical calculations of times of particular stages of the polymer molecule sliding down from an obstacles. My percentage contribution to this paper is 70%.

- Paściak P., Krawczyk M.J., Kułakowski K., "Velocity distribution in the Duke-Rubinstein model", International Journal of Modern Physics C 13 (2002) 829, IF: 0.784
  My contribution to this work consisted in the participation in the results interpretation. My percentage contribution to this paper is 20%.

- Krawczyk M.J., Dulak J., Kułakowski K., "Mean free path and peak dispersion in the geometration motion in gel electrophoresis", Electrophoresis 23 (2002) 182, IF: 4.325
  My contribution to this work consisted in the analysis of experimental data. My percentage contribution to this paper is 60%.

H.2 Inventions and other objects of industrial property which are granted patent protection and were demonstrated at national or international exhibitions

n/a

H.3 Monographs, academic publications in international or national journals that are not tracked by the JCR database

- Kułakowski K., Krawczyk M.J., Gawroński P., "Hate - no choice. Agent simulations", ed. by C. T. Lockhardt, Nova Sci. Publ., NY 2010, pp. 137-158
  My contribution to this work consisted in indication of communities structure of the analysed system. My percentage contribution to this paper is 30%.

- Krawczyk M.J., Kułakowski K., "Communities in networks - a continuous approach", arXiv:0709.0923v5
  My contribution to this work consisted in performing simulation of community detection in model networks. My percentage contribution to this paper is 80%.

H.4 Joint publications, collections catalogued, databases prepared, professional assessments

n/a

H.5 Impact factor of all publications in accordance to Journal Citation Reports (JCR):

49.61 (14.182+35.428)

H.6 The total number of citations in accordance to Web of Science (WoS):

43

H.7 Hirsh index in accordance to Web of Science (WoS):

6

H.8 Leadership in international or national research projects or participation in such projects

- grant SOCIONICAL (2009-2013) – Complex Socio- Technical System in Ambient Intelligence realized in FP7
- grant of Ministry of Science and Higher Education (2006-2009) „The use of modern functional genomics and bioinformatics for the characterization and modelling of biological processes of major importance in medicine and agriculture"

H.9 International and national awards for academic or artistic (as applicable) work

- The 2nd degree individual awards of the Rector for scientific achieves in year 2009
- The 3rd degree individual awards of the Rector for scientific achieves in year 2011
- The 1st degree team awards of the Rector for scientific achieves in year 2006
- The 2nd degree team awards of the Rector for scientific achieves in years 2005, 2007, 2008
- The 3rd degree team awards of the Rector for scientific achieves in year 2014, 2012

H.10 Talks and lectures at academic seminars and scientific meetings

Future:

- "Statistics on babies' names reflects the traditional regions in the United States", 19th International Academic Conference, September 16-19, 2015, Florence, Italy
- "Communities and classes of nodes in self-similar networks", Minisympozjum Fizyki Statystycznej, September 8th, 2015, Cracow, Poland

Past:

- "New aspects of symmetry of elementary cellular automata", Summer Solstice, June 27-29, 2013, Warsaw, Poland

- "On some consequences of symmetry in discrete systems with a circular polymer as an example", Summer Solstice, June 6-10, 2011, Turku, Finland
- "Communities in five networks: a meta-analysis", SunBelt XXX, June 29 - July 4, 2010, Riva del Garda, Italy
- "Looking for communities in networks: two algorithms, three kinds of noise", European Conference on Complex Systems ECCS'09, September 21-25, 2009, Warwick, UK
- "Communities in social networks", ICBAKE 2009, June 25-28, 2009, Cieszyn, Poland
- "Communities in networks", Frontiers in modern physics and its applications, May 28-29, 2009, Cracow, Poland

I Achievements in teaching and popularization of science, research co-operation. Participation in European programmes and other international or national programmes

I.1 European programmes

See Par. H.8

I.2 Active participation in international or national academic conferences

Lectures - see Par. H.10.
Posters presented at scientific conferences:

- Krawczyk M.J., "Communities and classes in symmetric fractals", European Conference on Complex Systems ECCS'14, September $22-26$, 2014, Lucca, Italy
- Krawczyk M.J., "Communities and classes in symmetric fractals", International Conference in Statistical Physics, July $7-11$, 2014, Rhodes, Greece
- Krawczyk M.J., "Local symmetries and compression of discrete systems", European Conference on Complex Systems ECCS'13, September $16-20$, 2014, Barcelona, Spain

- Krawczyk M.J., "Symmetry-driven reduction of the number of states in discrete systems", European Conference on Complex Systems ECCS'12, September 3 – 7, 2012, Brussels, Belgium
- Krawczyk M.J., Kułakowski K., "Culture dissemination with repulsion", European Conference on Complex Systems ECCS'12, September 3 – 7, 2012, Brussels, Belgium
- Krawczyk M.J., Kułakowski K., "How symmetry reduces the size of state space", European Conference on Complex Systems ECCS'11, September 12–16, 2011, Vienna, Austria
- Krawczyk M.J., Kułakowski K., "Networks of ground states of frustrated systems", European Conference on Complex Systems ECCS'10, September 13 – 17, 2010, Lisbon, Portugal
- Krawczyk M.J., Kułakowski K., "Looking for communities in networks: two algorithms, three kinds of noise", European Conference on Complex Systems ECCS'09, September 21 – 25, 2009, Warwick, UK
- Krawczyk M.J., "Identification of communities in social networks", The 2009 International Conference on Advances in Social Networks Analysis and Mining, July 20 – 22, 2009, Athens, Greece
- Krawczyk M.J., Dziedzicka-Wasylewska M., Kuśmider M. and Kułakowski K., "Differential equations method for clustering gene expression time-courses", Computational Biology and Bioinformatics, September 22–26, 2008, Cagliari, Italy
- Krawczyk M.J., "Subnetworks in genetic networks", International Conference in Statistical Physics, July 14 – 18, 2008, Kolympari, Greece
- Krawczyk M.J., International workshop on "Detection and visualization of communities in large complex networks", March 13 – 14, 2008, Louvain-la-Neuve, Belgium
- Krawczyk M.J., Kuśmider M., Dziedzicka-Wasylewska M., Kułakowski K., "Corregulation of selected genes in the rat hippocampus and cerebral cortex", German Conference on Bioinformatics, September 26 – 28, 2007, Potsdam, Germany
- Krawczyk M.J., Summer School on Socio-Econo-Physics, September 12 – 15, 2007, Windberg, Germany

- Krawczyk M.J., Kusmider M., Dziedzicka-Wasylewska M., Kulakowski K., "Modularity of clustering of a gene expression network", Systems Biology: Global Regulation of Gene Expression, Cold Spring Harbor Laboratory, March 29 - April 1, 2007, New York, USA
- Krawczyk M.J., Kułakowski K., "Pores in a two-dimensional network of DNA strands - computer simulation", ICCS 2006 : "Advancing Science through Computation", May 28 – 31, 2006, Reading, UK
- Krawczyk M.J., Paściak P., Kułakowski K., Dulak J., Dydejczyk A., "Gel electrophoresis of DNA - new measurements and the particle model", 17th Marian Smoluchowski Symposium on Statistical Physics, September 4 – 9, 2004, Zakopane, Poland
- Krawczyk M.J., Paściak P., Dulak J., Kopeć M., Kułakowski K., "Gel electrophoresis at high fields", 15th Marian Smoluchowski Symposium on Statistical Physics: Fundamentals and Applications, September 7 – 12, 2002, Zakopane, Poland
- Krawczyk M.J., Kopeć M., Kułakowski K., "High field electrophoresis - computer simulations", 7th Granada Seminar: Modeling of complex systems, September 2 – 7, 2002, Granada, Spain
- Krawczyk M.J., Dulak J., Kułakowski K., "Mean free path and band dispersion in the geometration motion in gel electrophoresis", ICES-2001: an Electrophoretic Odyssey, June 10 – 13, 2001, Verona, Italy
- Krawczyk M.J., Kułakowski K., "How geometration reduces the velocity of DNA in gel electrophoresis", ISPPP-2000: 20th International Symposium on the Separation and Analysis of Proteins, Peptides and Polynucleotides, November 5 – 8, 2000, Ljubljana, Slovenia

I.3 Participation in organizing committees of international and national scientific conferences

- member of the local organizing committee „International Conference on Computer Information Systems and Industrial Management - CISIM 2010", October 8 – 10, 2010, Krakow, Poland
- member of the local organizing committee „International Multi-Conference on Biometrics and Kansei Engineering - IEEE/ICBAKE 2009", June 25 – 28, 2009, Cieszyn, Poland

- member of the local organizing and scientific committees „2. Ogólnopolskiego sympozjum fizyka w ekonomii i naukach społecznych FENS 2006", April 21 – 22, 2006, Krakow, Poland

I.4 Prizes and awards other than those indicated in H.9

n/a

I.5 Participation in consortiums and research networks

n/a

I.6 Management of scientific research and development projects performed in collaboration with national and international partners from science and industry (other than those indicated in H.8 above)

n/a

I.7 Participation in editorial boards and other editorial activities

n/a

I.8 Membership in international or national organizations and scientific societies

n/a

I.9 Achievements in teaching and popularization of science

Teaching activities:

- Language C++, lecture and laboratory for students of the Faculty of Physics and Applied Computer Science AGH (since 2013)
- Language Python, elective lecture and laboratory for students of the Faculty of Physics and Applied Computer Science AGH (since 2005)

- Object programming (Java language), lecture for students of the Faculty of Physics and Applied Computer Science AGH (since 2008) , laboratory for students of the Faculty of Physics and Applied Computer Science AGH (since 2005)

- Engineering numerical methods, laboratory for students of the Faculty of Physics and Applied Computer Science AGH (since 2009)

- Numerical methods, laboratory for students of the Faculty of Physics and Applied Computer Science AGH (since 2007)

- Fundamentals of computer science, lecture for students of the Faculty of Physics and Applied Computer Science AGH (since 2004) oraz Międzywydziałowej Szkoły Energetyki (2004-2008) and laboratory for students of the Faculty of Physics and Applied Computer Science AGH oraz Międzywydziałowej Szkoły Energetyki (2003-2008)

- Physics, exercises for students of the Faculty of Electrical Engineering, Automatics, Computer Science and Biomedical Engineering AGH (2001-2005)

- Physics, Laboratory of physics I and II (1999-2000)

I.10 Scientific assistance to students as scientific supervisor

- Supervisor of M.Sc. degree theses at the Faculty of Physics and Applied Computer Science
  - "Publication meta-search engine", 2014
  - "Graphical data analysis", 2012
  - "Visualisation of the clusterings algorithms", 2012
  - "Interactive program for the Java language learning", 2010
  - "Time series analysis of gene expression - a dynamic model and selected algorithms for clustering", 2009
  - "Bioinformatic analysis of genes expression profiles", 2009

- Reviewer of bachelor of science and M.Sc. degree theses at the Faculty of Physics and Applied Computer Science AGH, the number of reviews: 16

I.11 Scientific assistance and co-supervision to Ph.D. students

n/a

I.12 Internships in foreign research or academic centres

- practice in the Martin-Luther-Universitat, Halle, Niemcy, February 5 – 12, 2012
- practice in the Faculty of Biochemistry, University of Vienna, November 10 – 18, 2000

I.13 Evaluations performed or other scientific studies made to order

n/a

I.14 Participation in expert and competition teams

n/a

I.15 Reviews of international and national research projects

n/a

I.16 Reviews of publications in international and national journals

- Physics Letters A, number of reviews: 2, 2010, 2014
- Physica A, number of reviews: 1, 2014
- European Physical Journal B, number of reviews: 1, 2013
- Modern Physics Letters B, number of reviews: 1, 2013

I.17 Activities other than those indicated in I.1 - I.16

Organizing activity in aid of the Wydziału Fizyki i Informatyki Stosowanej AGH

- organiser of the faculty seminar at the Faculty of Physics and Applied Computer Science AGH (since October 2005)

- organiser of the seminar of Complex Systems Group at the Faculty of Physics and Applied Computer Science AGH (since October 2005)
- member of the library commission (2013)
- member of the election commission at the Faculty of Physics and Applied Computer Science AGH (2012)
- member the faculty council (term 2012 – 2016)

Małgorzata Krawczyk