Complex Networks in “Environment-Economy” Systems

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Abstract: - In view of objectivizing the analysis of complex and/or hyper-complex systems, the paper undertakes to structure them into complex networks and further proposes matrix-vectorial patterns to calculate specific indicators of grades probability distribution as well as indicators of similarity measurement of complex networks nodes within environment-economy systems. Likewise, the authors approach the Complexity science in order to analyze complex networks at different levels of the complex systems. The paper emphasizes aspects on the classification, structure and basic notions relating to the approach to complex systems by using graphs theory.

Key-Words: - complex network, Complexity science, complex system, graphs, nodes, arcs, neighborhood

1 Introduction
It is widely known that Natural Environment and Economy are among the most complex systems that exist nowadays. The issue becomes even more complex when it comes to economic integration within the natural environment, which leads to the idea that the Environment-Economy system is actually a hyper-complex system. In addition to the application of eco-energetic and emergetic analysis (Pillet, G, Odum, HT, 1987) other complementary methods may also be envisaged.

We point out that we make reference to complex networks specific to complex or hyper-complex systems. On the one hand, the complex system that is a set of elements containing several interacting entities whose behavior can not be explained individually, but starting from the behavior of an individual entity on the basis of which we can assess the behavior of the system as a whole. On the other had, the hyper-complex system is a set of elements found in a structural and functional relationship of interdependence and mutual interaction, forming a whole whose parts (units, ideas etc..) are in excess, i.e. beyond the average values of complex systems. These types of systems are characterized by complex networks.

Hyper-complex systems of environment-economy type, which also include systems from agriculture, food industry and environment, synthetically expressed, for instance, within the framework of agriecosystems, may be piloted with the elements, principles and mechanisms of complex networks. It is the flows of information that characterize all the networks components, which might explain the mechanisms of integronic relations between the economy and the natural environment and related applications.

Starting from complex networks that were more deeply analyzed, such as those in banking and financial field (Tertişco, M., 2007), we endeavor to extrapolate some methods and parameters in case of hyper-complex systems of Environment – Economy type (E-E). Thus, the purpose of this paper is to develop and test methods meant to identify nodes agglomerations of "community" type starting from the assessment of node pairs similarity. Knowing the characteristics of a network allows for a more rational allocation and efficient operation of resources, in line with the dynamic balance of the system, and enables us to ensure adequate operation efficiency.

2 Method
In order to analyze the computer-assisted network and to identify community groups, three methods are foreseen: (a) selecting corresponding sub-graphs in the network; (b) determining the vectors specific to the incidence matrix of the network; (c) conceiving the mathematical and computed pattern. The first method consists of selecting corresponding sub-graphs in the network by identifying nodes or arcs with special characteristics. For instance, two nodes in the network are considered equivalent from structural point of view provided both have the same neighbors. The exact structural equivalency is rarely met but the approximate structural equivalency is used as basis in the so-called method of hierarchical clustering. Thus, if five nodes are noticed to have many common neighbors, this may be a sign of a
community group. This method of identifying arcs agglomerations of community type in the network is called the “method of arcs analysis”.

The second method consist of determining the vectors of the incidence matrix of the network and, taking into account particular properties of these vectors, there are identified agglomerations of Community type which are present in the network. The Community structure of the network may be highlighted by inspecting the adjacent matrix. Since the complex networks in the field of integrating economic activities within the natural environment are very large, the method of detecting arcs agglomerations through visual inspection of the network graph or adjacent matrix is excluded. These agglomerations may be identified only by appropriate computer-aided means of calculating the whole process of identification.

A third destination of empirical data, following a statistical processing, is the conception of a mathematical model or a similar computer-based pattern (e.g. Monte Carlo method) for the processes taking place in the network. This pattern allows: performing tests on forecasting future developments of the network, prevention of disasters and so forth.

3 Approach to “Complexity”

The difficulty of approaching the Complexity consists of accepting networks as entity able to operate on complexity and, on the other hand, to work as a team. In other words, one may have knowledge of Chaos Theory or Disaster Theory, yet, one can not operate at the level of Complexity. For instance, Figure 1 shows a network or a map of the main interactions that define the COMPLEXITY as a whole.

Therefore, we can not talk about complex networks, unless we make synthesis references about the "complexity science". Thus, the Science of Complexity, like any other science, has a well defined object of study as well as specific methods and techniques, aiming at a full understanding and application of the phenomena, processes, properties and knowledge arising from these studies.

Fig.1 –Principle Map of Complexity networks
To be more specific, the science of complexity undertakes the study of complex systems and develops techniques and models that are appropriate to the behavior of complex systems in time and space. Just like any other science, it has specific operating "tools", developed by mathematics and physics over the last century. The latter ones have developed independently, but together they form a set of conceptual and technical, concrete and useful tools used for the study of Complex Systems. These are: Fractal Geometry, Theory of Chaos, Synergetics and Theory of Disaster.

One operating way includes the analysis of complex networks at different levels of complex systems, with application of some appropriate theories.

### 3.1 Classification of complex networks

Complex networks are classified according to various criteria, such as those synthesized in Table 1.

<table>
<thead>
<tr>
<th>Item</th>
<th>CRITERION</th>
<th>EXAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Specificity of the real field the process it represents comes from</td>
<td>ecological networks, economic networks, technological network, computing networks, superstructure networks; hydrographic networks, biological networks, educational networks, social networks, scientific collaboration networks, etc.</td>
</tr>
<tr>
<td>2</td>
<td>Type of graph of the network</td>
<td>non-oriented graph, oriented graph, bipartite non-oriented graph, bipartite oriented graph - Petri network, mixed networks, community networks, etc.</td>
</tr>
<tr>
<td>3</td>
<td>După caracterul determinist ori aleator al sistemului real Determinist or arbitrary character of the real system</td>
<td>Determinist networks, stochastic networks</td>
</tr>
<tr>
<td>4</td>
<td>Geographical spread</td>
<td>global networks, national networks, regional networks, local networks</td>
</tr>
<tr>
<td>5</td>
<td>Equal number of neighbors of all nodes</td>
<td>adjusted networks – of grid type with equal mesh, non-adjusted networks</td>
</tr>
</tbody>
</table>

### 3.2 Assessment of parameters specific to complex systems within the environment-economy system

In a complex or hyper-complex system, many factors (such as economic companies) collaborate, interact and influence each other on a mutual basis. These interactions occur within "groups of collaborators" which are formed according to certain processes, specific activity, or are grouped according to other criteria or interests. The study and analysis of such real complex systems may be carried out on the basis of some experimental data that may be stored in databases.

May the set of units (species, population, types of resources, companies, etc.) \( V = \{v_1, v_2, v_3, v_4, \ldots, v_N\} = \{1, 2, \ldots, N\} \), be represented by the same group (biome, ecosystem, agroecosystem, financial bank, etc.). The links among these units are expressed by specific interactions (material, energy, information flows, financial transactions, etc.) which are represented through actions, processes, activities, transfers from one account to another, etc.). Provided there is one single action between any pair of connection nodes, the total number of possible activities is as follows:

\[
M = N(N-1)/2
\]

and corresponds to the total number of possible connections between different pairs of nodes \( N \). For example, if \( N = 3 \), the three possible links are: \((1.2)\), \((1.3)\) and \((2.3)\). Yet, provided nodes links may be obtained among themselves (elementary loops in the network), then the total number of possible connections is:
The statistical analysis of the network attempts to find characteristics that were previously obtained. The built on the basis of initial empirical data and local represented by the nodes of the complex network, (species, population, economic companies), obtaining answers about the units community data which stood at the basis of graph formation, i.e. the mathematical result obtained from the analysis of the graph network.

### 3.3. Structure of complex systems and definition of basic notions

A way of approaching the structure of complex and hyper-complex systems is supported by the theory of graphs. The network is made up of nodes, which, at their turn, have N neighbor vectors. A graph is characterized by the set of nodes and number of arcs (actions, activities, flows etc.). For example, in a graph, the set of nodes is $V=\{V_1,V_2, ..., VN\}$, and the set if arcs is $E=\{e_1, e_2, ..., em\}$. This graph of the complex network may be associated with the N neighbor vectors of all the nodes. These vectors characteristic of network nodes are used to calculate some indicators of local character, which allows us to answer questions like:

- what is the average length of a chain (path) of collaborating units?
- what is the number of direct "collaborators" of each unit?
- what is the density of network connections in each unit in relation to the others?

Another purpose of the graph is the use of empirical data which stood at the basis of graph formation, i.e. obtaining answers about the units community (species, population, economic companies), represented by the nodes of the complex network, built on the basis of initial empirical data and local characteristics that were previously obtained. The statistical analysis of the network attempts to find answers to questions like:

- what are the groups of units connected by collaboration links and mutually beneficial interests?
- how intense are the links among these groups whose connector is "collaboration" with the pennant unit of the group?
- what units have greater influence upon the others?
- are there divisions (decomposition in small groups) and what caused this division?
- what are the crucial connections for the functioning of the group?

Another destination of empirical data, following the statistical processing, is to build a mathematical model or a similar computer-based model (e.g. Monte Carlo method) for the processes taking place in the networked system. This model allows: (a) analyses on forecasting future developments of the network (b) prevention of disasters, (c) protection of the network against outside attacks, within the competitive struggle of biological, ethnic, economic or financial type etc.

These problems specific to complex networks are solved by taking into account the information extracted from the adjacent matrix and some characteristics of local network nodes. Therefore, an Ai vectors associated to the node i from the graph has N elements ($k=ai1… aik… aIN$) corresponding to the N nodes of the network:

$$Ai = [ai1,ai2,…,aIN],$$

where $aij = 1$ if node j of the network and its neighbor i (namely, if between node i and node j there is a single arc of length $L = 1$) and $aij = 0$ otherwise. We call vector (3) neighbor vector or characteristic vector of node i.

We point out that an important feature of each node is the node degree, i.e. the number of node neighbors. This is calculated by summing up the terms of vector Ai. For node i, the degree is noted ki:

$$ki = ai1 + … + aIN = Ai \times Ai',$$

where the transposed characteristic vector was noted with $Ai'$. One aspect of great interest in the theory of graphs is the path between two nodes i and j. This path is defined as a sequence of consecutive nodes (i 1, i 2, ..., j-1, j) or as the sequence of arcs connecting node i to node j: $\{(i+1, i+2), (i+2, i+3), ..., (j-1, j)\}$. A circuit is a path which closes in the node where it started from. The path, starting from node i and finishing at node j, with the shortest possible length, is called the geodesic between i and j.

The length of geodesic between i and j is called the distance between i and j, it is noted with d (i, j) and expresses the number of arcs on the shortest path.
between i and j. The set of nodes (i) placed at
distance 1 from node i is called the i neighborhood.
The maximum distance between i to any other node
in the graph G is called centricity of node i. The
highest value of the centricity between all nodes is
called the graph diameter, and the minimal value is
called the graph radius. The average distance is
often called the characteristic of path length. These
parameters may be established on the basis of the
nodes neighbor vectors. A subset W of nodes with a
subset of arcs (defined on W with representation in
E) is called subgraph.

4 Conclusion

Knowing the characteristics of a network allows for
a more rational allocation and efficient operation of
resources, in line with the dynamic balance of the
system, and enables us to ensure adequate operation
efficiency.

A way of approaching the structure of complex and
hyper-complex systems is supported by the theory of
graphs, the analysis of the complex network
describing a network made up of nodes that have N
neighbor vectors, the graph being characterized by
the set of nodes and number of arcs (actions,
activities, flows etc.).

The fuzzy assessment of some of the properties is
often preferred to precise, mathematical solution, on
account of the fact that in case of networks with
high complexity degree, the evolution and the
properties of the network is more important than the
mathematical result obtained from the analysis of
the graph network.

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