14 Growing Pyramidal Networks

14.1 Intelligent systems memory structuring

Formation of intelligent systems memory structure needs to be done simultaneously with perception of information and under the impact of the information perceived and already stored. The memory structure reflects the information perceived. Information structuring is an indispensable function of memory. [Gladun, 2003]

The main processes of structuring include formation of associative links by means of identifying the intersections of attributive representations of objects, hierarchic regulation, classification, forming up generalized logical attributive models of classes, i.e. concepts.

Under real conditions of information perception there is often no possibility to get whole information about an object at once (for example, because of faulty foreshortening or lighting during the reception of visual information). That is why the processes of memory formation should allow for the possibility of "portioned" construction of objects models and class models by parts.

In different processes of information processing, objects are represented by one of the two means: by a name (convergent representation) or by a set of meanings of attributes (displayed representation). The structure of memory should provide convenient transition from one representation to another.

Systems, in which the perception of new information is accompanied by simultaneous structuring of the information stored in memory, are called **self-structured** [Gladun et al, 2008]. Self-structuring provides a possibility of changing the structure of stored in memory data during the process of the functioning because of interaction between the received and already stored information.

The building of self-structured artificial systems had been proposed to be realized on the basis of networks with hierarchical structures, named as "***growing pyramidal networks***" (**GPN**) [Gladun et al, 2008]. The theory as well as practical application of GPN was expounded in a number of publications [Gladun, 1987], [Gladun, 1994], [Gladun, 2000], [Gladun and Vashchenko, 2000].

Pyramidal network is a network memory, automatically tuned into the structure of incoming information.

Unlike the neuron networks, the adaptation effect is attained without introduction of a priori network excess. Pyramidal networks are convenient for performing different operations of associative search. Hierarchical structure of the networks, which allows them to reflect the structure of composing objects and gender-species bonds naturally, is an important property of pyramidal networks. The concept of GPN is a generalized logical attributive model of objects' class, and represents the belonging of objects to the target class in accordance with some specific combinations of attributes. By classification manner, GPN is closest to the known methods of data mining as decision trees and propositional rule learning.

GPN realization has following stages:

- building the structure of a network for some initial set of objects, assigned by attributive descriptions;
- training the structure, with a purpose to allocate its elements, allowing classifying all objects of the initial set;
- recognizing the belonging to some class of objects of certain object, which not belongs to initial set of objects.

The growing pyramidal networks respond to the main requirements to memory structuring in the artificial intelligent systems [Gladun, 2003]:

- in artificial intelligent systems, the knowledge of different types should be united into net-like structure, designed according to principles common for all types of knowledge;
- the network should reflect hierarchic character of real media and in this connection should be convenient for representation of gender-type bonds and structures of composite objects;
- obligatory functions of the memory should be formation of association bonds by revealing intersections of attributive object representations, hierarchic structuring, classification, concept formation;
- within the network there should be provided a two-way transition between convergent and displayed presentations of objects.

The research done on complex data of great scope showed high effectiveness of application of growing pyramidal networks for solving analytical problems. Such qualities as simplicity of change introduction the information; combining the processes of information introduction with processes of classification and generalization; high associability makes growing pyramid networks an important component of forecasting and diagnosing systems, especially in the area of GMES. The applied problems, for solving of which GPN were used are: forecasting new chemical compounds and materials with the indicated properties, forecasting in genetics, geology, medical and technical diagnostics, forecasting malfunction of complex machines and sun activity, etc. Special kind of applications is aimed to support intelligent data processing in GMES.

14.1.1 GPN theoretical foundations

The word "object" here and further is understood in a broad sense is there can be a real physical object, some process, a situation, etc.

The model of classes of the objects, used for the decision of tasks of classification, diagnostics and forecasting, should include all the most important attributes describing a class. The model also should display for this class the characteristic logical connections between essential attributes. Therefore, the basic attention concentrates on formation of the generalized logical multivariate models of objects classes. Such models, in fact, are the concepts that correspond to the classes of objects [Voyshvillo, 1967], [Gorskii, 1985].

The concept is usually defined in logic as an idea that reflects essence of objects. Most of used concepts are the result of generalization of attributes that characterizes the objects of the class.

The concept "attribute" can be used for characterizing the objects and can be used in such logic operations as extraction, recognition, identification, etc. It is necessary to note, that separation of attributes on essential and unessential is conditional and depends on problems for which decision they are used.

✓ Concept

From a philosophical point of view, the concept consists of two parts – extensional and intensional:

- extensional part covers all instances belonging to this concept;
- intensional part includes all the properties that representative to these instances.

The connections between instances and their attributes play an important role in determining the hierarchical relationship between concepts and attributes.

The set of the instances, generalized in concept, constitute the volume of defined concept. In system of knowledge, the concepts play a role of base elements for composing propositions and other logic forms of thinking. Transition from a sensual step of cognition to abstract thinking, actually, means transition from reflection of the world in the form of perception and presentations to its reflection in concepts.

Classification, generalization, structuring of the perceived information, its inclusion in system of knowledge, is carried out based on an available set of concepts. In these processes two basic functions of concepts: recognition and production of the elements models of the world, in which the bearer of knowledge operates, are realized. Recognition processes became for a long time object of research and automation while production of models for the present is little-investigated problem. Production of models plays the important role in creative activity. Only by a concrete definition of concepts we can create (for example, to draw) images of concrete houses, trees, cars, etc. Production of elements models of the world underlies designing of the engineering objects.

Attributes belonging to concept by their role in realization of the basic functions of concept divide on two types – disjunctive and unified:

- disjunctive attributes are attributes, which do not occur or occur seldom in concepts volume. These attributes are most effective at realization of recognition functions;
- unified attributes are those attributes, which are inherent in all or many elements of concept volume refer to, but they can be widespread and outside of concept volume. Without these attributes, the production of elements models of the world is impossible.

For example, for all birches such attributes, as presence of a trunk, roots, and crown are characteristic. It their unifying attributes which are inherent in all trees. A well-known disjunctive attribute of birches is white color of a bark.

The degree of detailed elaboration of model created based on concept depends on the purpose of a task. The model of the bridge created at the decision of a task "to draw a bridge", essentially differs on a degree of detailed elaboration from the model of the bridge created at the decision of a task "to design the bridge".

The success of the decision of the problems including production of models depends on that, how much used concepts correctly and full characterize corresponding classes of elements of the world.

Now, it is possible to give more constructive definition of concept, more suitable by consideration of information-technical aspects of problems of formation and processing of concepts.

Concept – an element of the knowledge system, representing the generalized model of some class of instances.

In processes of recognition and production of models, the concept is used as logic function of the attributes, having the value "true" for instances from volume of concept and value "false" in other cases.

✓ System of concepts

The set of concepts included in the system of knowledge, will be called the system of concepts of knowledge bearer.

Systems of concepts are hierarchical, as a rule. Volumes of concepts of all levels of hierarchy, except for bottom, are formed by consolidation of volumes of some concepts of lower levels. For example, the volume of concept "fruit" unites volumes of concepts "apple", "pear", etc.

Systems of concepts are dynamical. The structure of concepts varies because of interaction of their bearers with an environment, and during the decision of problems.

At each moment of time, the state of system of concepts reflects individual experience of its bearer. Therefore, separate concepts and systems of concepts in the whole are subjective.

Any system of concepts by virtue of the discreteness, limitation of structure of concepts, imperfection of separate concepts cannot reflect variety and a continuity of the real world. Volumes of the concepts which have been not introduced "by definition", as a rule, have no precise dividing boundaries. There are many of the transitive forms that complicate carrying out of conditional boundaries between volumes of concepts. There are many transitional forms that complicate definition of conditional boundaries between volumes of concepts.

Because of incompleteness of the world mapping in concepts system, and of concepts subjectivity, univocal identification of elements of the world based on concepts system often appears inconvenient or even impossible. Therefore, volumes of many concepts can be considered as fuzzy sets. Each bearers of concepts system possesses the membership function, which, thus, has subjective character.

✓ Inductive formation of concepts

From logic structure point of view, the concepts are categorized as:

- conjunctive concepts, which can be described by conjunction of attributes;
- disjunctive concepts, which can be described by disjunction of conjunctions of attributes;
- concepts with the exclusive attributes, reflecting absence of some attributes in the instances, which belongs to concept volume.

The concepts, included in everyday practice, usually are conjunctive. More complex logic structure is characteristic for the concepts, formed in the research process.

In this case, the logical complexity of the concepts usually arises following circumstances:

- the attributes space is incorrectly chosen;
- training set is incomplete reflects specificity of concept volume;
- the volume of formed concept consists of instances that are vastly different from each other.

Consider a task of inductive formation of concepts for not intersected sets of objects $V_1, V_2, \ldots, V_n$, , each set represents some class of objects with known properties. Let L – the set of objects used as training set. All the objects of set L are represented by sets of attribute values. Relations $L \cap V_i \neq \varnothing$ and $V_i \not\subset L \left(i = 1,2,\ldots,n\right)$ take place. Each object from set L corresponds to one of set V_i. It is necessary to generate n concepts by analysis L. The amount of these concepts must be sufficient for correct recognition of belongings of anyone $l \in L$ to one of set V_i.

In forming the concept corresponding to set V_i, the objects of training set included in V_i, are considered as examples of set V_i, and the objects, not included in V_i, – as counterexamples of set V_i.

Each concept, generated on the basis of training set, is approximation to real concept. The proximity of concepts depends on representativeness of training set, i.e. on the detailization of the concept volume peculiarities.

Problem of inductive formation of concepts is similar to the problem of learning pattern recognition. And in both cases as a result of learning a model of a class of objects is constructed. At formation of concepts stronger requirements are made to this model (concept). It must provide not only recognition, but also the opportunity to generate models of concrete objects. In this regard, the model should be reflected attributive, structural, and logical characteristics of objects.

The training set usually has the tabular form. The rows of the table correspond to the set of objects properties, columns – to attributes. Names of classes are specified in a special column. The concept, which is formed because of the analysis of the training set, is usually described by a logical expression in which the variables are the names of the attributes values.

Known methods of formation of concepts [Gladun, 1987] [Bongard, 1967], [Vagin, 1988], [Gladun and Vashchenko, 1995], [Pospelov, 1986], [Gladun and Rabinovich, 1980], [Gladun and Vaschenko, 1995], [Michalski et al, 1986], [Piatetsky-Shapiro and Frawley, 1991] as a matter of fact are methods of controlled choice of the attributes values that characterize the classes of objects. The choice can be simplified due to use of adequate representation of the analyzed information.

14.1.2 Requirements to the methods of concepts formation

During the work, following requirements to the methods of concepts formation are revealed:

- for increasing the reliability of the diagnosis or the forecast, it is necessary to consider dependence of the defined variable from combinations of known attributes, i.e. to consider joint simultaneous influence of attributes. The formed concept should reflect such dependences;
- depending on a choice of a method of training for concepts of the same class of objects various logic descriptions can be received. Naturally, there is a question on quality of logic models. The best results of application of concepts for classification, diagnostics, and forecasting, as a rule, correspond to more generalized concepts, i.e. concepts that are described by more simple logic expressions. Degree of complexity of logic expression can be estimated by the number of its variables. The method of concepts training should provide formation of as more as possible simple concepts;
- choice operations, such as a choice of values of properties, objects, combinations of values of signs, etc., prevail in processes of knowledge mining. It is a combinatory problem. The volume and time of choice operations quickly grows with increase amount of data. This effect of "information explosion" blocks practical application of many methods. In this connection, there is a necessity for use the network structures reducing amount of search operations at realization of processes of knowledge mining.

14.1.3 Requirements to the network structure used for the knowledge mining

The key enabler of increase of search operations efficiency is use of network structures for modeling environments in which problems solving. Orientation to real applied environments essentially raises a level of requirements to network models. We shall define the features of real environments rendering strong influence on processes of the problems solving:

- multicoupling. Real environments usually include many objects connected by a lot of relations;
- heterogeneity. For real environments the variety of objects and relations is characteristic;
- hierarchy. In real environments it is necessary to operate with the compound objects representing compositions of more simple objects;
- dynamism. Real environments are usually subject to frequent changes.

Given the above features of real environments, we formulate requirements to the network structure, representing the environment.

- the network should possess the developed associative properties, i.e. to provide effective performance of various search operations;
- the network should reflect the hierarchy of real environments and therefore should be convenient to represent genus-species relations and structures of composite objects;
- in a network the means limiting zones of search by time, spatial or substantial criteria should be stipulated, i.e. the network should provide selectivity of search on a time, spatial or meaningful context;
- at construction of a network the classes of objects and situations should be formed; input of the new information into the network must be accompanied by the classification process;
- the network should allow parallel execution of search operations.

14.2 Pyramidal networks

The set forth above requirements are answered to the full with pyramidal networks [Gladun et al, 2008].

A growing pyramidal network (GPN) is an acyclic oriented graph having no vertexes with a single incoming arc. Examples of the pyramidal networks are shown in figures below. Vertices having no incoming arcs are referred to as ***receptors***. Other vertices are named ***conceptors***. The ***subgraph*** of the pyramidal network that contains vertex **a** and from all the vertices that belong to subgraph there are paths to vertex **a** is named the pyramid of vertex **a**. The set of vertices contained in the pyramid of vertex **a** is referred to as the ***subset*** of vertex **a**. The set of vertices reachable by paths from vertex **a** is named the ***superset*** of vertex **a**. The set of vertices that are connected with paths to vertex **a**, is referred to its superset.

In subset and superset of the vertex, ***0-subset*** and ***0-superset*** are allocated, consisting of those vertices, which are connected to it directly.

When the network is building, the input information is represented by sets of attributes values describing some objects (materials, states of the equipment, a situation, illness etc.). Receptors correspond to values of attributes. In various tasks, they can be represented by names of properties, relations, states, actions, objects or classes of objects. Conceptors correspond to descriptions of objects in general and to crossings of descriptions and represent GPN vertices.

14.2.1 Building of GPN

Initially the network consists only of receptors. Conceptors are formed as a result of algorithm of construction of a network. After input of object attribute description, corresponding receptors switch to a state of excitation. The process of excitation propagates through the network. A conceptor switches into the state of excitation if all vertices of its 0-subset are excited. Receptors and conceptors retain their state of excitation during all operations of network building.

Let $\mathbf{F_a}$ be the subset of excited vertices of the 0-subset of vertex **a**; **G** be the set of excited vertices in the network that do not have other excited vertices in their supersets. New vertices are added to the network by the following two rules:

Rule A1. If vertex **a**, that is a conceptor, is not excited and the power of set $\mathbf{F_a}$ exceeds 1, then the arcs joining vertices of set $\mathbf{F_a}$ with the vertex **a** are liquidated and a new conceptor is added to the network which is joined with vertices of set $\mathbf{F_a}$ by incoming arcs and with the vertex **a** by an outgoing arc.

The new vertex is in the state of excitation. Rule A1 is illustrated in Figure 171(a,b). According to the Rule A1, the condition for adding a new vertex to the network is a situation, when certain network vertex is not completely excited (at least two vertices of 0-subset are excited). Figure 171(a) shows a fragment of network in some initial state. Receptors 4, 5 switch to a state of excitation, the network switches to state (b), and a new vertex appears – a new conceptor. Receptors 2, 3 switch to a state of excitation additionally. The network switches to state (c).

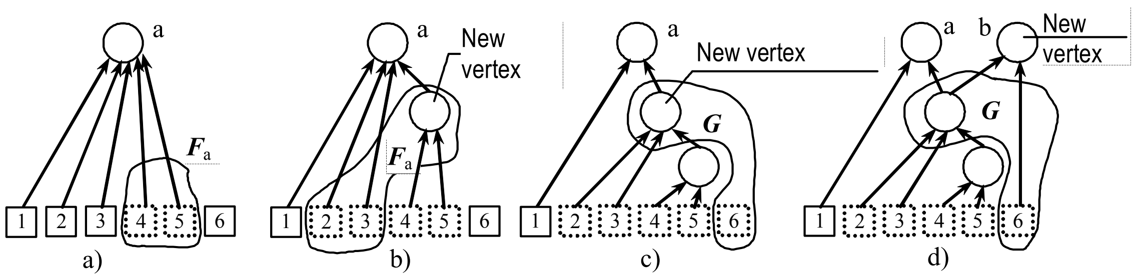

Figure 171. Pyramidal network building

New vertices are inserted in 0-subset of vertices, which are not completely excited. New vertices correspond to intersection of object descriptions, represented by incoming arches. Once new vertices have been introduced into all network sections where the condition of rule A1 is satisfied, rule A2 is applied to the obtained network fragment, concluding the object pyramid building.

Rule A2. If the power of set G exceeds 1 element, a new conceptor is added to the network, which is joined with all vertices of set G by incoming arcs.

The new vertex is in the state of excitation. Rule A2 is illustrated in Figure 171(c,d). The state (d) was obtained after the excitation of receptors 2-6.

In applying the Rule A1 the main cross-linking relation is a relation of intersection of receptor set, excited by input of the object description and other sets of receptors included into pyramid, recently formed by conceptors. Rule A2 concludes the building of pyramid, which represents complete description of the introduced object.

✓ Properties of a pyramidal network

Let us note some properties of pyramidal networks.

Depending on applied area in which networks are used, the receptor can represent the attribute value, the elementary fact from the description of a situation, value of an economic parameter, a symptom of illness, the letter, a word, etc. Conceptors correspond to descriptions of objects, situations, realizations of processes or the phenomena, words, phrases, plans, and also crossings of descriptions.

The pyramidal network is the network memory, which is automatically customized on structure of the input information. Optimization of the information representation due to adaptation of network structure to structural features of entrance data is as a result reached. In addition, unlike neural networks, the effect of adaptation is reached without introduction of aprioristic redundancy of a network.

Pyramidal networks are convenient for execution of various operations of associative search. For example, it is possible to select all the objects that contain a given combination of attribute values by tracing the paths that outgo from the network vertex corresponding to this combination. To select all the objects whose descriptions intersect with the description of a given object it is necessary to trace the paths that outgo from vertices of its pyramid. Rules A1, A2 establishes associative proximity between objects having common combinations of attribute values.

Hierarchical organization is an important property of pyramidal networks. This provides a natural way for reflecting the structure of composite objects and generic-species interconnections.

The algorithm of a network building provides an automatic establishment of associative affinity between objects based on common elements and their descriptions. All the processes connected with a network building at processing one description are localized in rather small part of a network – a pyramid corresponding to this description. The important property of semantic networks of pyramidal structure is their hierarchy allowing naturally mapping structure of compound objects and genus-species relations.

Conceptors of the network correspond to combinations of attribute values that define separate objects and conjunctive classes of objects. By introducing the excited vertices into the object pyramid, the object is referred to classes, which descriptions are represented by these vertices. Thus, during the network building the conjunctive classes of objects are formed, the classification of objects is performed without a teacher. Classifying properties of pyramidal network are vital for modeling environments and situations.

Profitability is also the advantage of pyramidal networks, because identical combinations of attributes values several objects are represented in network by one common pyramid.

In a pyramidal network, the information is stored by its mapping in structure of a network. The information on objects and classes of objects is presented by vertex ensembles (pyramids) distributed on all network. Entering of the new information causes redistribution of links between vertexes, i.e. change of network structure.

Certainly, the full advantages of pyramidal networks are appeared at their physical realization supposing parallel distribution of signals on a network. The important property of a network as means of storage of the information is that the opportunity of parallel distribution of signals is combined with an opportunity of parallel reception of signals on receptors.

This property appears useful at applications of pyramidal networks in robotic systems, the automated systems of scientific researches, systems of the automated designing. Conversion from converged representation of objects (conceptors) to expanded (sets of receptors) is performed by scanning pyramids in top-down and down-top directions.

✓ Concept formation in a pyramidal network

Training GPN consists in formation of the structures representing concepts, on a basis of attributive descriptions of the objects incorporated into classes with known properties.

Concept is an element of knowledge system, representing generalized logic attributive model of objects class. This model is used in processes of objects recognition. The set of objects generalized in concept is its volume.

The combinations of attributes allocated in ready-built pyramidal network, representing descriptions of objects of training set, are used as "a building material", a basis of further logic structure of concept.

Let L be the pyramidal network representing all of training set objects. For formation of concepts $A_1, A_2, \ldots, A_i, \ldots, A_n$ corresponding to sets $V_1, V_2, \ldots, V_i, \ldots, V_n$, pyramids of all objects of training set are scanned in order. The vertices of scanned pyramid during its scanning are considered excited. Special vertices in network are identified in order to recognize objects from the concept volume. They are referred to as check vertices of a certain concept. At performance of inductive generalization, it is natural that the most important attribute or the combination of attributes describing group of objects – concept A_i, those vertex from pyramid A_i, which meet in pyramid A_i more often. Such attributes (or their combinations) are necessary for noting as check vertices. Check vertices are used in the further at decision about belonging of a new object to the concept. If in a pyramid of concept A_i there are some vertices, which include into equal quantity of objects from the given concept volume, it is natural to choose from the given vertex such, which unites maximal quantity of attributes (receptors) from a concept pyramid. This vertex defines the most typical combination of attributes of the objects incorporated into concept. In selecting the check vertexes, two characteristics of network vertices are used:

- $\{m_1, \ldots, m_i, \ldots m_n\}$, where m_i $(i = 1,2,\ldots,n)$ is a number of objects of volume of concept A_i, which pyramids include the given vertex;
- k is the number of receptors in the pyramid of this vertex.

For receptors $k = 1$. While scanning, the pyramid is transformed by the following rules:

Rule B1. If in the pyramid of an object from concept volume A_i, the vertex, having the largest k among all the vertices with the largest m_i, is not a check vertex of concept A_i, then it is marked as a check vertex of the concept A_i.

The rule allows existence several vertexes among the excited vertexes with identical m_i, exceeding m_i of other excited vertexes. If in group of the vertexes having largest m_i, values k of all vertexes are equal, any of vertexes can be marked as check vertex of concept A_i.

The rule B1 is illustrated in Figure 172. In this situation, vertex 6 is selected as check vertex, because it has the largest k among vertices with the largest m_i (6, 13, 14). Values m_i are shown inside symbols of vertices.

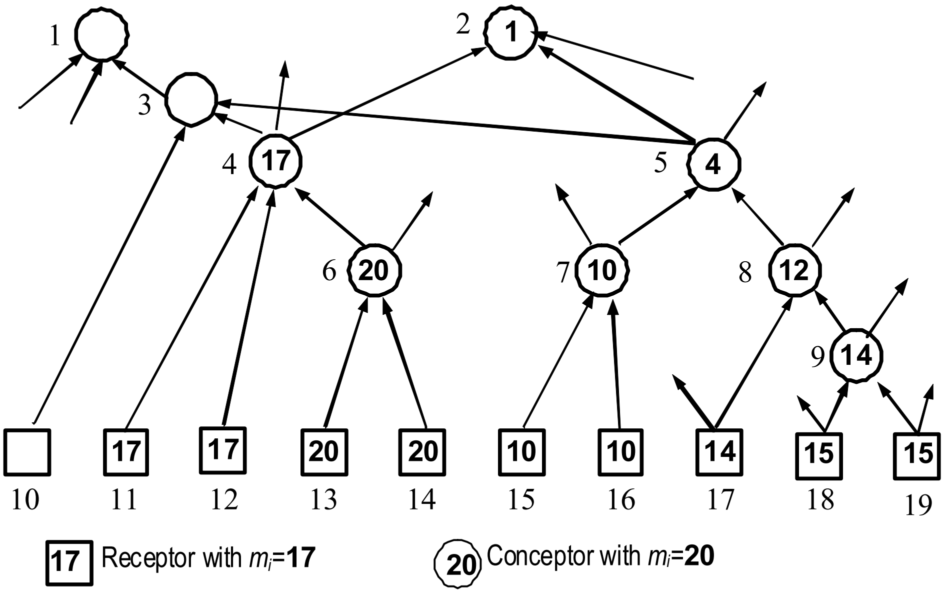

Figure 172. Forming of pyramidal growing network – rule B1

Rule B2. If the pyramid of an object from concept volume A_i contains check vertices of other concepts whose supersets do not contain excited check vertices of concept A_i, then in each of these supersets the vertex, having the largest k among all excited vertices with the largest m_i, is marked as a check vertex of concept A_i.

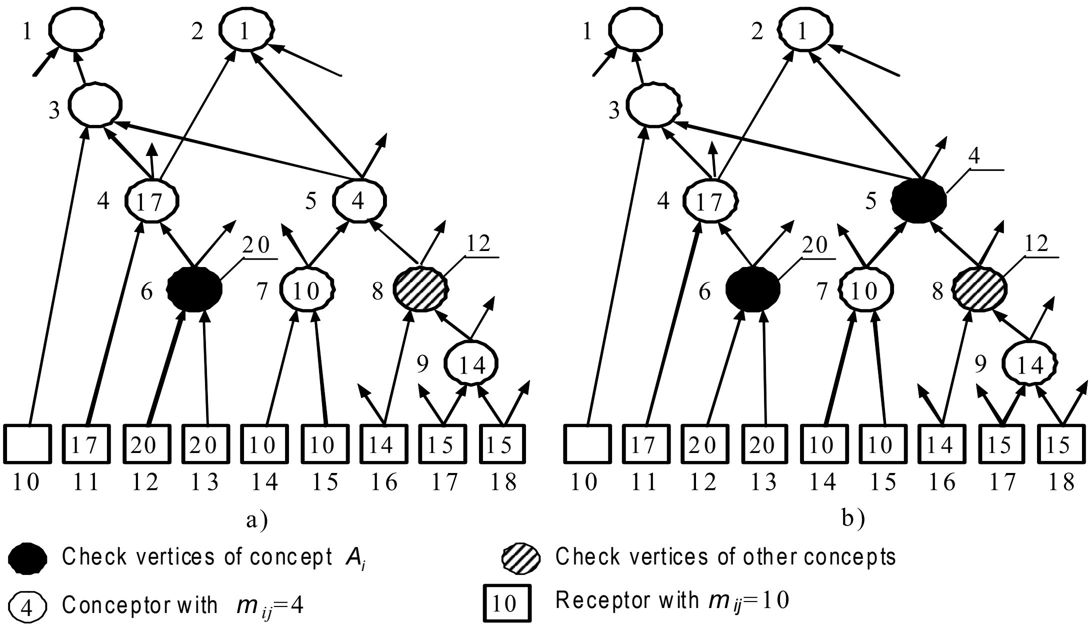

Figure 173. Forming of pyramidal growing network – rule B2

According to this rule the excitation of the pyramid of vertex 2 (Figure 173a) on the condition, that it represents an objects from concept volume A_i, results in choosing vertex 5 as the check vertex of concept A_i (Figure 173b). By check vertexes we select the most typical (having the largest m_i) combinations of attribute values, belonging to objects from concept volume. For example, selecting the vertex 8 as a check vertex means selection of combination of value attributes, corresponding to receptors 17, 18, 19.

If at least one new check vertex appears while scanning objects of the training set, i.e. conditions of Rules B1 or B2 have been performed once at least, the training set is rescanned. The algorithm stops if during the scanning of the training set no new check vertex appears.

14.2.2 Recognition on basis of GPN

The task of recognition is based on the following rule.

Certain object belongs to the concept volume A_i if its pyramid has check vertexes A_i and does not contain check vertices of any other concept not having excited check vertices of concept A_i concept in their supersets. If this condition does not hold for any of the concepts, the object is referred to as unrecognized.

The execution time of the above algorithm is always finite. If the volumes of the formed concepts $V_1, V_2, \ldots, V_i, \ldots V_n$ do not intersect, than after execution the algorithm the recognition rule completely divides the training set into subsets $L_i = V_i \cap L\left(i = 1 \ldots n\right)$

The formed concepts are represented in the network as ensembles of check vertices.

There is an algorithm [Gladun, 1987] of composing the logic descriptions of concepts, formed in the network as a result of the training process, described above. The formed logical expression contains logical relations, represented by allocation of check vertices, describing the concepts in the network, defining different classes of objects.

For example, the concept, presented on Figure 173b check vertices with numbers 5 and 6, by following expression is described:

$$(12\wedge13)\vee(14\wedge15)\wedge\neg(16\wedge17\wedge18).$$

The analytical tasks, such as diagnostics or forecasting, can be reduced to the task of classification, i.e. to belongings the research object to a class of objects, with a property characteristic or a set of properties significant for prognosis

Classification of new objects is performed by comparing the attribute descriptions with the concept, defining a class of predictable or diagnosing objects. Objects can be classified by evaluating the value of the logical expressions that represent corresponding concepts. The variables, corresponding to the attribute values of the recognized object, set 1, other variable set 0. If the entire expression possesses the value 1 which means the object is included into volume of concept.

In concept, which is formed by algorithm, the general essential attributes of objects from volume of concept and logic relations between attributes are reflected. Unifying attributes are allocated as a result of performance of rule B1. At performance of rule B2 disjunction attributes are allocated.

An important distinction of a method of concepts formation in growing pyramidal networks is the possibility to introduce in concepts the so-called excluding attributes which do not correspond to objects of a researched class. As a result, the formed concepts have more compact logic structure, which allows increasing the accuracy of diagnosis or forecasting. In logic expression the excluding attributes are presented by variables with negation.

All search operations in growing pyramidal network are limited to rather small fragment of a network, which includes an object pyramid and vertices directly linked to it. As a result, we have a possibility solve practical analytical problems based on large-scale data.

14.3 Program complex CONFOR

Methods for solution of regularities discovery tasks based on pyramidal networks, and methods of using of the retrieved regularities for decision making described in the previous section are implemented in program complex CONFOR (Abbreviation of CONcept FORmation). In the case of decision-making in risk management, the described objects are assigned to specific disasters and / or emergent situations. This makes it possible to apply universal approach of growing pyramidal networks to analysis of attributive risk management and disaster emergencies.

Let us consider briefly basic functions and structure of a program complex.

14.3.1 Architecture of CONFOR

The basic functions of program complex CONFOR are:

- discovery of regularities (knowledge) inherent to data;
- using of the retrieved regularities for object classification, diagnostics and prediction.

Main program unit and interrelations between subsystems are presented on Figure 174.

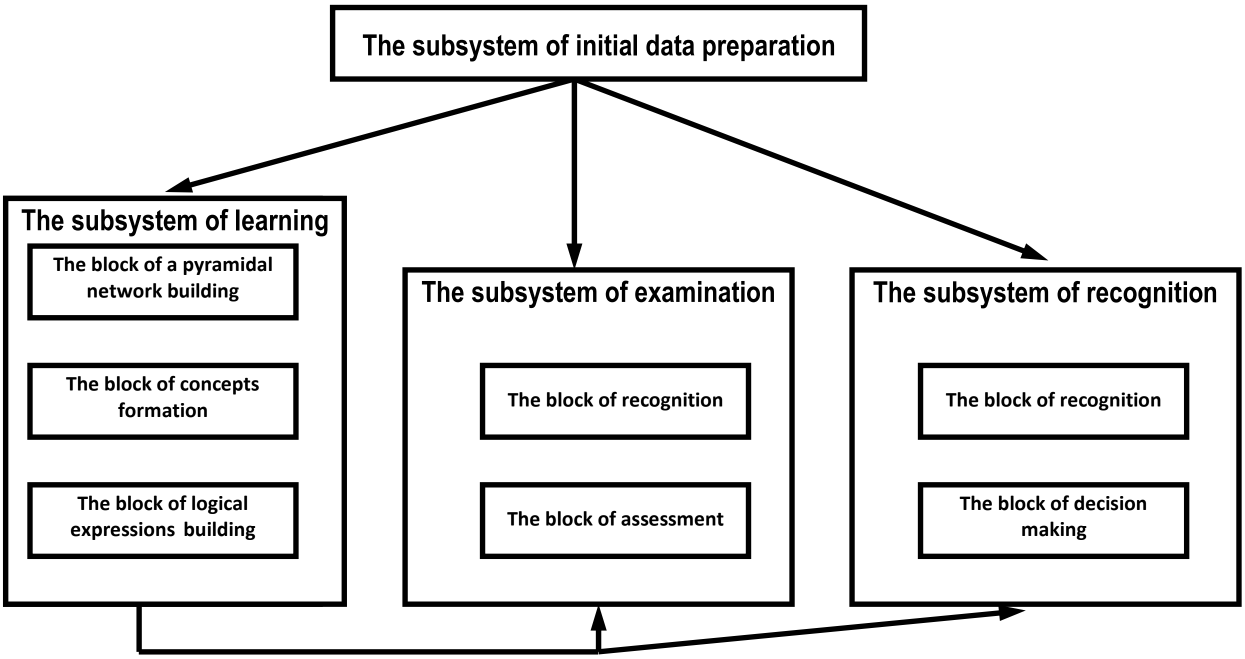

Figure 174. The structure of program system CONFOR

The program complex CONFOR includes following subsystems:

1. Subsystem of initial data preparation.
1. Learning subsystem.
2. Examination subsystem.
3. Recognition subsystem.

14.3.2 Initial data preparation subsystem

The subsystem of data preparation can be functionally extracted in the separate block though it is an integral part of subsystems of training, examination, and recognition. The subsystem realizes multitude of the operations, allowing entering attributive descriptions of situations directly from the screen or from the previously prepared text file.

The subsystem will transform the entered information in the form of training, examination, or recognition set, to internal representation, which is used for construction or the analysis of a pyramidal network.

Objects of the training, examination, or recognition set are represented by attribute descriptions, i.e. by sets of attribute values.

Before operating with the system, it is necessary to:

- choose the set of attributes that will be used for describing investigated objects;
- specify for every attribute a set of its values. Attribute values can be given in numerical, Boolean or nominal scales. Numerical attributes must be discretized, that is divided into subintervals;
- describe objects using the chosen attribute values, that is for every object specify its value for every attribute;
- specify for every object (of the training and examination set) the class name that the object belongs to.

The entered attribute descriptions of situations are displayed on the screen in the form of the table, owing to what it is convenient for supervising and editing.

Input attribute descriptions of situations from the screen is provided with a following set of functions: Add Column, Add Row, Delete Column, Delete Row, Rename Column.

Input attribute descriptions of situations from the previously prepared text file is carried out by means of function "Import". The test file can be prepared outside of a tool by means of the text editor in the form of a *.txt-file according to strictly certain syntax: the first line – heading; lines-descriptions of objects further follow; each line comes to an end with a symbol "line feed"; elements of a line are separated by a symbol "a comma (,)"; unknown values of attributes fall, but the divider (,) is put, i.e. empty value is designated as ","; for a designation of a fractional part of a quantitative attribute the "point (.)" is used.

After input of descriptions of situations (from the screen or from a file), the columns containing a name of object (situation) and a name of a class (type of situation) should be marked in appropriate way. With this purpose, next functions are used: to choose a column "Object"; to choose a column "Class".

The specified functions expand opportunities of a tool as research system, allowing investigating the same training set from the various points of view, easily changing an attribute, which serves as a name of a class.

14.3.3 Learning subsystem

Subsystem of learning realizes the discovery of the regularities that characterize the class of emergency. Input data for a subsystem of learning is served training set, which includes examples of the situations, described as various types (classes). Each class of situations should be presented by a quantity of examples; sufficient that based on them the regularity describing the given class has been allocated. Examples of situations are represented by set of attributive descriptions. Attributive description of a situation should include a name of a situation, a class to which the situation belongs, and a set of attributes values, which characterize a situation.

Output data for a subsystem of learning is served regularities, which characterize classes of disasters situations.

Process of learning consists of following stages:

- representation of initial data in the form of a pyramidal network;
- concepts formation on the basis of a pyramidal network;
- construction of the logic expressions corresponding generated concepts.

✓ Block of pyramidal network building

The block of a pyramidal network building realizes the first stage of process of training when internal representation of training set objects will be transformed to a pyramidal network.

As the basic process at regularities extraction is search of combinations of the attributes values describing groups of similar objects, as a rule, it is necessary to look through repeatedly objects training set that with growth of objects number and of number of attributes values leads to "information explosion". Representing of data in the form of a pyramidal network allows to avoid this danger, first of all, due to features of algorithm of the network building providing allocation of the common combinations of attributes values during input of objects in a network, and also due to associativity and hierarchy of the network. Only two viewings of training set are necessary for full a network building.

The pyramidal network is dynamic structure, which is restructured depending on the incoming information. The network consists of two types vertices: receptors and conceptors. Receptors correspond to values of attributes. In various tasks, they can be represented by names of properties, relations, states of the equipment, a situation, actions, objects, or classes of objects. Receptors have no input connections.

Conceptors correspond to crossings of objects descriptions and to descriptions of objects in general and represent GPN vertices. Conceptors of the first type is named as intermediate vertices and have input and output connections. Conceptors of the second type – the main vertices, which can have output connections only in that case when the description of the object, corresponding the given main vertex, is a part of the description of some other object.

The main process of a pyramidal network building, at which in a network the common combinations of attributes values (all intermediate vertices are building) are fixed, is realized even at the first viewing of objects descriptions of training set. At the second viewing, the network only is corrected to provide unequivocal representation of each object in the form of a separate pyramid (with one main vertex). At network building objects of training set are entered into a network serially and thus the description of the next object is compared to those objects of training set which already have been entered into a network. Comparison is carried out by tracing output connections of receptors from the description of considered object in a direction to the main vertices of pyramids. Tracing is carried out by consecutive transition from the analysis in vertex of lower level of a network to the analysis of higher level.

During tracing it is formed and corrected TBC (the table of target communications) in which pairs analyzed units in the form of "the subordinated vertex – the subordinating vertex" are fixed. The "excited" fragment of a network, which is already constructed fragment of a network, which includes receptors from the description of considered object, is as a result allocated.

Thus are fixed both completely excited vertices of a network, and partially excited. Vertex at which all input connections conduct from receptors from the description of selected object is considered as completely excited. At partially excited vertex from receptors from the description of selected object, two input connections conduct, at least. Other input connections can conduct from receptors, which correspond to the values of attributes not inherent in selected object.

If on a way of tracing of receptors output connections there are completely excited vertex, it means, that these vertex should be included in a pyramid of selected object, and process of tracing proceeds. At detection of partially excited vertex process of tracing in this direction is stopped. Process of tracing finally stops, when partially excited vertices and the "highest" completely excited vertices are revealed and fixed all. "Highest" completely excited vertices are named such completely excited vertices from which do not conduct output connections to other completely excited vertices.

As to the beginning of the second viewing in a network intermediate and main vertices are already constructed all, at this stage also calculation m_i is carried out for each vertex (m_i is the number of excitation for each i-th class). Number of excitation of vertex for some class to equally number of objects of the given class in which pyramids there is this vertex.

✓ Block of concepts formation

The block of concepts formation realizes process of regularities discovery proper. This block on the basis of the analysis of the constructed pyramidal network selects from the combinations of attributes values most essential to everyone class and determines connections between them. Vertices, which correspond to the selected combinations, were named control vertices.

The formed concepts are represented in the network structure as ensembles of check vertices, which belong to corresponding classes.

Process of concepts formation is carried out by consecutive updating formed concepts on each object of training set.

In spite of the fact that during updating training set is looked through some times, this process is carried out much more quickly, than process of a network building because each time the area of viewing is limited only to a pyramid of object. Pyramids are looked through "from top to down", i.e. in a direction from the main vertices to receptors. Process ends, when there are no conditions for occurrence of new check vertices, i.e. objects of training set are divided completely.

✓ Block of logical expressions building

The block of logical expressions building makes it possible to represent the generated concepts in the form of logic expressions. Each logical expression, which corresponds to concept, has as operands of attributes value by means of which situations were described, and as operators – conjunction, disjunction, and negation. Representation of concept in the form of logical expression is evident, is well interpreted, and can be used by the expert for the analysis with the purpose of deeper understanding of regularities, which are inherent in a object domain. Logical expressions' building is carried out consistently for each class, which objects are presented in training set. Generated logic expressions are written in a text file, which can be screened by a special command, or is read by means of a text editor.

After adjustment for the next class all check vertices of the given class are analyzed. Check vertices of a considered class are named by "positive" check vertices, all check vertices of other classes are considered "negative" in relation to a considered class. Construction of logic expression begins with ordering positive check vertices of a considered class in decreasing order m – their excitation numbers for the given class. Each "positive" control unit is a basis for formation of a corresponding disjunctive member of the logic expression, representing concept of the considered class.

Formation of each disjunctive member begins with even not considered check vertices with the greatest m. First of all in a text file the is written number m which corresponds to number of objects of the training set belonging the given class and containing in its description receptors, corresponding the chosen check vertex. Then in a text file the receptors of the pyramid of the selected node are written out, for which the pyramid is scanned in the direction "from top to down". In a text file receptors are bound by symbol of conjunction (&). Such conjunction we shall name base conjunction for a formed disjunctive member.

Further so-called conjunction-exceptions form for what in superset of positive check vertices search of the nearest negative check vertices is carried out. Nearest negative checked vertices are the vertices on a path to which from positive check vertices, there are no other check vertices. As negative checked vertices the vertices belonging to any other class are considered.

If those are not present in a network, in a text file the symbol of a disjunction (V) enters and formation of the next disjunctive member begins. If in superset of positive check vertex there are negative check vertices, formation of conjunction-exception proceeds by tracing out the receptors entering into a pyramid of negative check vertex, but without taking into account receptors which have entered into a pyramid of positive check vertex.

Written out receptors are united by the symbol of conjunction (V), undertake in brackets and join with earlier generated part of logical expression through symbols of conjunction (&) and negation (¬). The analysis of negative check vertices and formation of corresponding conjunction-exceptions also is carried out in order decreasing m, describing a class corresponding negative check vertex. In this case formation of a disjunctive member comes to end after the analysis of all check vertices which are negative in relation to the given positive check vertex.

After all positive check vertices of considered class are analyzed; changeover to formation of logic expression for a next class is carried out.

14.3.4 Examination subsystem

The subsystem of examination is intended for testing quality of a tool training and quality of training set. The quality of tool training depends from:

- qualities of tools used for training;
- a material for training, i.e. structure of objects of training set and a manner of their description.

As the algorithm of concepts formation based on a pyramidal network provides 100% division of learning set, testing of quality of tool training is reduced to check quality of training set by recognition of examination set objects. Comparison of objects recognition results of examination set to the information on a real accessory of situations to classes allows to judge about quality of a complex training.

The subsystem of examination includes following blocks:

- **block of recognition analyzing situations**, which do not enter into training set but for which their accessory to one of investigated classes is known;
- **block of an assessment**, which gives out the information on quantity of correct, wrong and uncertain answers of a subsystem.

The important feature of realizable process of recognition is the opportunity to give out uncertain answers when recognizable objects contain in the description a combination of receptors, characteristic simultaneously for different classes, or when recognizable objects are not similar to objects of training sample. A large number of incorrect and uncertain answers of a subsystem demonstrate the necessity continuation of the learning by improving of training set.

Process of recognition can be carried out both based on the analysis of the trained pyramidal network, and by means of the constructed logic expressions.

The block of an assessment compares with the results received at recognition of objects of training set, with the information on a real accessory of objects to classes and gives out a percentage of correct, wrong, and uncertain answers of a subsystem.

14.3.5 Recognition subsystem

The subsystem of recognition realizes second of the basic functions of a complex, namely, use of the regularities allocated in a learning stage for classification of new situations and outputting of the control decision on elimination of an unforeseen contingency.

The subsystem of recognition consists of following blocks:

- **block of recognition**, which allows to classify a new situation to one or another class;
- **block of decision making**, offering to the operator the recommendation at the choice of the operating decision with the purpose of normalization the contingency.

For recognition in a subsystem is used the same block, as in a subsystem of examination. The block of decision-making, as well as the block of assessment of examination results, can give out both exact and uncertain answers. As each class of objects of training set represents the contingency, identification of a new contingency is unequivocally connected with sequence of control actions on its normalization. Identification of an accessory of a new contingency to some class is the operator prompting. Operator makes the final decision on a choice of actions on normalization of a situation.

In case of the uncertain answer the subsystem gives out the additional information on that, how much distinguished situation is similar to the situations corresponding different classes, or absolutely not similar to situations from training set.

For an estimation of a similarity degree the function of confidence is used. This function is calculated based on the analysis of conjunctions involved in the recognition of this situation. Function of confidence reflects a percentage parity of conjunctions informativity, describing the regularities of different classes of situations.

14.4 Discussion

The main characteristic of the pyramidal networks is the possibility to change their structure according to structure of the incoming information. Unlike the neural networks, the adaptation effect is attained without introduction of a priori network excess. Pyramidal networks are convenient for performing different operations of associative search. Hierarchical structure of the networks, which allows them to reflect the structure of composing objects and gender-species bonds naturally, is an important property of pyramidal networks. The concept of GPN is a generalized logical attributive model of objects' class, and represents the belonging of objects to the target class in accordance with some specific combinations of attributes. By classification manner, GPN is closest to the known methods of data mining as decision trees and propositional rule learning.