4th International Conference and Expo on
Computer Graphics & Animation
September 25-26, 2017 Berlin, Germany

2-SIMPLEX PRISM AS A COGNITIVE GRAPHIC TOOL FOR DECISION-MAKING AND ITS JUSTIFICATION IN INTELLIGENT DYNAMIC AND GEOINFORMATION SYSTEMS

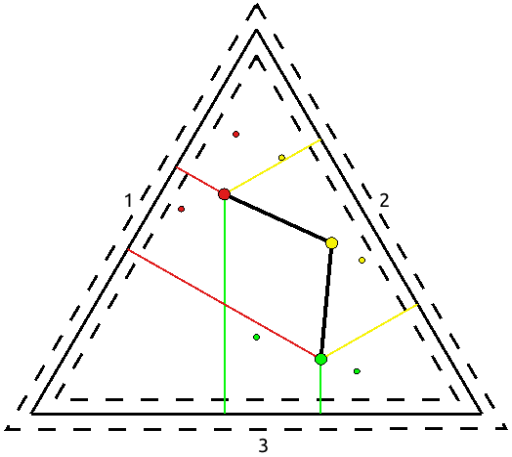
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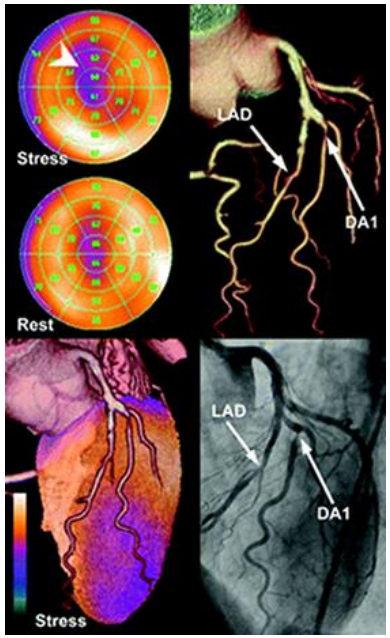
The research is funded by the Russian Foundation for Basic Research (project №16-07-00859)

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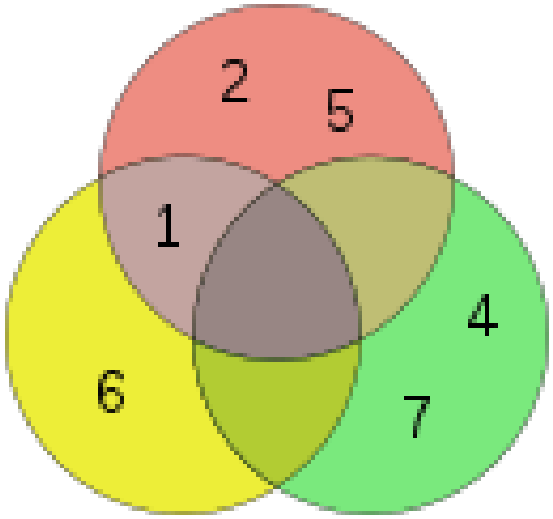
Introduction 1/1





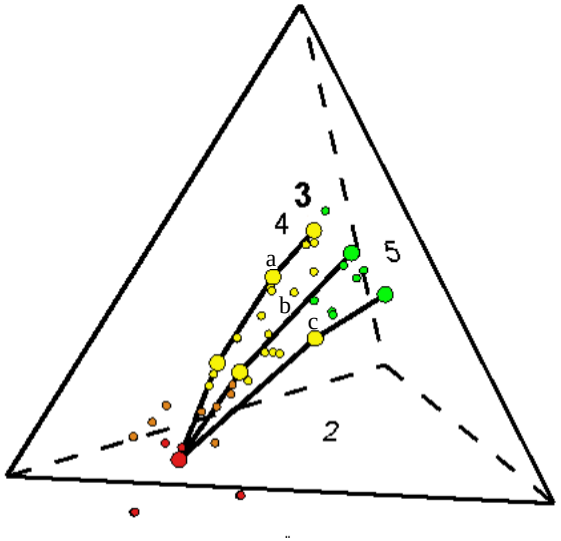
Cognitive Graphics Tools (CGT) are one of the directions of artificial intelligence. Cognitive Graphic was investigated and described by Pushkin in his monograph (1971). CGT were developed in the 80s of the XX century in the works of Pospelov and Zenkin (1991). A large number of CGT funds have been created and developed, including such persons as Finite Graphs and Networks (Basaker 1965), Cognitive Maps (Axelrod 1978), Cognitive Graphics System (Albu, Khoroshevskiy 1990), Medical CGT (Kobrinskiy 1996), Radar plots (Saary 2008), Chernov Faces (Raciborski 2009), the ternary diagram (Wang, Feng, Hoong Chu 2012), 2-simplex (Yankovskaya 1991) and others.

Introduction 1/2



CGT allow to represent the contents of the studied object or process on a computer screen.
CGT visually and clearly reflects the essence of a complex object (phenomenon, process), and is also capable of providing a fundamentally new decision (idea, hypothesis).
A remarkable example of unequivocal use of cognitive graphics tools is Leonhard Euler's "logical circles" (Euler Diagram or Venn Diagram), which are used to visually represent all basic sets and classes operations and to perform imaging of Aristotle's syllogistics.

Introduction 1/3



An important feature of CGT is targeted influence on the intuitive imaginative thinking mechanisms.
Dynamism represented by CGT can effectively represent the dynamics of the patterns of objects under investigation in time.
CGT allows to visualize the content of the problem of scientific interest and activate "the researchers to actively search for new knowledge with usage of higher creative mechanisms of thinking“ (Zenkin).

Introduction 1/4

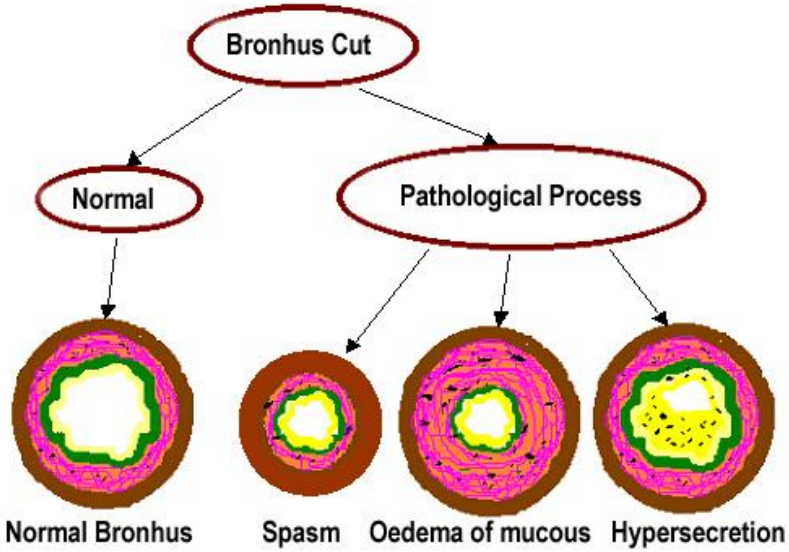
Currently, cognitive graphics tools are widely used in different areas of information technology for solving various problems in concrete and interdisciplinary problem areas, such as medicine (diagnosis of diseases, treatment and preventive measures, rehabilitation of patients as well as solving organizational and managerial problems), education, geology, engineering, electronics, sociology, psychology, psychiatry; ecobiomedicine; ecogeology.

Cognitive graphics tools are used in a variety of intelligent systems for analysis of information structures of knowledge and data, identification of different kinds of regularities in data and knowledge, and decision-making and decision justification, in intelligent training and testing systems for optimization of the learning process, for visualization and prediction of education process results, etc.

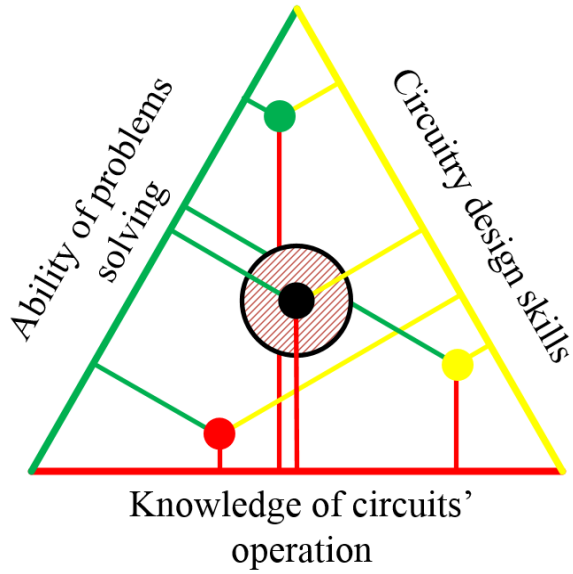
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Problem Background and Mathematical Basics of Intelligent Systems Construction 2/1



1) Simple tree data structure of pathological processes in bronchus (bronchial asthma)

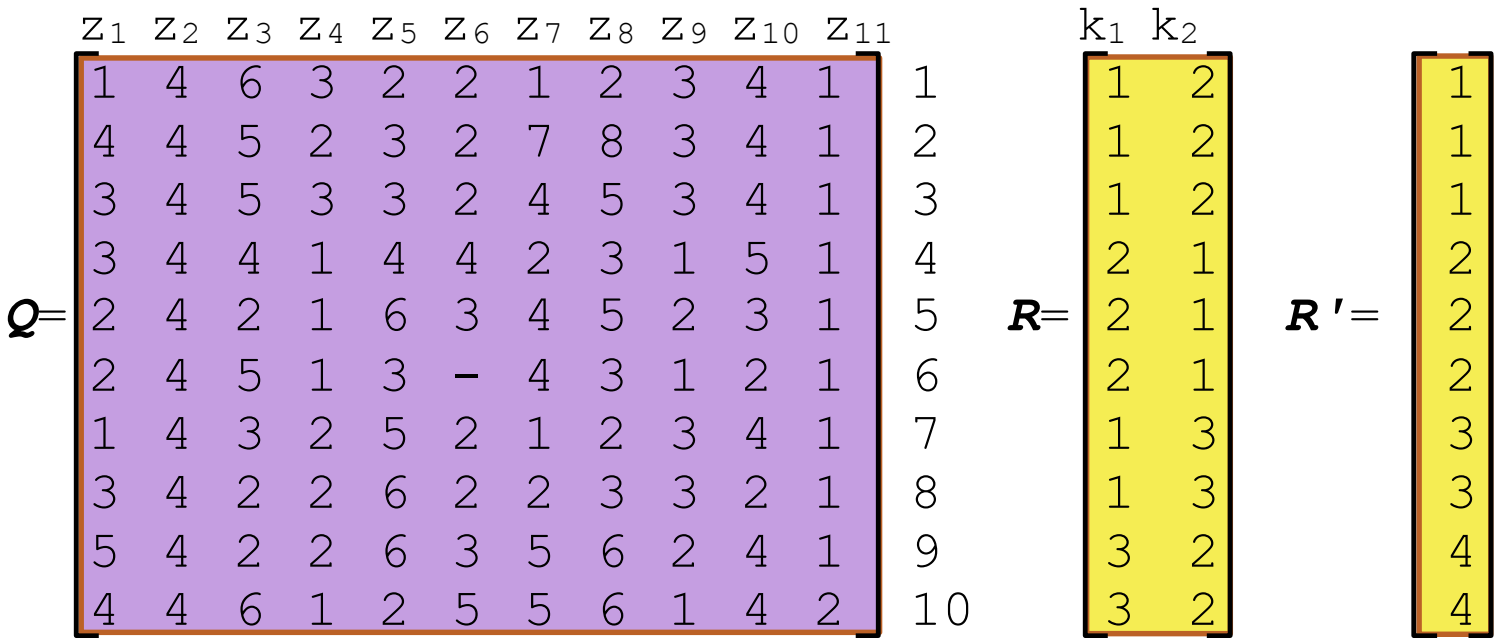


2) 2-simplex cognitive tool to estimate current level of students' knowledge

Classification of CGT by way of representation:
1) naturalistic, familiar graphic images of real objects are used as CGT
2) not having a mapping in the ordinary reality

Problem Background and Mathematical Basics of Intelligent Systems Construction 2/2

We use unusual matrix way for represented the data and knowledge.



Q – integer descriptions matrix

R – integer distinction matrix

R' – one-column matrix whose elements are the numbers of patterns.

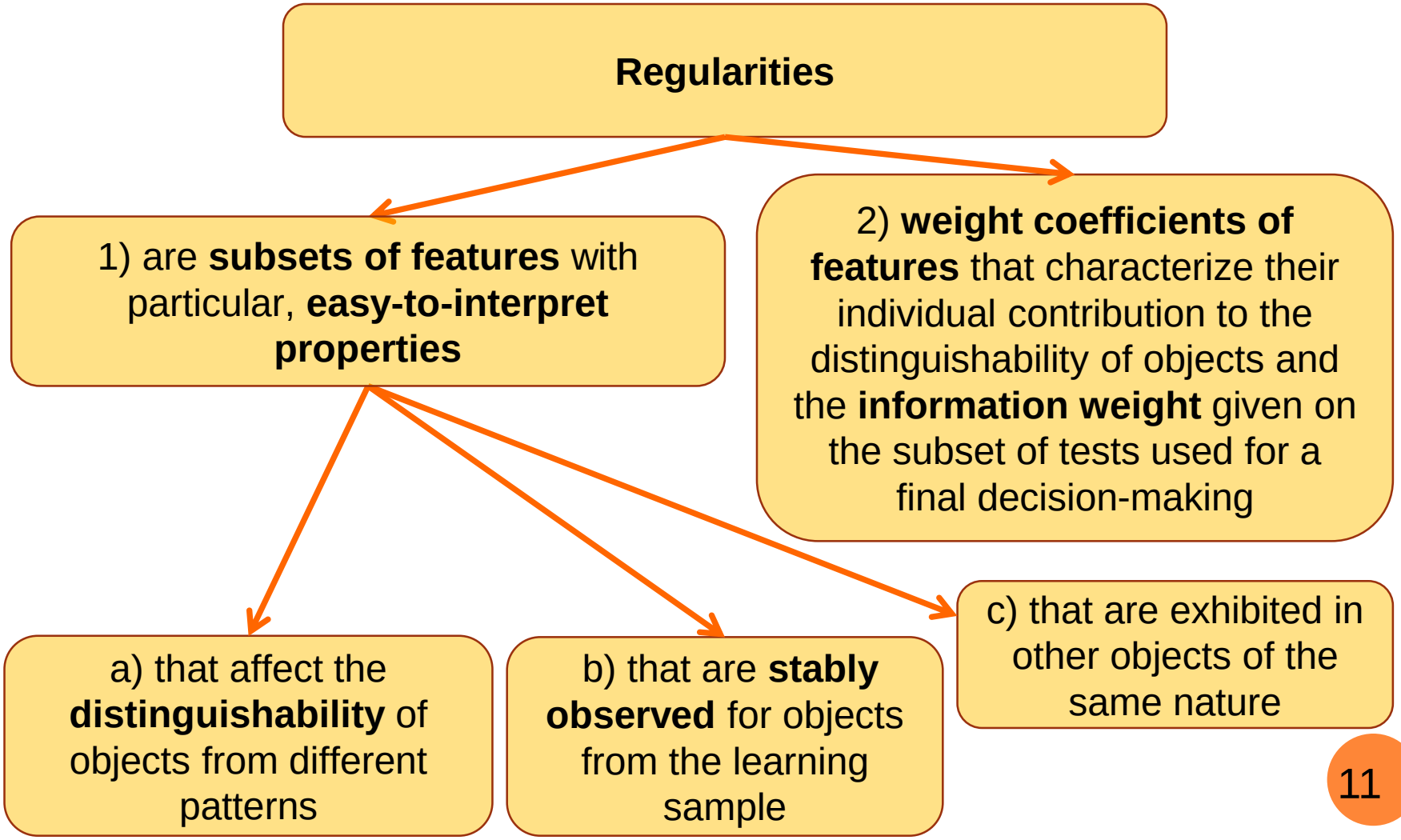
$z_1, z_2, \ldots, z_{11}$ - characteristic features

k_1, k_2 - classification features

Problem Background and Mathematical Basics of Intelligent Systems Construction 2/3

- **Rows** of description matrix ***Q*** are mapped to **objects from learning sample** of a problem field;
- **Columns** of descriptions matrix ***Q*** are mapped to **characteristic features**, which describe each object;
- The **element q_{ij}** of the matrix ***Q*** determine the value ***j***-th feature for ***i***-th object if the value is defined, and "-" if the value is undefined;
- Each **row** of the matrix ***R*** is corresponded to the row of the matrix ***Q*** having the same index;
- **Columns** of the matrix ***R*** are corresponded to distinguishing levels that represent **classification features**;
- The **set of all nonrepeating rows of the matrix *R*** is compared to the number of selected patterns presented by the **one-column matrix *R'*** ;

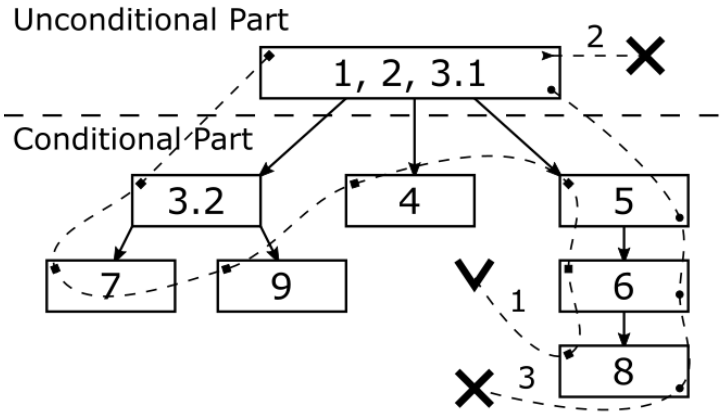
Problem Background and Mathematical Basics of Intelligent Systems Construction 2/4



Problem Background and Mathematical Basics of Intelligent Systems Construction 2/5

- The **irredundant implication matrix** is constructed on the base of matrixes ***Q*** and ***R*** and defines distinguishability of objects from different patterns (classes at the fixed mechanism of classification).
- A **diagnostic test (DT)** is a set of features that distinguishes any pair of objects that belong to different patterns and constructed on the base of unredundant implication matrix with application of logical-combinatorial algorithms (i.e. column coverings findings).
- The DT is called **"irredundant" (dead-end**) if it includes an irredundant amount of features (i.e. on the base of irredundant column coverings).
- The DT is called **"unconditional"** if all features of the object under study included in test are used simulteniously in decision-making process.
- **Decision-making** on belonging of **object under study** to one or another pattern on everyone unconditional irredundant DT (**UIDT)** is performed out with use of **threshold value of conditional degree of proximity** of the object under study to the patterns.

Problem Background and Mathematical Basics of Intelligent Systems Construction 2/6



- A.E. Yankovskaya proposed to use MDTs, which presented a new paradigm of development of intelligent systems based on test methods of pattern recognition.
- MDT is a compromise between unconditional and conditional components which used for decision-making in intelligent systems as well as in blended education and training.
- **Unconditional component of the MDT** represents the object features which are used simultaneously in decision-making process a random sequence (for education area a feature is corresponded to a question)
- **Conditional component of the MDT** is characterized by sequential checks of features, depending on the values of the previous features (for education area it is a sequence of presented questions).

Problem Background and Mathematical Basics of Intelligent Systems Construction 2/7

Definition of a membership object ***x*** under study to pattern ***k*** is defined based on the **coefficient** of conditional **degree of proximity** (a_k) of object under study to the pattern (class) ***k***, calculated by the formula:

$$a_k = \frac{S_k^x}{S_k},$$

where x – object under study,

k – pattern (class),

S_k – coefficient of interclass similarity (similarity of objects inside the pattern (class)),

S_k^x – coefficient of similarity object ***x*** under study with pattern (class) ***k***

Problem Background and Mathematical Basics of Intelligent Systems Construction 2/8

Theorem. Suppose $\boldsymbol{a_1, a_2, \ldots, a_{n+1}}$ is any set of simultaneously not equal to zero numbers where n - dimension of a correct simplex. Then there is one and only one such point what $\boldsymbol{h_1:h_2:\ldots:h_{n+1} = a_1:a_2:\ldots:a_{n+1}}$, where h_i (i = 1; 2; …; n + 1) – distance from this point to the *i*-th side.

The theorem is the foundation for decision-making and its substantiation with cognitive tools in the form n-simplex.

Coefficient h_i (i = 1; 2; …; n + 1) represents the degree of conditional proximity of the object under study to the i-th pattern. The advantage of this fact is that the n-simplex possesses the property of the constancy of the sum of distances (h) from any point to each side and the property of ratios preservation $h_1:h_2:\ldots:h_{n+1} = a_1:a_2:\ldots:a_{n+1}$.

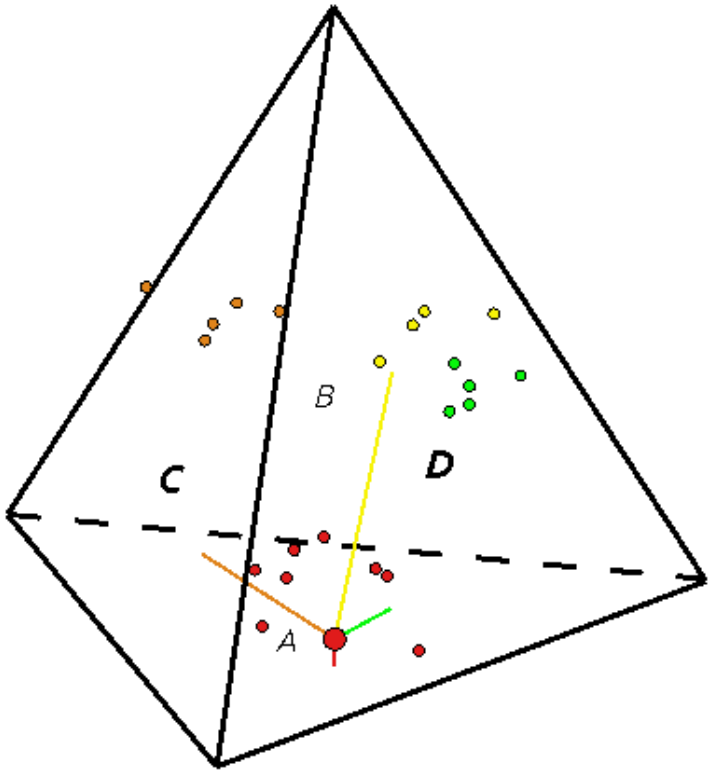
Problem Background and Mathematical Basics of Intelligent Systems Construction 2/9

For 3-simplex **distances h_1, h_2, h_3, h_4** are calculated on the basis of **coefficients a_i** and normalization operation from the following relations:

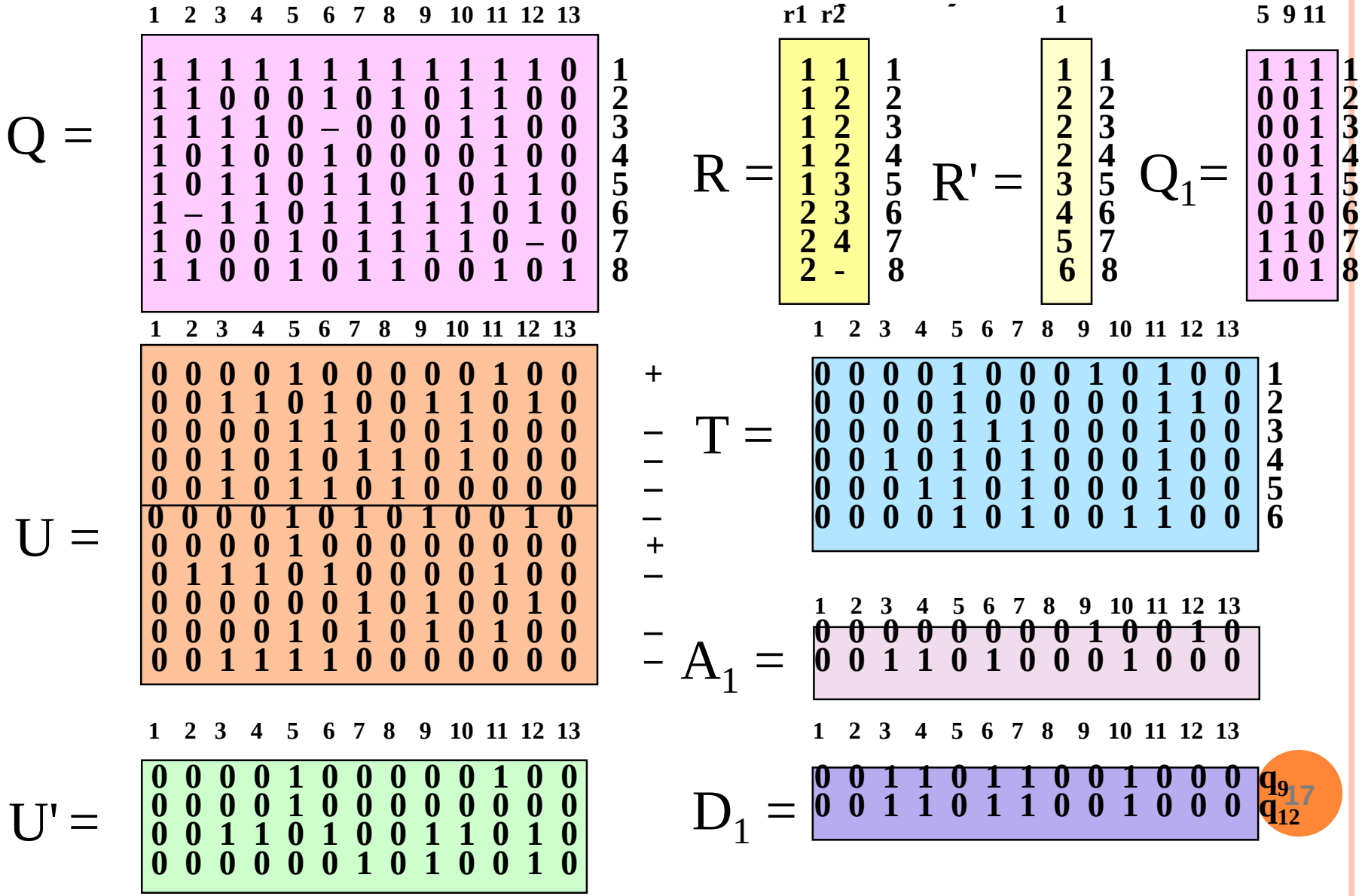
$$\begin{cases} h = \sum_{i=1}^{4} h_i \\ h = \alpha \sum_{i=1}^{4} a_i \\ \frac{h_1}{a_1} = \frac{h_2}{a_2} = \frac{h_3}{a_3} = \frac{h_4}{a_4} \end{cases}$$

by the formula $h_i = \dfrac{h \cdot a_i}{\sum_{i=1}^{4} a_i}$,

where α – scaling coefficient.



Problem Background and Mathematical Basics of Intelligent Systems Construction 2/10



Problem Background and Mathematical Basics of Intelligent Systems Construction 2/11

Regularities

q_1 - constant feature
q_{13} - noniformatic feature
q_8 - unessentional feature
q_6, q_7, q_{10} - dependent features on features q_9, q_{12}
q_{11} - stable feature on r^1_1
q_7, q_8 - stable features on r^2_1
$q_5, q_7, q_9, q_{11}, q_{12}$ - stable features on r^2_2
q_3 - q_7, q_9, q_{12} - stable features on r^3_2
q_9, q_{12} - alternative features
q_3, q_4, q_6, q_{10} - alternative features
$(q_5, q_{11}), q_9$ - optimal mixed test
$q_5, q_{11}), q_{12}$ - optimal mixed test
$(q_5, q_{11}), q_6, q_7$ - mixed test
$(q_5, q_{11}), q_3, q_7$ - mixed test
$(q_5, q_{11}), q_4, q_7$ - mixed test
$(q_5, q_{11}), q_7, q_{10}$ - mixed test
q_5, q_{11} - obligatory features (unconditional components of diagnostic tests) $q_3, q_4,$

Problem Background and Mathematical Basics of Intelligent Systems Construction 2/12

PURPOSE OF IMSLOG-2002

— formation of knowledge about objects in concrete problem or interdisciplinary area

— regularities revealing in data and knowledge

— decision rules construction on the basis of revealed regularities

— recognition of object under investigation

— decision-making and its justification

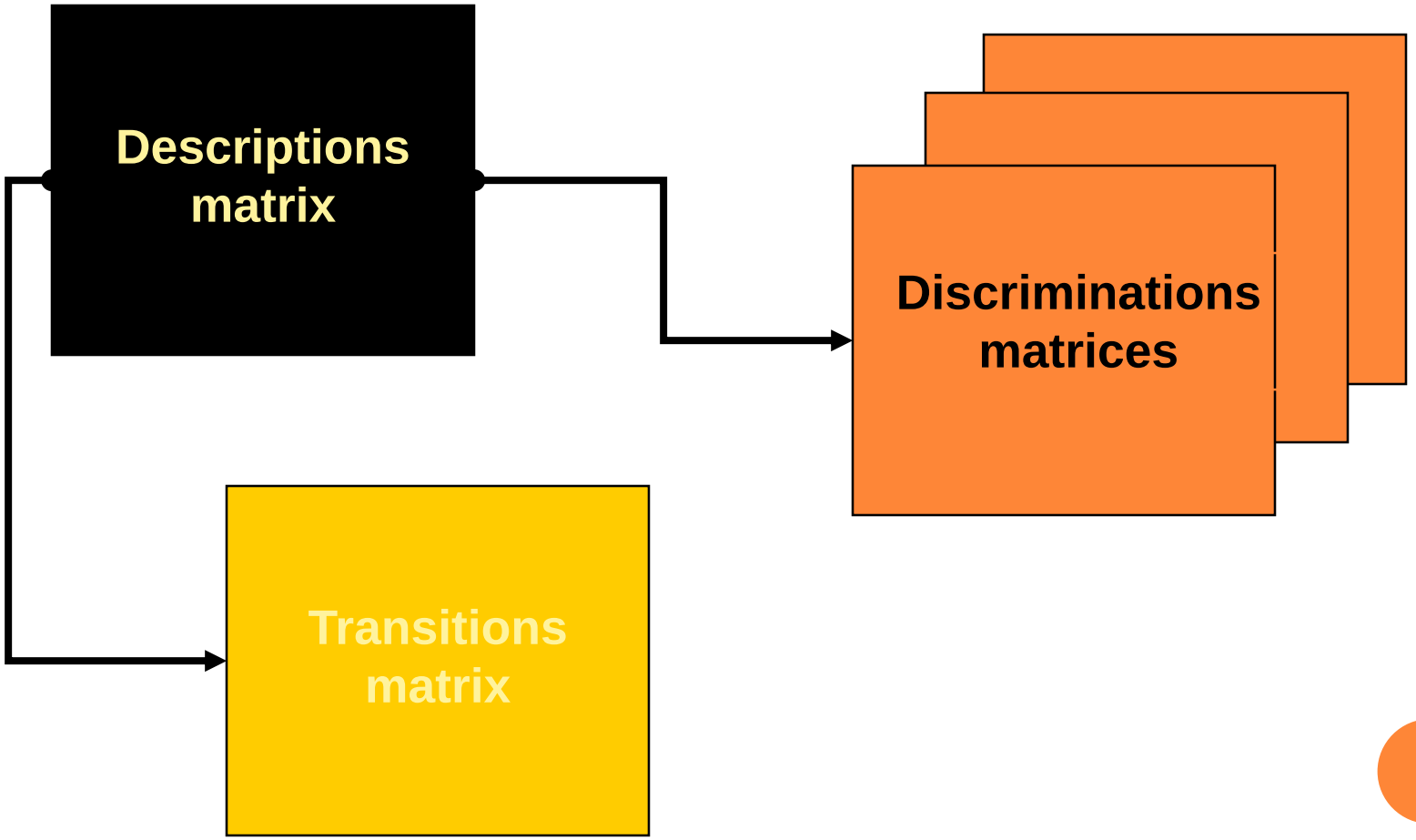
Problem Background and Mathematical Basics of Intelligent Systems Construction 2/13

BASES OF TEST PATTERN RECOGNITION

- nontraditional matrix method of data and knowledge representation
- deep optimizing logic-combinatorial transformations in features space
- logic-combinatorial and logic-probabilistic methods of test pattern recognition
- methods of complex decision-making
- cognitive means of decision-making and justification of decision-making results

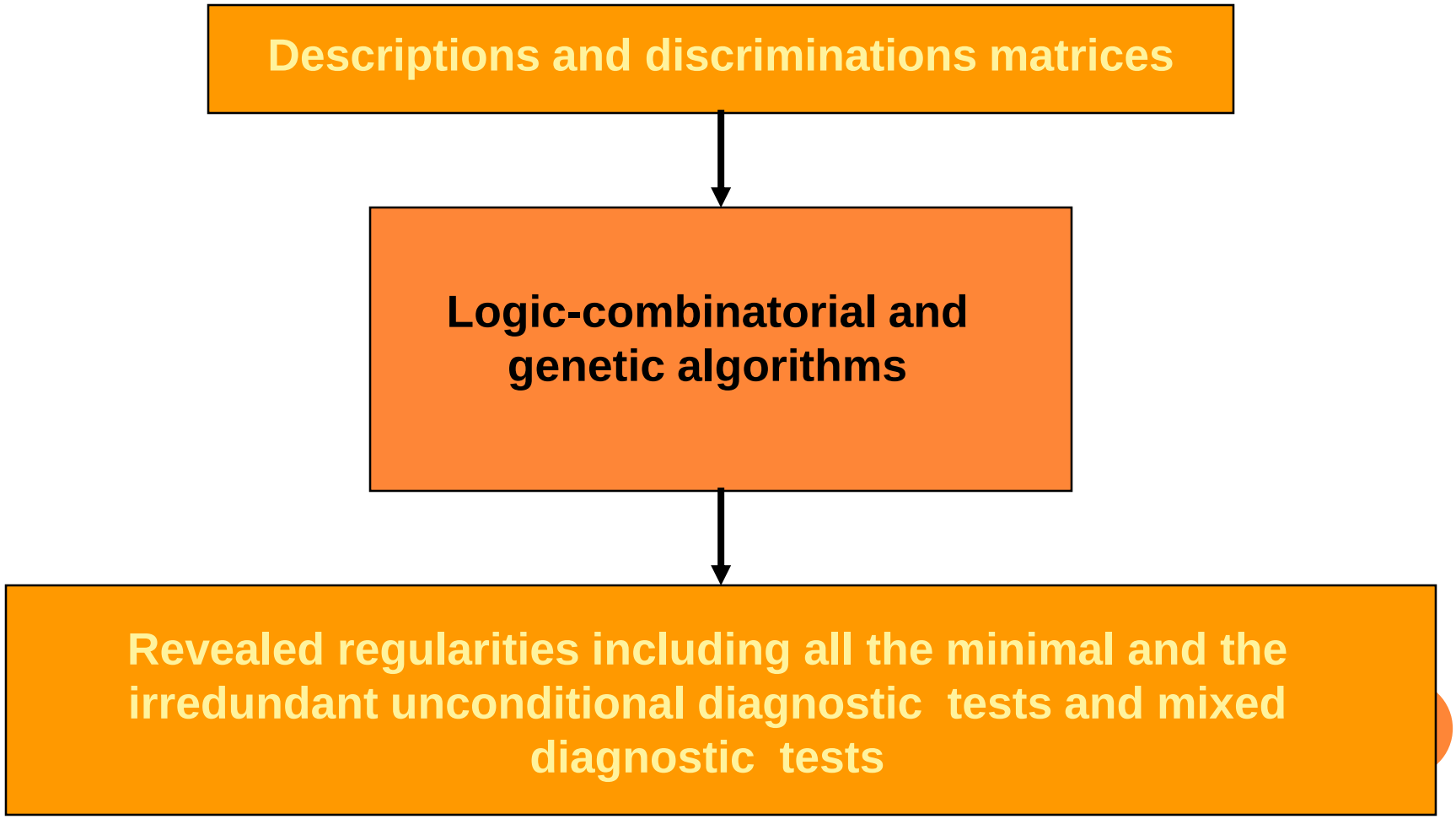
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DATA AND KNOWLEDGE REPRESENTATION



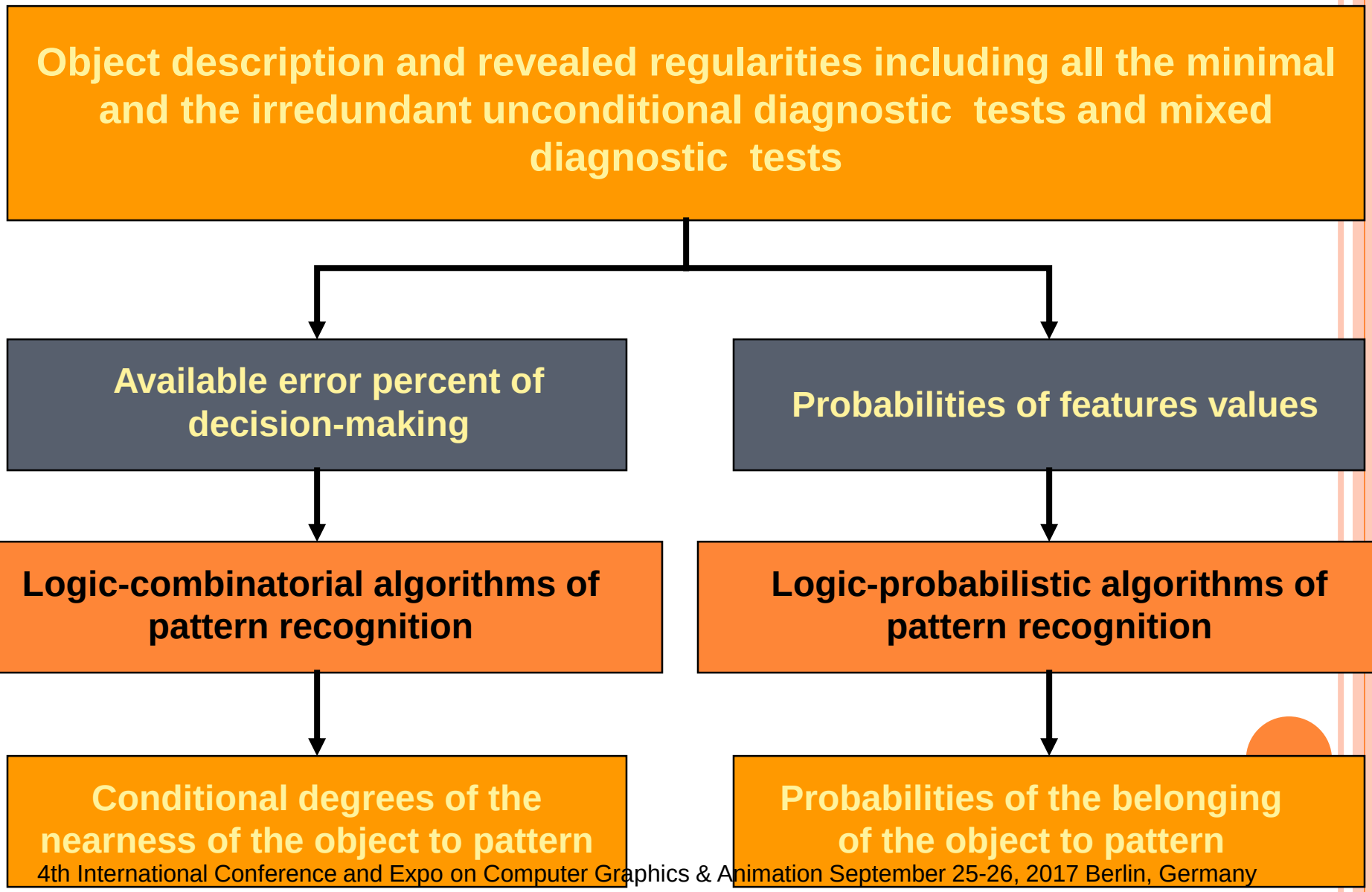
Problem Background and Mathematical Basics of Intelligent Systems Construction 2/15

BLOCK-SCHEME OF REGULARITIES REVEALING



Problem Background and Mathematical Basics of Intelligent Systems Construction 2/16

BLOCK-SCHEME OF DECISION-MAKING



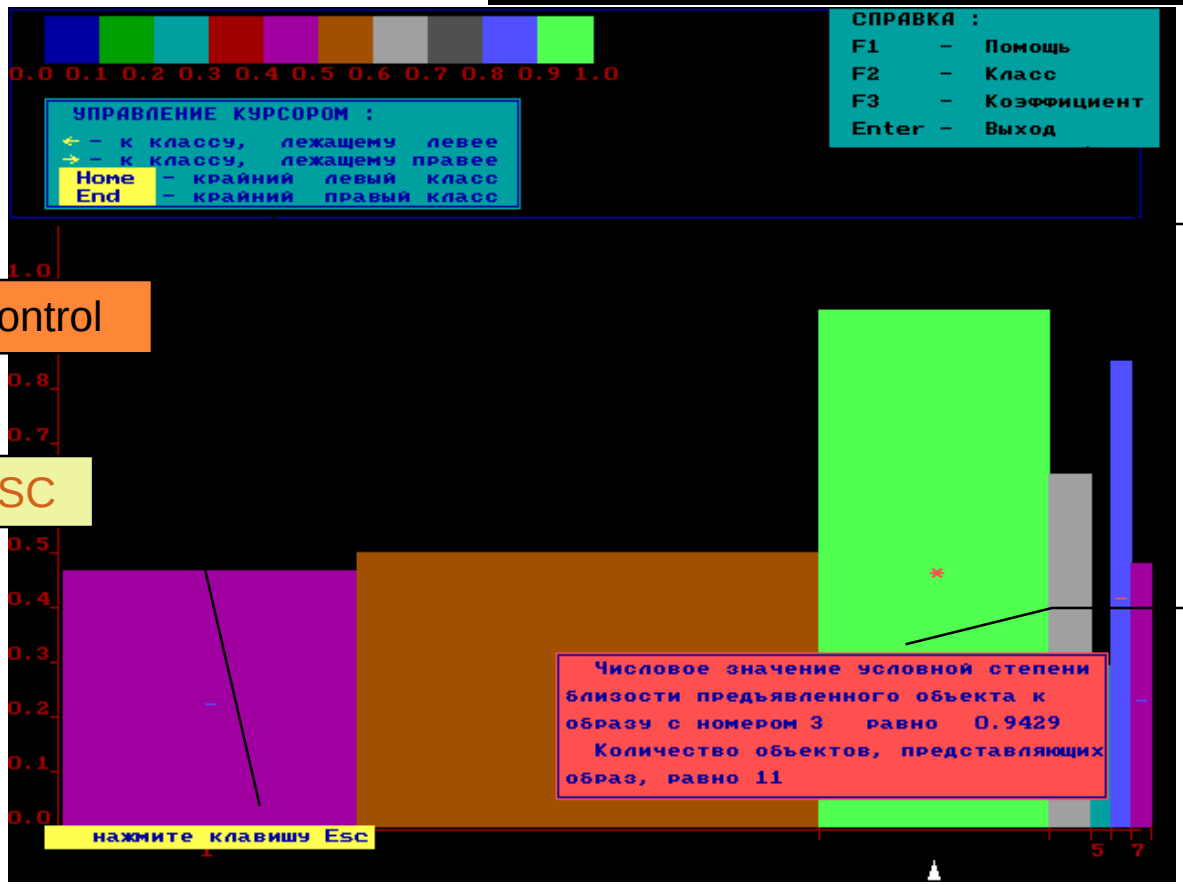
Problem Background and Mathematical Basics of Intelligent Systems Construction 2/17

COGNITIVE MEANS

- Special type histogram
- Equilateral triangle
- Special round diagram, rectangle & interval

Problem Background and Mathematical Basics of Intelligent Systems Construction 2/18

SPECIAL TYPE HISTOGRAM



Cursor control

Press ESC

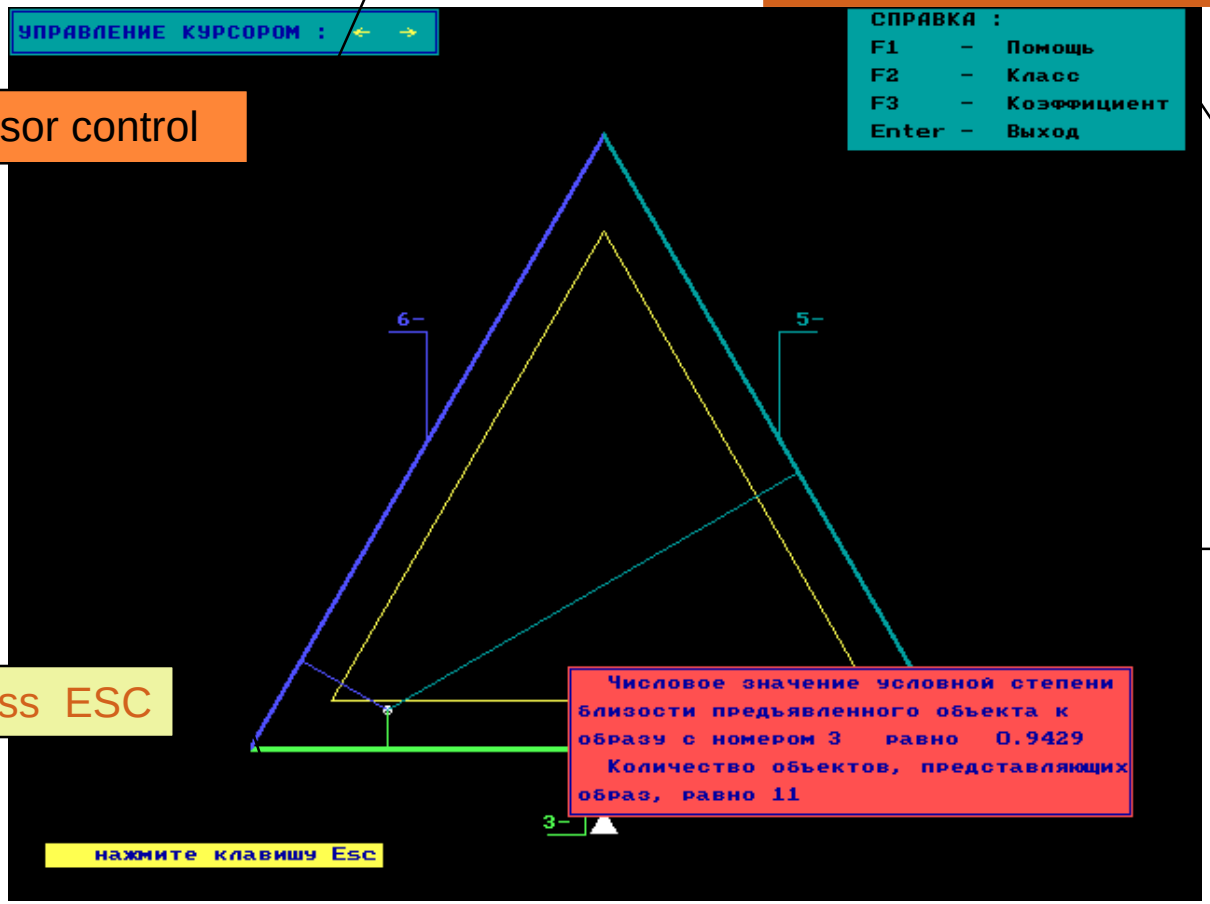
HELP
F1 - Context Help
F2 - Class
F3 - Coefficient
Enter - Exit

Coefficient of nearness between object & pattern

Rectangle height reflects conditional nearness degree between object (patient own diagnosis) & pattern (the same disease as phenomenon). Rectangle width shows size of tutorial sample. Star (*) indicates on decision have made.

Problem Background and Mathematical Basics of Intelligent Systems Construction 2/11

EQUILATERAL TRIANGLE



Cursor control

HELP
F1 - Context Help
F2 - Class
F3 - Coefficient
Enter - Exit

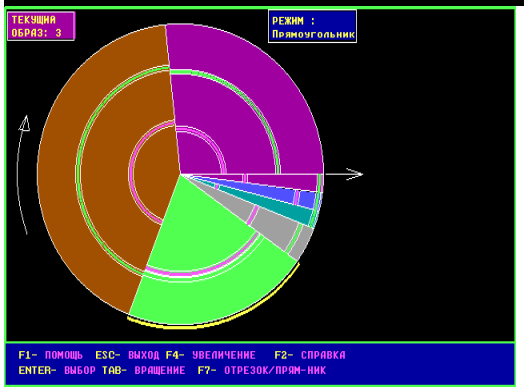
Press ESC

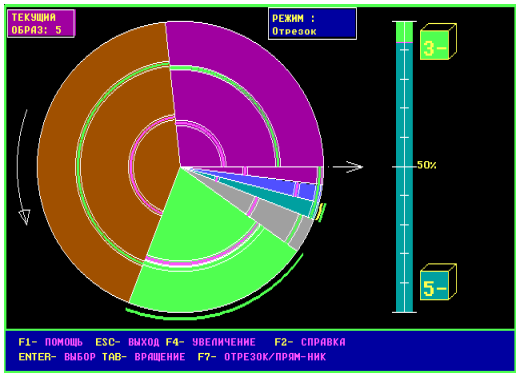
Coefficient of nearness between object & pattern

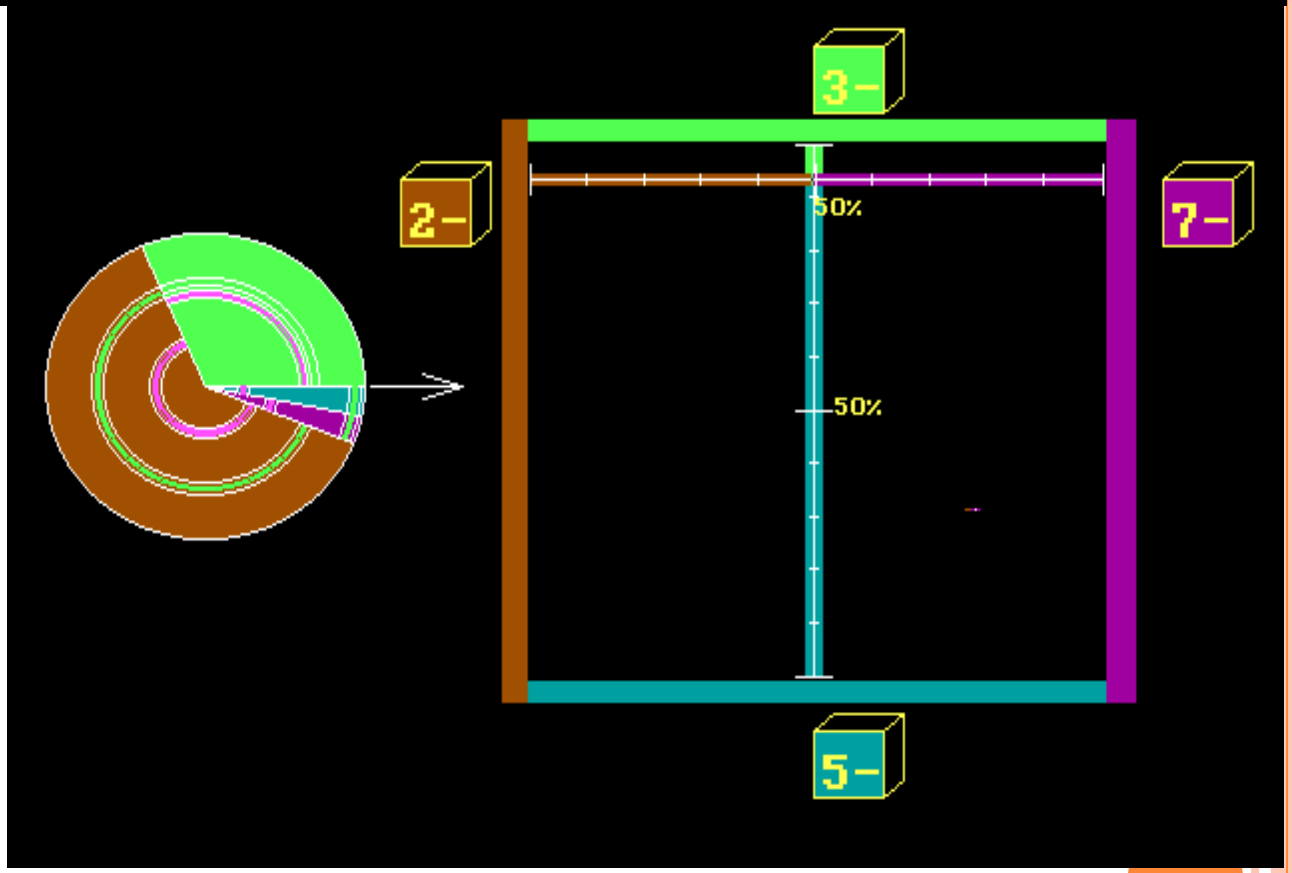
Illustration reflects dimensional arrangement of object (patient own diagnosis) with respect to any 3 patterns (differential diagnosis). Side of triangle is one of the patterns. Position of white point (patient diagnosis) informs about diagnosis nearness to distinct disease (side) & error of decision made (relatedness to internal triangle).

Problem Background and Mathematical Basics of Intelligent Systems Construction 2/12

Special round diagram, rectangle & interval



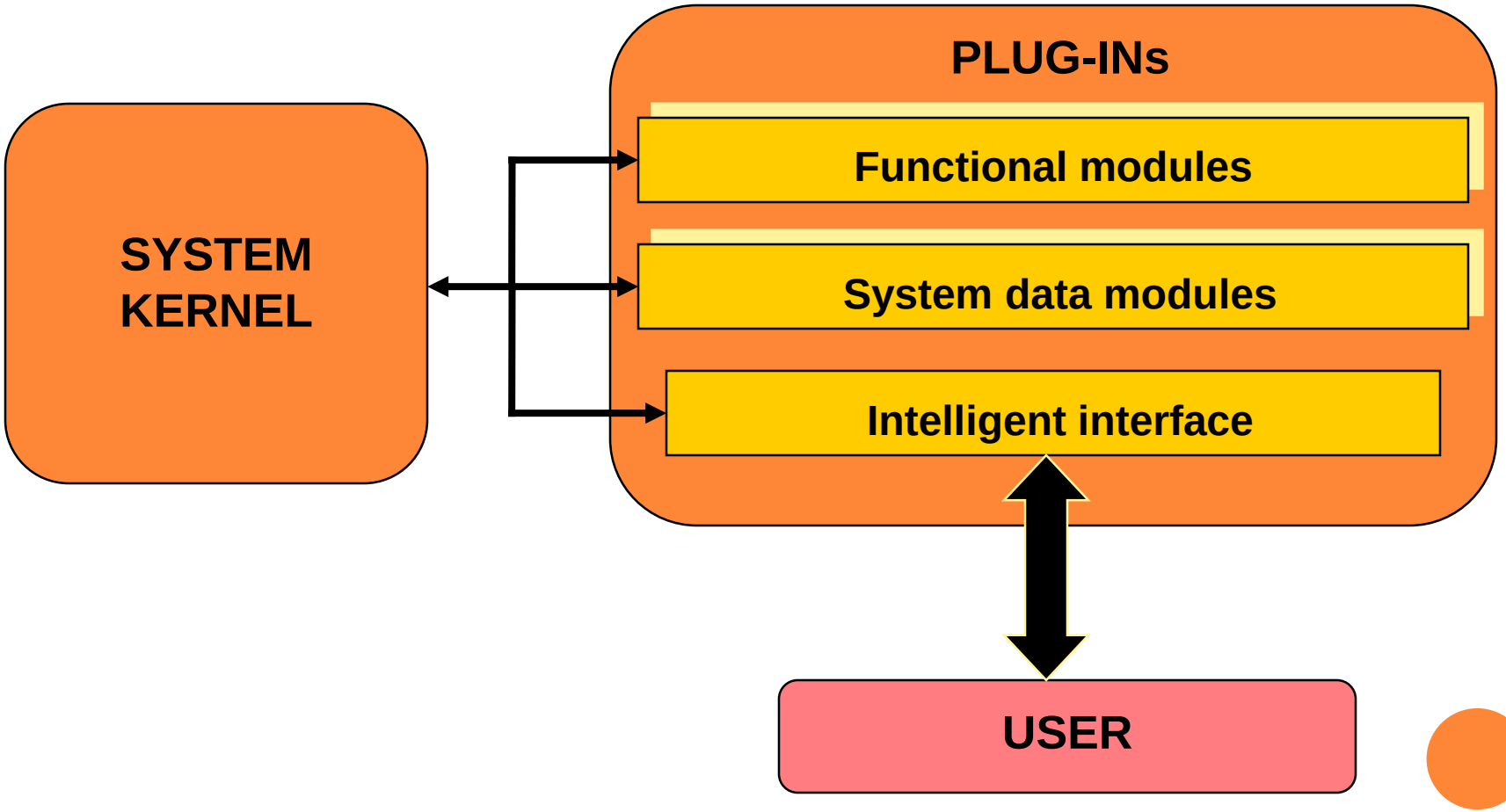




These pictures characterize the relation between coefficients of objects similarity within pattern & object compared with pattern.

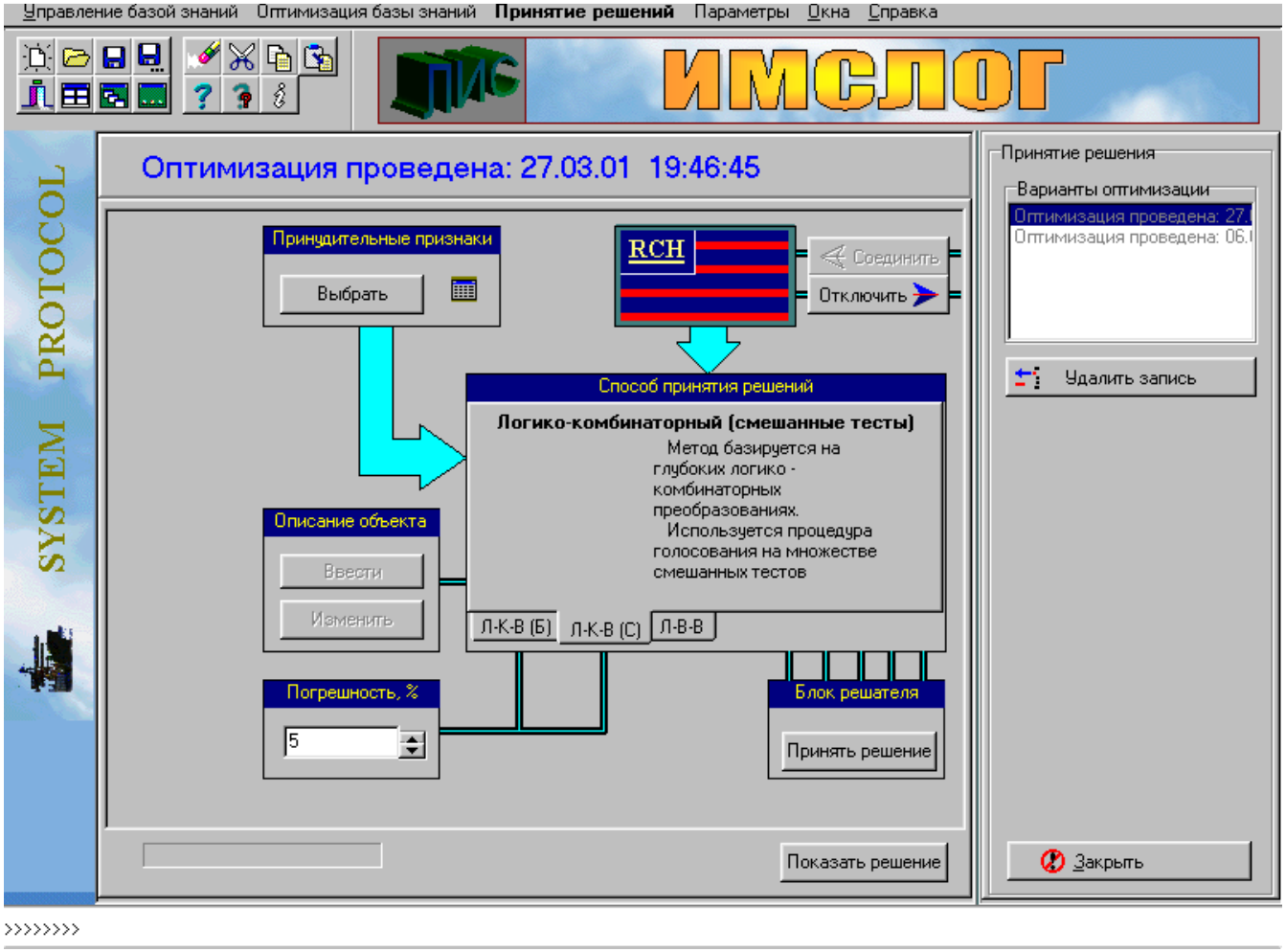
Problem Background and Mathematical Basics of Intelligent Systems Construction 2/13

ARCHITECTURE OF IMSLOG-2002



Problem Background and Mathematical Basics of Intelligent Systems Construction 2/14

DIALOG WINDOW EXAMPLE



Problem Background and Mathematical Basics of Intelligent Systems Construction 2/15

CONSTRUCTION STAGES OF APPLIED INTELLIGENT SYSTEMS

1. The systematization and the structuring information required for solving the tasks in this problem area, definition of the functional system structure, its architecture and methods of recognizing are most suitable for solving the tasks.
2. The grouping required configuration by the way of linking the corresponded program modules.
3. The creating knowledge base modules, the regularities revealing and the construction of decision rules.
4. The final tuning of applied system.

Problem Background and Mathematical Basics of Intelligent Systems Construction 2/16

IMSLOG-2002 ALLOWS:

- essentially to raise the efficiency of development process and the construction of the applied intelligent systems supporting different information technologies of test pattern recognition
- to construct the intelligent recognizing systems of different configurations with comfortable interface
- quickly and simply to modify already the constructed systems with taking into account increasing user needs
- to solve both theoretical and practical problems of diagnostic, classification, prognosis and management

Problem Background and Mathematical Basics of Intelligent Systems Construction 2/17

Application areas

- medicine
- psychology
- sociology
- geology
- civil engineering
- genetic
- economic
- medicine of emergent situations
- ecogeology
- ecobiomedicine
- design
- ecology
- education

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2-simplex Prism as a Cognitive Graphic Tool 3/1

- For the first time 2-simplex prism was proposed by author and Yamshanov for decision-making and its justification within intelligent dynamic diagnostic systems in 2015 and within intelligent dynamic predictive systems in 2016.
- 2-simplex prism is a triangular prism which has identical equilateral triangles (2-simplices) in its bases. The height of the 2-simplex prism in intelligent dynamic systems corresponds to the dynamic process time interval under consideration.
- The results of each of the diagnostic, predictive decisions are shown in the form of points in 2-simplices disposed on cross-sections of 2-simplex prism.

2-simplex Prism as a Cognitive Graphic Tool 3/2

- The height of 2-simplex prism is divided into a number of time intervals. The number of time intervals corresponds to the number of diagnostic or predictive decisions.
- The distance between two adjacent 2-simpleces is directly proportional to the time interval between adjacent 2-simpleces.
- For intelligent geoinformation systems the height corresponds to the distance from initial point to final destination.
- In this case the distance between two adjacent 2-simpleces corresponds to the distance between two points on a map.

2-simplex Prism as a Cognitive Graphic Tool 3/3

Distance for the basis of the prism to i-th 2-simplex h_i' corresponds to the fixation moment of object under investigation features and it is calculated based on the following formula:

$$h_i' = H' \cdot \frac{T_i - T_{\min}}{T_{\max} - T_{\min}}$$

where H' - length of 2-simplex prism preassigned by a user and corresponded to the investigation duration,

T_i - timestamp of features fixation of object under investigation for i-th examination,

$T_{\min}$ - timestamp of features fixation of object under investigation for 1-th examination,

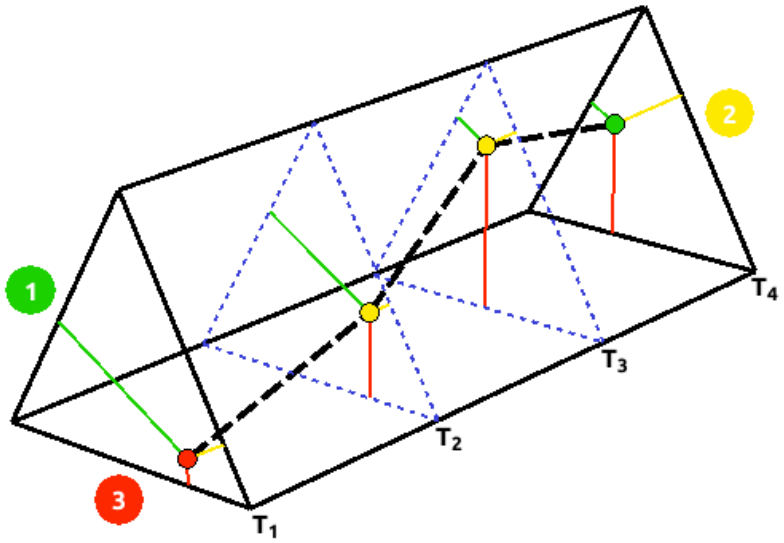
$T_{\max}$ - timestamp of features fixation of object under investigation for last examination.

Because 2-simplex prism is based on the 2-simplex description of all 2-simplex objects is also right for 2-simplex prism.

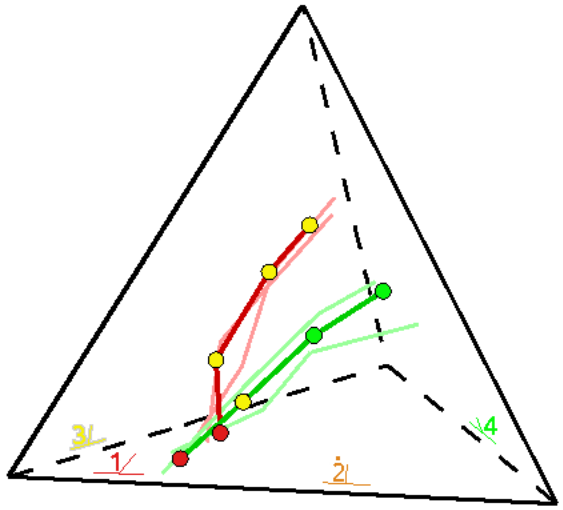
2-simplex prism allows representing visually as well the dynamic processes as the modeling one or another process which is necessary for a big amount of problems and cross-disciplinary areas: medicine, economy, genetics, building, radioelectronics, sociology, education, psychology, geology, design, ecology, geo-ecology, eco-bio-medicine etc.

2-simplex Prism as a Cognitive Graphic Tool 3/4

Illustrating examples of using 2-simplex prism and 3-simplex for dynamic diagnostic, forecasting processes



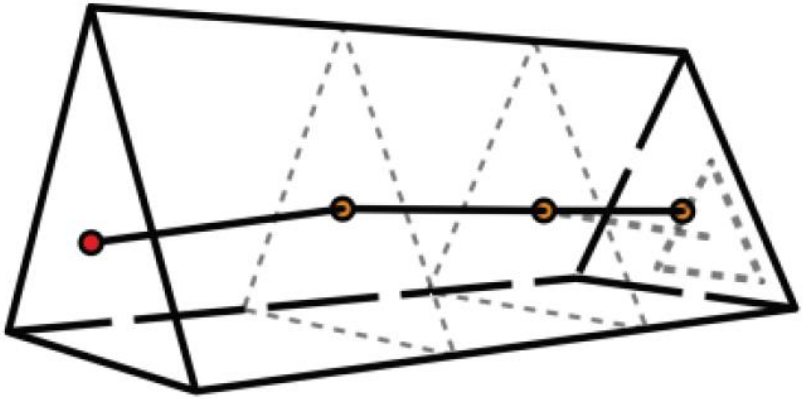
2-simplex prism cognitive graphic tool for dynamic diagnostic process



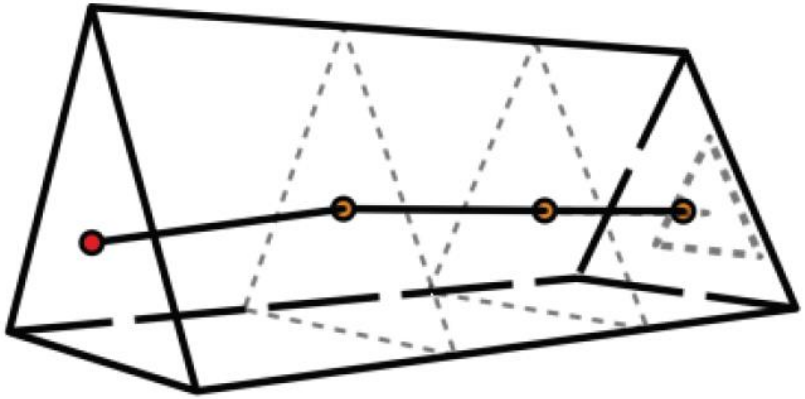
3-simplex prism cognitive graphic tool for dynamic diagnostic process

2-simplex Prism as a Cognitive Graphic Tool 3/5

Illustrating examples of using 2-simplex prism for forecasting processes



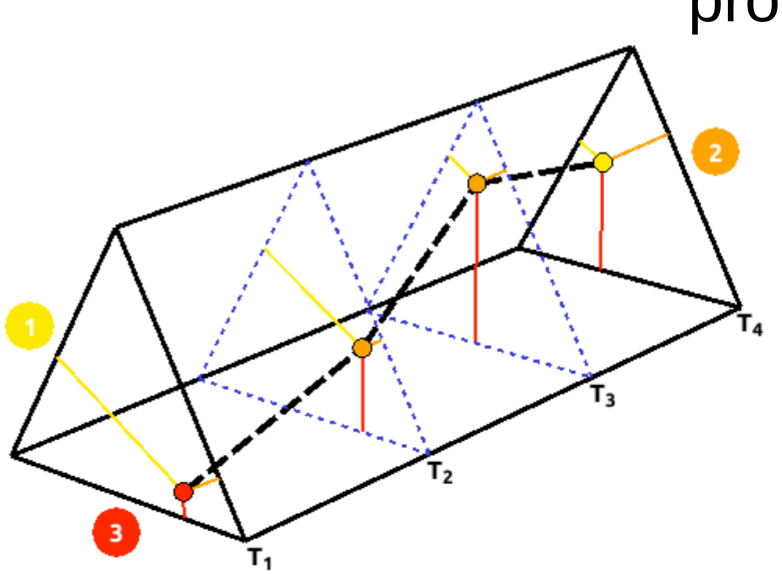
a) square polynome



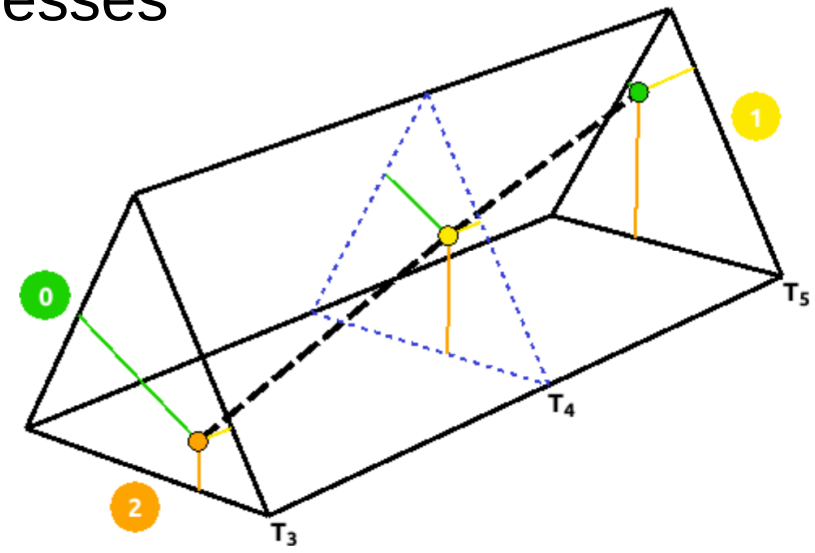
b) linear polynome

2-simplex Prism as a Cognitive Graphic Tool 3/6

Illustrating examples of using 2-simplex prism for forecasting processes



а)

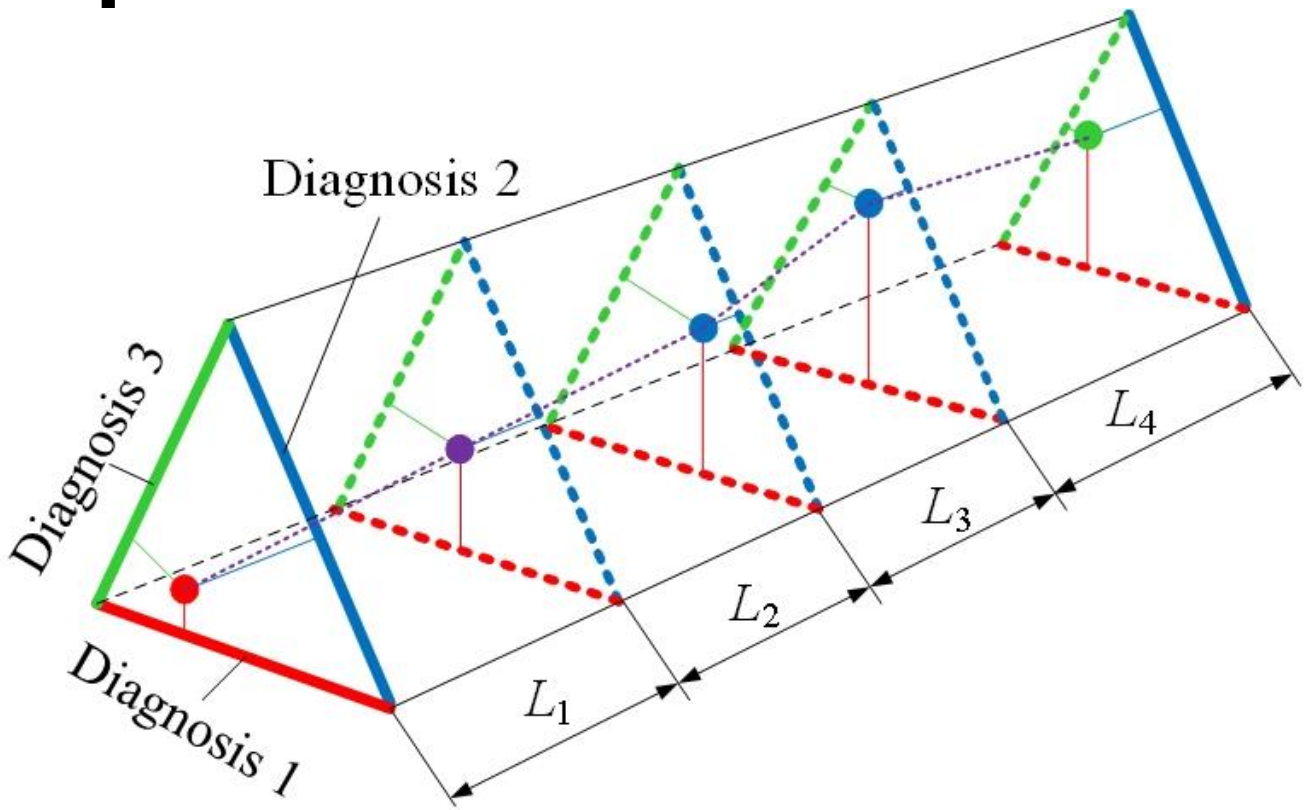


б)

Results of diagnostic tests for organizational stress revealing using 2-simplex prism:

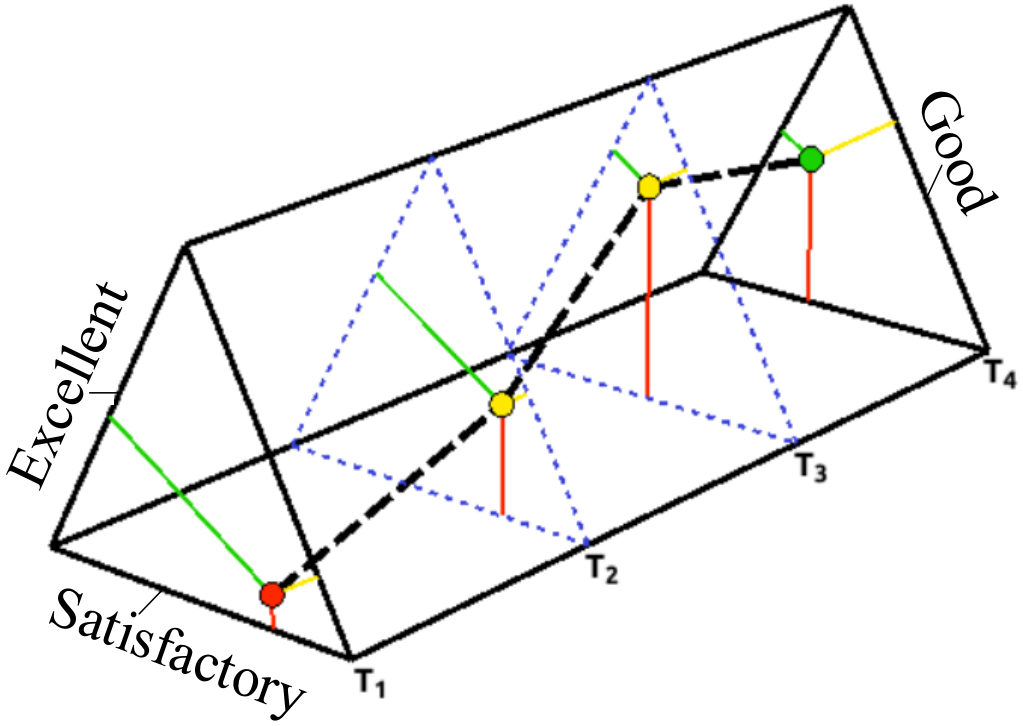
а) from 1st to 4th diagnostic test, *б*) from 3rd to 5th diagnostic test

2-simplex Prism as a Cognitive Graphic Tool 3/7



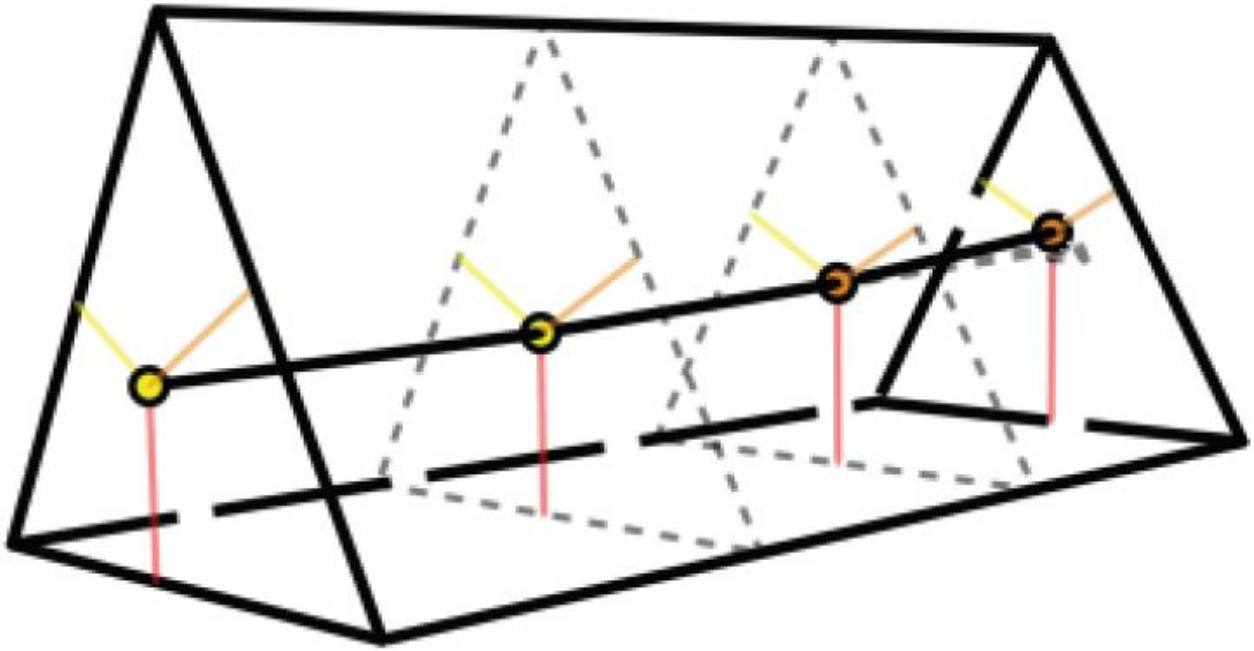
Results of diagnostic tests for intelligent geoinformation systems
L_1, L_2, L_3, L_4 – distances between geographical points

2-simplex Prism as a Cognitive Graphic Tool 3/8



Learning trajectory construction via 2-simplex prism cognitive tool

2-simplex Prism as a Cognitive Graphic Tool 3/9



2-simplex prism application for prediction of students' learning results

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Conclusion 4/1

- Original cognitive graphic tool 2-simplex prism for decision-making and its justification is developed
- Usage of 2-simplex prism in various problem areas for decision-making and its justification in intelligent dynamic and geoinformation systems is proposed
- IIS IMSLOG is developed using new cognitive graphic tools
- Intelligent dynamic systems are constructed based on IIS IMSLOG in such problem areas as medicine, psychology, organizational stress diagnostics, education and consistent results are obtained
- Future development of the approach under consideration is proposed

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