ITHEA

# International Journal

# INFORMATION CONTENT & PROCESSING

2016 Volume 3 Number 4

**International Journal**
**INFORMATION CONTENT & PROCESSING**
**Volume 3 / 2016, Number 4**



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**International Journal "INFORMATION CONTENT AND PROCESSING" Volume 3, Number 4, 2016**

Edited by the **Institute of Information Theories and Applications FOI ITHEA**, Bulgaria, in collaboration with
Institute of Mathematics and Informatics, BAS, Bulgaria,
V.M.Glushkov Institute of Cybernetics of NAS, Ukraine,
Universidad Politechnika de Madrid, Spain,
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Institute for Informatics and Automation Problems, NAS of the Republic of Armenia.

Publisher: **ITHEA®**
Sofia, 1000, P.O.B. 775, Bulgaria. www.ithea.org, e-mail: info@foibg.com
Technical editor: Ina Markova

**Printed in Bulgaria**



**ISSN 2367-5128 (printed)** **ISSN 2367-5152 (online)**

# COGNITIVE MODELING OF ACTIVITY AND BEHAVIOR OF SURGEON

**Vitaliy Zinakov, Svetlana Masalóva**

***Abstract:*** *The article considers the cognitive paradigm of activity and behavior of surgeon as the cognizing subject from the standpoint of the system approach. Cognitive model of the surgeon is a very complicated system and requires clarification of all aspects of his medical activity in the subsystems: "surgeon - profession", "surgeon - patient", "surgeon - surgeon", "surgery - society", "surgeon - own self." Combining both epistemological and empirical qualities, the operating surgeon in aggregate of performed cognitive functions actively shows his creativity, increases the level of surgical skill, and introduces innovations in the medical practice. Surgeon improves his professionalism thanks to the use of cognitive mechanisms of adaptation, activation and regulation of the cognitive medical activity.*

***Keywords****: Cognitive paradigm, flexible rationality, systematic approach, cognizing subject, surgeon, medical activity, medical cognition, activity, individual and collective subject, cognitive matrix.*

## The problem

At the stage of postnonclassical science understanding of the subject has radically changed. New paradigms with the introduction of new approaches and methods of scientific cognition such as synergetic, informational, cybernetic, mathematical, logic and nonstandard, etc., The greatest heuristic potential, in our view, has a modern ***cognitive paradigm*** for explaining and understanding the activity of the subject, its creative cognitive process from the standpoint of the content, forms and mechanisms of cognition.

Cognitive science as a science about general principles, governing mental processes in the human brain interprets man as a perceptive activity of the subject, actively perceiving and producing information. In a professional activity and in their cogitative activity of the subject of cognition is guided by a specific methodology, including schematics, programs, plans, and strategies.

From the perspective of cognitivism it is of significant interest to identify the features of activities and behavior of a surgeon as one of the most exciting specialties in medicine. We interpret ***surgeon*** as a cognitive activity of the subject with the greatest creative potential heuristic explanation and understanding of the activity process in their professional field.

Modern medicine is a vast and deeply differentiated branch of scientific knowledge. The *object* of its study is people. Its medical knowledge is historically closely connected with philosophy, which also examines the man, his nature and essence. From antiquity over two thousand years doctors have developed sustainable thinking need for a holistic (volumetric) view of the system of bodily-spiritual nature of man.

But a doctor himself, as a subject of activity, behavior and cognition, is the object of science.

## Metodology of Flexlible Rationality

*Methodology flexible rationality* is applied to study the characteristics of the activity and behavior of a surgeon, revealing the correlation of rational and irrational in cognition, many of the nuances of the cognitive paradigm for interdisciplinary research of the subject.

We consider ***flexible rationality*** as a form of scientific rationality, taking into account the pre-logical and anthropological features of the cognizing subject [4]. The application of flexible categories of rationality is especially important for the analysis of *intermediate* stage of the subject activity, a stage of *finding a solution* to a specific problem.

The nature of the cognizing subject is ambivalent: in its psychological "matrix" of knowledge it is represented in at least two differential slices – *experiential (ontical) and epistemological*. At the same time, a man is an integral (holistic) subject of cognition in its third hypostasis, in which he synthesizes his dual biosocial nature.

Thus, from the viewpoint of post-non-classical science the nature of the cognizing subject is expressed in its dual functioning as *an epistemological-ontical* subject:

A) the carrier of the rationality (epistemological subject),

B) media irrational - feelings, emotions, desires, moods, intuition, faith, doubt, will, etc. (as an ontical subject).

Subject, intuitively using in its activities the knowledge and irrational form as a cognitive instrument, discovers a variety of opportunities for obtaining new knowledge about the object and about itself as a cognizing subject, its cognitive capabilities and abilities. This is the cognitive potential of the subject in any kind of activity.

## The activity of a surgeon as a system

The activity of a surgeon is a *medical activity*. It is carried out by a doctor, a subject and media medical of consciousness, knowledge and the medical activity itself.

The profession of a surgeon applies to the professions of *subject*-*subject* type. A cognitive model of the surgeon as the perceptive activity of the subject presupposes the clarification of all sides of his medical activities in " surgeon — a profession", "the surgeon — patient", "surgeon - surgeon", "surgeon — society", " surgeon — self". But all these aspects are "closed" in the person of a surgeon. The result of cognitive activity of a surgeon as an open system, dependent on environmental conditions and mating taking into account many factors that affect the adoption of a decision; is a system of meanings, "***cognitive matrix***" of a surgeon. It describes his inner world, the worldview, the attitude, "world perception", performing the role of cognitive "tools". Their cognitive analysis involves the study of socially prescribed, surgical collective knowledge and expertise of an individual surgeon.

## System “surgeon – profession"

The specifics of a doctor are determined by the uniqueness of: 1) *object* of study (the sick, the wounded); 2) *tasks* that a doctor has to solve (diagnostic, therapeutic, preventive, etc.); 3) *conditions* of activity, etc. The specifics of surgeon are that he has received training in diagnostic and surgical treatment of diseases and injuries. The etymology of the word "***surgeon***" decrypts the essence of surgical activity: from the ancient Greek. ***χερί*** — hand + ancient Greek. ***ἔργον*** — work, action. That is, surgeon literally "***heals with hands***", really changes the body of a patient, and constructs it in accordance with the logic of treatment adopted by surgeon and the treatment model. In this medical activity, surgeon relies on his theoretical and practical training.

Two levels of knowledge are known — empirical and theoretical. At the ***empirical level*** of cognition, doctor must fix the processes, phenomena and relationships between them, arrange necessary and accidental factors in medical record and behavior of a patient, escape from immaterial, focus the observation on the search for essential properties and dependencies in the disease of a patient, diagnose the actual state of a patient. At the ***theoretical level***, a particular *synthetic* method of mental activity of a doctor is dominated - processing in the contemplation of views, and then the concepts that give medical theory a kind of integrity, thought concreteness. Theoretical knowledge gives the opportunity to dissect the nature and causal connection of certain phenomena in the human body. Only at this level of knowledge in the most concentrated kind appear all the distinctive features of the medical knowledge results in deep comprehension of the essence of disease and the life essence of the patient.

Today a health worker has no right to be a pure empiricist. "That is why now there is an acute problem of improving the theoretical training of physicians, developing his *philosophical culture of thinking*" [9]. Medicine will become not only a practical art of healing, but also the integration of theoretical science. The relationship of medicine and philosophy began with the appearance of the first signs of abstract thinking in medical business, and continues today. Medicine together with philosophy understands the complex world of a human's life, controlling his health. At the same time it becomes the object of special philosophical knowledge. Philosophical methodology of medicine (— and cognitive paradigm) is designed by performing heuristic, coordinating and integrating function to stimulate ***the increment*** of medical knowledge as a particularly sensitive way of integral knowledge about a person and his body. The activities of a surgeon is based on a critical understanding of philosophical and subject-conceptual spheres of doctor's activity, covering all the processes of course and cure of a disease.

In working with a patient, surgeon relies on the results of the preceding activity of other clinicians (therapists, neurologists, clinicians, etc.), who carried out diagnosis, treatment and prevention of the disease of this patient.

The fundamental strategic importance is ***diagnosis***, which begins the actual work of a doctor, who uses methods of observation, assessment of detected symptoms, conclusions. Algorithm examination of a patient is determined by a deductive scheme of the diagnostic process, including inquiry, direct (clinical) examination of a patient, provisional diagnosis, additional methods of examination, clinical diagnosis.

The **stages** of the diagnostic process are:

- identification of *symptoms* is the primary information about a disease, but not yet defining its essence;
- combination of symptoms in *syndromes* –connection and unity of all phenomena is defined as a result of the essence of the pathological process;
- *the establishment of the nosological form of a disease* (higher stage of the diagnostic process) leading to the establishment of deeper relationships and causal dependencies between them.

"*The diagnostic process* is primarily a process of medical thinking, higher rationalization which can be achieved only by relying on the laws of logic" [10].

It is noticeable that the process of setting diagnostic, curative and preventive tasks is carried out under conditions of variability of the original data and time constraints when providing medical care for urgent reasons. Symptoms and syndromes help a doctor to simulate mentally the holistic clinical picture of a disease, to study and analyze the causes, conditions and mechanisms of its emergence and development. The price of the defects and errors of medical practice corresponds to its importance, sometimes it is defined as the highest value of health and human life [8].In broad terms, we can distinguish the following ***cognitive tools of a doctor*** inherent to any cognitive entity:

- reflection as a fundamental means of knowledge;
- representation is ambivalent on the nature of the phenomenon of simultaneous representation-reflection of the object and its replacement-design (simulation);
- convention – a mandatory event communicative by nature, inter-subjective activity of cognition;
- interpretation – the moment of cognition and interpretation of meanings, and a way of being that exists by understanding [5, p. 42-43].

Surgeon uses different methods and forms of rational and irrational cognition (e.g., intuition, imagination, etc.), adequately revealing its potential as an activity of the learning subject, interested in the implementation of their cognitive abilities and skills. Using different cognitive technologies, surgeon becomes the subject of ***interpretative***, conducting operationally-methodological activity and his treatment of patient information.

Operating surgeon shows his ***active*** nature in his surgical work, acting in terms of problematic non-standard situations when "implementation" with a scalpel into the patient. There might "open" a completely different visual actual pattern than expected on medical records and the results of preliminary examination of a patient. This situation is given by the uniqueness of the body and the human personality and the openness of their systems. A surgeon has to cope with this new information "on the spot", "here", ", "now". However, the feature of an object of knowledge and a specificity of tasks that should be solved by a surgeon during surgery, places a number of requirements to his intellectual activity. One of them is the ***holistic perception of the object***, and this must be often done ***instantly***! Therefore, during surgery direct impression plays an important role, or, as expressed by M. M. Prishvin, ***the impression of "first sight***": "Small must get to know itself in a whole with all parts" [7]. You must develop the ability to perceive the whole through the detail. Through the details doctor needs to see the direction of disease development and possible solutions to surgical challenges, surgical help for a patient.

Of course, such a penetration into the essence of the surgical situation on the operating table and experience comes not at once. For an initial procedural stage of its practical operating activities young surgeon often manifests its irrational features as a subject, searches for solutions, trying different technologies. At the same time there is a risk of failure, blunders, mistakes, even death surgery. But in the course of extensive practice***, surgeon finds himself*** in the forms of strict rationality with its maximum achievable certainty, the requirement of *objectivity* of thinking. The subjectivity in assessing the facts and diagnostic findings is the most common cause of medical errors associated with lack of critical attitude of a doctor to his philosophics. Subsequently many years of operational experience and competence formation allows surgeon to achieve the maximum level of readiness for the active innovative surgical operation, improve constantly his medical knowledge and medical skills, apply new technologies, methods of operation, and make new constructive decisions. And that ***medical creativity*** is a byproduct of medical practice*; it is the very essence of it*! A successful operation when you use the latest achievements of medical science is an ***art***. It is safe to say that a doctor and especially a surgeon is not a profession, it is a ***vocation***.

In general, being a surgeon is one of the most difficult specializations of medical practice in constant readiness to conduct operations (sometimes in extreme situations and conditions). Moreover, the systematic preventing of patients, maintaining accounting records, etc. complement the responsibilities falling on his shoulders.

## System " surgeon — patient"

In the course of his professional work, surgeon is in contact with a patient's personality. In this interaction between doctor and patient there are many cognitive aspects that reflect the personality characteristics of these subjects.

Significant change in motivational sphere is peculiar for *patient's personality* expressed in the allocation of the leading motive and the installation - the preservation of life and health. With proper mindset and relationship, patient believes in the possibility and virtue of a doctor to cure him, hopes for recovery. The leading principle is *the principle of care and trust in a doctor* in fulfilling all his instructions, requirements, and assignments.

*Surgeon's personality* is characterized by the manifestation of individual psychological traits, properties, characteristics, and competencies. From this point of view, surgeon should be emotionally stable, physically healthy, firmly know his business. "Steel nerves", high stress tolerance, patience and thoroughness are just a few of the qualities that are essential to the specialist. On the reception of patients surgeon like any doctor must be sociable and polite as well as prompt and attentive from the point of view of professionalism, possess broad knowledge in different fields of medicine, and be aware of the necessary standard regulations in the field of health. Empathy, respect, interest, warmth and support are the key components of interpersonal skills of a surgeon.

In addition to cognitive aspects, there is a rich body of bioethical principles and mechanisms in collaboration of a surgeon and a patient in accordance with the strategic ***aim*** of modern medicine - a patient's well-being and health, which are subordinate to traditional classic goals - protecting health and life of a patient. The leading principle of biomedical ethics is the *principle of respect for the rights and dignity* of a man.

In its activity, surgeon as the subject of cognition has been *active* since he is interested in collaboration with a patient, without which his medical practice is simply impossible — no one to operate! The reason for a meeting of a doctor and a patient is a problem of the latter with health. Thus, a surgical patient cannot do without a doctor-surgeon, and surgeon — without a patient. Communication between a doctor and a patient can be called forced intercourse, as the main motive of meetings and conversations is the appearance of one of the participants in the interaction of health problems and doctor's "*forced" socializing* due to his profession. Activity of a surgeon as a professional depends on the results of this interaction. Thus , a surgeon, as a subject of medical practice, possessing the ability of self-awareness and self-development, ***replicates himself***, i.e. acts as a creative subject, improving his professional skills.

Additionally, in his active medical practice, a surgeon ***transforms*** the consciousness and inner world of a ***patient*** for recovery, as well as to provide information and humanitarian security of his medical practice. After all, the credibility of a doctor is at least 50 % of a treatment success. Therefore, patient as an object, is given to the surgeon, as a subject, in the forms of his activity. Taking into account the fact that a surgeon is constantly initiative and active, he "is a necessary pole of subject-object relations" [3, p. 156]. A surgeon as a subject ***transforms himself*** as well in relations with a patient.

But we should not forget that patient ***comes with activity***. He responds to any action of a surgeon – constructive or not very effective. Patient will also react in two ways: either "he will fit" in the architectural-constructive project of a surgeon, or "interact with a gap in harmony with him - like with "an extraneous body ", "an enemy", making an attempt on his health, freedom, inner peace. And in this sense patient is (becomes) also the *subjec*t, influencing interpersonal process (forces surgeon with flexible thinking and a well-developed empathy use appropriate psychological techniques and methods of communication), as well as his own process of self-discovery in preparation for surgery and postoperative period.

In different historical times there were the following models of ***medical ethics*** in the relationship of doctor and patient:

- *Model of Hippocrates* (5-4 centuries BC) - "do no harm", thus, doctor wins social trust of patient.

- *Model of Paracelsus* (the middle ages) - "do good" – there is an emotional and spiritual contact between doctor and patient (paternalism), kindness of a doctor, on the basis of which the entire treatment process is built.

- *Deontological model* (modern) - the principle of "confidentiality", based on strictly binding moral prescriptions of the medical community and society, as well as the will and mind of doctor.

- " *Honor Code* " - for each medical specialty; non-compliance is fraught with disciplinary action.

- *Oath of the Russian doctor* (1994) and the Code of medical ethics of the Russian Federation (1997) — for Russian doctors.

The following four synthetic ***models of the relationship between a doctor and a patient*** have been currently developed in the modern world [10]:

1) *Model of "technical" type* — a physician-scientist should "be impartial", rely on facts, avoid value judgments.

2) *Model of sacral type* – a paternalistic model "does not do harm", similar to relations between a parent and a child; refusal of morality by a patient, because he loses the ability to make decisions, he shifts them to a doctor.

3) *Model of a collegial type* - doctor and patient should treat each other as colleagues striving for a common goal - to eliminate diseases and keep the health of a patient.

4) *Model of a contract type* - a contract or an agreement between doctor and patient is the most consistent with real-life environment.

Doctor needs to take into account *patient's behavior pattern* towards him. There are kinds of different and even opposite relationships of patients to doctors like indifference, distrust, conflict, approval, admiration and even love. Doctor responds differently to these emotional forms of interpersonal contact. But in any case he must display moderation, interest in creating and establishing psychological comfort in interaction to enhance the motivational orientation of a patient to optimism, recovery, favorable outcome of disease treatment. "The most popular medication is the doctor himself. And if to you see it with the eyes of a patient, the identity of a doctor is the most powerful placebo" [1]. We should strive to release patient's negative feelings and develop positive emotions that can serve as a psychotherapeutic agent recovery and give unpredictable results recovery — for prompt, proper and adequate complex treatment.

Despite the diversity of approaches cooperation of surgeon and patient consists of four key components of the doctor 's behavior within his medical practice: support, understanding, respect, sympathy.

Medicine, as a branch of human activity, occupies a very special place because the science in it is *combined with such values* and approach that have nothing to do with science. ***Compassion*** as the basis of the medical approach is a human approach, outside of which medicine does not exist! However, compassion does not mean sentimentality. It is a *creative responsiveness to the suffering of a patient and his situation*. The response is creative enough to encourage a doctor to take action, with respect to a specific person and his significance [6].

## System "surgeon - surgeon"

Surgeon works in a team of a certain medical institution. Therefore, for successful work it is important to consider all the nuances of interacting with colleagues. In this regard, there is a distinction between individual and collective (group) medical (medical) entities.

*Surgeon as an individual medical subject* is an individual, ontical subject, individual surgeon, a specialist with individual natural-social characteristics, the activity of which is aimed at a patient as a medical subject. Cognitive functions of a competent personality of a surgeon reveals his perceptions of the world in terms of introduction of medical innovations in surgery, certain adaptation mechanisms, activation and regulation of the private medical educational activities.

The integration of all cognitive functions of a surgeon as an individual entity allows deploying innovative surgical activities in more extended scale. *Surgeon as a collective (group) subject* has the same functions of an individual subject, but of a larger scale and public nature, i.e. it is a carrier of specific code of practices, knowledge and collective consciousness. Medical staff of any medical institution (clinic, hospital, dispensary, medical institution/University, community/Association of surgeons, etc.) can be considered as a collective medical subject.

In relations between colleagues, there are following ***ways of behavior and interaction*** a) cooperation, collaboration; b) competition, rivalry. At the *micro level* (within a team of a specific medical institutions) and *macro level* (within the community of surgeons of the city, region or country) creative possibilities of each surgeon are revealed. ***Forms of communication and interaction*** between professionals are in form of meetings, consultations, presentations, extensive joint surgery, scientific and practical conferences, forums, congresses of surgeons of related specializations, etc.

In addition to the interaction of a surgeon with other surgeons, he contacts directly with physicians of other specialties (anesthesiology, resuscitation) and paramedical staff (nurses — operating, procedural, ward).

Doctor and nurse become a dominant couple, affecting other multidisciplinary interaction and in particular on the nature of the relationship with patients. Surgeon performs the role of diagnostician and prescribes treatment and nurses become performers, distributors of medication, etc. The relationship of physicians with fellow nurses is based on common sense, understanding, professional respect, tact, responsiveness, friendly cooperation. Surgeon realizes that a nurse performs the role of a real physician's assistant, his assistant and partner.

## System of "surgeon — society"

Surgeon as a subject acts in society. He interacts with others by means of various socio-communicative and other relations of a different nature such as spatial, psychological, interpersonal, professional, group, national, universal, etc. It is considered that a "real" doctor is a benchmark for wide public not only in matters of health protection (for example, he must not smoke, drink alcoholic beverages, has to lead an active lifestyle, eat well), but also morality. There is an opinion that a doctor should be fully committed to medicine, compassionate, self-rigorous, moderate in his demands, sensible with assessments and able to develop strength of spirit and determination in difficult situations.

## System of "surgeon — self"

Here a cognitive model of a surgeon is based on the synergy of anthropological and methodological characteristics of the flexible rationality, i.e. the peculiarities of his temperament, character, memory, perception, attention, imagination, will, abilities, etc.

Under normal conditions, the **temperamen**t is manifested only in the peculiarities of an individual style, without defining the performance of a surgeon. In extreme situations (surgery, complex cases, accidents, deaths, conflicts with patients, colleagues, administration, etc.) the influence of temperament on the efficiency of enhanced, learned behaviors becomes ineffective, requires additional energy to mobilize the body. Knowing your temperament, surgeon must rely on positive qualities and overcome negative ones.

Temperament serves as a common foundation of many other personality traits, especially **characte**r. Temperament does not determine the path of development of specific features of character, temperament itself is transformed under the influence of character qualities. The development of character and temperament in this sense is interdependent. The interweaving of various features of character and temperament largely determines surgeon’s individuality, his personality, his charisma. Surgeon should be strong and courageous. Strength of character must be used for the benefit of a patient. Amenity of temper and a sense of compassion, inherent in every intellectual demands from a surgeon to have his boundaries. He must show ruthlessness when necessary for the benefit of a patient and it is impossible to do without it.

For successful operations special voltage of psyche is needed- **will**, power, control over actions, behavior and moods. Will, restraint and self-control in dramatic conflict or unforeseen extreme situations on the operating table require the mobilization of all mental reserves in order to suppress involuntarily arising situations like feelings of fear, confusion and hopelessness.

Another quality that surgeon must possess is a **flexible intelligence**, an ability to make quick, sometimes instant decisions and implement them rapidly. Slow-wittedness and slowness of a surgeon goes bad for a patient. At the same time, an ability to transform thoughts into solutions and solutions into actions has saved a lot of lives. Therefore, surgeon needs to treat each decision with a sense of responsibility, remembering that failure to comply with the decision relaxes the will. The thought of a surgeon is a marching orders. Words actually affect the body.

Most doctors' labor is characterized by a significant intellectual burden, in some cases, accompanied by large physical efforts, and always places high demands on operational and **long-term memory, attention, stamina**, long-term preservation of health and complex of personal qualities of a doctor, allowing him to work in contact with sick people during the whole professional experience, while maintaining the required level of professionalism and compassion.

Doctor, especially a surgeon, is constantly in a state of chronic **stress**. It should be removed. Throughout activity of a surgeon such things as profession pride, boundless faith in it, faith in its humanity and usefulness to society, surgical creativity help the doctor especially in difficult periods. It perfectly demonstrates the unity of the empirical and the rational, since will is certainly made up of two different elements –art of handwork (tactile dexterity, dexterity) and scientific thinking. One without the other will prove fruitless. It requires *clarity and speed* of a violinist's and a pianist's fingers, *accuracy of a good eye* and *alertness of a hunter*, an *ability to distinguish the slightest nuances of color and shades*, like the best artists do, *a sense of form and harmony of the body*, as the best sculptors possess, *care of lace makers and embroiderers of silk and beads, the skill of cutting inherent to experienced cutters and model shoemakers*, and most importantly *–an ability to sew and tie knots with two or three fingers blindly*, at great depth, i.e. showing features of professional magicians and jugglers. Many surgical operations are as precise as carpentry and locksmith services with the use of thin mechanical techniques. Operations are sometimes similar to artistic appliques or mother-of-pearl and precious woods inlays and eye surgery, in particular, requires jewelry work. So, the extraordinary complexity of the abdominal topography and pathology requires from an abdominal surgeon not only properties, knowledge and ingenuity of architects and engineers, the courage and determination of the generals, the sense of responsibility of lawyers and statesmen, but also high technical skill orientation, excellent techniques of sewing and cutting and true art in solving puzzles , presented with many cases of close-loop obstructions and volvuli [See: 2]. Overall, a perfect surgeon must have the following qualities: accuracy – imagination – the talent of the Creator – scientific curiosity – patience – humor — luck.

## Conclusions

Cognitive modeling of performance and conduct of the surgeon is based on the understanding of the status of the surgeon as the activity of the cognizing subject. His social and natural qualities are manifested in a certain perspective that a physician regulates, directs, and corrects, in accordance with the requirements of medical practice. Determining factors and source activity is the surgeon's compassion, commitment and activity, revealing his nature and essence as a professional.

In general, operating surgeon is characterized by rational *epistemological* properties (as the creator of the models to their surgical operations) and *empirical* (ontical, irrational) of the cognitive qualities that are combined to create the ***integrity*** of the surgeon as to the perceptive activity of the subject in all its guises and manifestations. The combination of *rational and irrational* in each surgeon contributes to the diversity of interpretations, decisions, projects operating on patients, and determines the charisma of a doctor and the complexity of his behavior as a specialist-professional.

Modern practicing surgeon understands the ethical standards of professional patient research, quality improvement of his health and essence. The *mentality* of a modern doctor includes philosophical, moral and ethical qualities, the ideas of true humanism, the desire to possess aggressively psychological and philosophical knowledge, professional skills within the framework of deontology as a science of care duty.

Surgeon as the subject of cognition is the generator of all these interweaving and transformations thanks to the constant activity of his consciousness and self-awareness. As Nietzsche said, "the light is inside me."

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## Authors' Information


*Vitaliy Zinakov - Rostov Regional Oncology Center. Rostov-on-Don, Russia.*

*Major Fields of Scientific Research: cognitive science; endoscopic surgery, abdominal surgery, surgery on soft tissues, abdominal and pelvic organs; reconstructive surgery on the gastrointestinal tract and other organs.*

*E-mail: v_zinakov@mail.ru*



*Svetlana Masalóva - Rostov institute of advanced training and professional retraining of educators. Rostov-on-Don, Russia.*

*Major Fields of Scientific Research: cognitive science, methodology of science, philosophy, philosophy of science, philosophy of education, cultural studies, religious studies, and others.*

*E-mail: msi7@mail.ru*

# CONTEXT DEPENDENCE OF COOPERATION INDEX JUDGMENT SCALES IN PRISONER'S DILEMMA

**Maurice Grinberg, Evgeniya Hristova**

***Abstract**: Context effects in the iterated Prisoners' Dilemma (PD) games are investigated with special focus on dynamical effects, i.e. effects due to interactions between the players in the course of the game. Cooperation index is computed as a ratio of the payoffs and is used to characterize how cooperative a given PD game is. The context is set by a first stage of the experiment in which games with low (0.1 and 0.3), high (0.7 and 0.9) and full (0.1–0.9) range of the games' cooperation index are played by different groups of players. In a subsequent stage, differences between the groups are found in the evaluation of how people would play in games with the full range of cooperation indexes. In the three groups, correlations between the previous game outcome and the following move are established showing a peak in the cooperative moves after a game in which both players have been cooperative. Possible relations of the results obtained with similar psychophysical findings are discussed.*

***Keywords**: cooperation, context effects, social interactions, experimental game theory*

## Introduction

In recent years, more and more attention has been paid to the difficulties encountered by rational choice theory when applied to social phenomena involving interactive decision making e.g. [Colman, 2003]. These difficulties are related to the fact that in complex decisions the lack of information about other people's choices, time and resource limitations make the outcome unpredictable by any pure rational theory.

In game theory, based on the expected utility theory, the basic assumption is that each prospect (game) is considered separately and the resulting choice should be based only on the attributes (respectively, utility) of the particular prospect or game.

In experiments, however, people behave more 'irrationally' and receive higher payoffs than rationality theory would predict. It is widely accepted now that a strict theory of rationality is evidently insufficient for explaining human interaction [Colman, 1995]. The problems that this theory encounters when trying to describe or predict the outcomes of experiments are due mainly to the non-accounting of context effects. There are many experiments that demonstrate the influence of context in judgments and decision making and theories accounting for these effects (e.g. the range-frequency theory [Parducci, 1974], its extension to multi-attribute judgments [Cooke & Mellers, 1998], the expectation driven assimilation and contrast model [Manis, Biernat & Nelson, 1991].

Although most of these theories deal with perceptual stimuli or involve a choice among a set of alternatives, it can be expected that they can be applied to choices of moves during playing as well. This could be possible especially in the case when the games can be distributed in a range defined by some quantity derived from the payoffs. In PD games, we are dealing with in this paper, such a quantity is the Cooperation Index (CI) [Rapport & Chammah, 1965].

In order to check this assumption, several experiments with PD games have been performed [Vlaev & Chater, 2007]. They demonstrate the existence of context effects – effects of assimilation and contrast – due to the different range distribution and different combinations of games with respect to CI. In these studies, the basic assumption is that during decision making (choice of a move in a game) people employ the same judgments and comparison processes as during perceptual tasks, and hence the same principles and mechanisms are involved, which would lead to context effects that are similar to the ones observed in perceptual tasks (like magnitude estimation for example).

In the present paper, a somewhat different approach was chosen, based on the same assumptions. Firstly, we tried to explore the context effect due to a preliminary exposure to PD games with specific CI range on subsequent judgments about the likely choices made by the subjects for PD games taken from the whole CI range. Secondly, we wanted to determine to what extent the moves made by the subjects were influenced by the time-course of the game, by previous players' moves and game outcomes, which we call in the paper 'dynamic' context effects (see the discussion of similar effects in [Rapoport & Chammah, 1965]; and of sequential effects in [Parducci, 1974]).

The article is organized as follows. In Section 1, the goals of the article are stated and discussed as well as the hypotheses to be tested. In Section 2, an outline of the experimental design is presented. The results from the experiment are presented and discussed in Section 3. In Section 4 we give a general discussion of the experimental outcomes and draw some conclusions.

## 1. Goals and Hypotheses

### *Goals*

In order to study the context and dynamic effects, considered above, we use the well-known PD game. We are interested in how the decisions subjects make are influenced by context (e.g. range of other games' CI in the sequence), by the dynamics of the playing and by the different payoffs in the game (reflected by CI in each PD game). On the other hand, we want to study how context, which in our case are the previously played games taken from the lower or higher CI range, affects the judgments of people's likely moves in games from the full CI range.

### *The Prisoner's Dilemma Game*

The payoff table for this game is presented in Figure 1. The players simultaneously choose their move – *C* (cooperate) or *D* (defect), without knowing their opponent's choice.

**Player II**

| Player I | | *C* | *D* |
|---|---|---|---|
| | ***C*** | **R, R** | **S, T** |
| | ***D*** | **T, S** | **P, P** |

Figure 1: Payoff table for the PD game. In each cell the comma separated payoffs are the Player I's and Player II's ones, respectively. The payoffs R, S, T, P satisfy T > R > P > S and 2R > T + S.

In an isolated game, the *D* strategies are strongly dominant for both players because each player receives a higher payoff by choosing *D* rather than *C* whatever the other player might do. The dilemma is that if both players adopt *D* strategy, the payoffs (P, P) are lower for both of them than if they both had chosen dominated *C* strategies. In the latter case however, they have to trust their opponent and take the risk of getting the lowest payoff – S (taken to be 0 in the present experiment).

Rapoport and Chammah [Rapoport & Chammah, 1965] have proposed the so-called Cooperation Index (CI) with CI = (R–P)/(T–S), as a predictor of the probability of C choices, monotonously increasing with CI. In Figure 2 two examples of PD games with CI equal to 0.1 and 0.9, respectively are presented.

**Player II**

| Player I | C | D |
|---|---|---|
| **C** | 56, 56 | 0, 60 |
| **D** | 60, 0 | 2, 2 |

CI=0.1

**Player II**

| Player I | C | D |
|---|---|---|
| **C** | 56, 56 | 0, 60 |
| **D** | 60, 0 | 50, 50 |

CI=0.9

Figure 2: Examples of PD games with different CI.

Further in the paper, we assumed that CI defines a scale (a cooperativeness scale), along which the PD games can be distributed. By treating cooperativeness as a cognitive dimension measured by CI, we can borrow concepts from psychophysics and investigate for the existence of context phenomena in judgment and decision making similar to those found in psychophysics (see [Vlaev & Chater, 2007]).

***Hypotheses***

In the light of the goals presented above the following hypotheses are tested:

- When primed with *low-* or *high range CI* games sessions, we expect a change in the whole subject's judgment scale similar to the one observed in psychophysical experiments. The subjects who participated in the *low range CI* condition will underestimate the cooperativeness of the games and those who participated in the *high range CI* condition will overestimate the cooperativeness of the games over the full range of CI's.
- Players move choices depend not only on the game at hand or the combination of games in a session, but also on the previous moves of the player and his opponent, and on the previous game outcomes in the session.

## 2. Method

### *Experimental design*

The experiment had three parts. In the first part, subjects played a sequence of PD games against a computer. There were three experimental conditions that differed in the CI range of the games.

In the second part, the subjects were asked to judge what people would play in a set of full CI range games, using a 7-point scale. In this stage, we expected to find some differences between the three groups, corresponding to different experimental conditions from the first part.

In the third part of the experiment, we wanted to explore the way subjects perceive games without playing them. In this part, we test if subjects distinguish PD games according to their CI. This would justify the consideration of the latter as an analogue to a psychophysical quantity.

**Part 1. Play Against the Computer.** Each subject played 50 PD games against the computer. On the interface, the moves were labeled ‘1’ and ‘2’. Further in the paper, we will use for convenience *cooperation* (C) instead of move ‘1’ and *defection* (D) instead of move ‘2’.

The computer uses a modified version of the tit-for-tat strategy that takes into account the 2 previous moves of the player. This allowed the subject to choose her own strategy. The payoffs were presented as points, which were transformed into real money at the end of the experiment. The subjects were asked to play in a way to maximize their score. No emphasis on cooperation and defection has been made. After each game, the subjects got feedback about their and the computer’s choice and could monitor permanently the total number of points they have won and its money equivalent. The subjects received information about the computer’s payoff only for the current game and had no information about the computer’s total number of points. This was made in order to prevent a possible shift of the subject’s goal – from trying to maximize the number of points to trying to compete with the computer by just earning more points than it, as observed in the pretests. Thus, the subjects were supposed to pay more attention to the payoffs and their relative magnitude and indirectly to CI.

The games were randomly generated for each subject with maximal payoff T between 22 and 78 points in order to avoid possible effects due to large differences between the values of the payoffs in different games. Games were presented in a random order with respect to CI.

There were three experimental conditions that differed in the CI ranges of the games played.

- *Control* condition – each subject played 50 games covering the whole range of CI, including 10 games for each CI equal to 0.1, 0.3, 0.5, 0.7, and 0.9, respectively.

- *Low-range-CI* condition – each subject played 50 games, including an equal number of games with CI equal to 0.1 and 0.3.
- *High-range-CI* condition – each subject played 50 PD games with high-range CI, including an equal number of games with CI equal to 0.7 and 0.9.

**Part 2. Game ratings.** Subjects were asked to make judgments for different games, covering the whole CI range, about their cooperativeness. 35 PD games (equal number of PD games with CI = 0.1, 0.3, 0.5, 0.7, and 0.9) were presented on the computer screen one at a time. The subjects had to respond to the question 'What do you think people would play in this game?' using a 7 point scale – from 'definitely 1 (*C*)' to 'definitely 2 (*D*)'. Subjects did not receive feedback after each game if their rating was right or wrong. But at the end of this part of the experiment they received additional points (money) for their ratings. In this stage, we expected to find some differences between the three groups due to the different experimental conditions in the first part.

**Part 3. Free game grouping.** Subjects were asked to group 20 games (4 for each CI equal to 0.1, 0.3, 0.5, 0.7 and 0.9, respectively) and specify the criteria applied. The results were transformed in a similarity matrix and used in a multidimensional scaling (MDS) procedure. Here, we wanted to explore the way subjects perceive PD games without playing them (thus discarding direct dynamical effects).

### *Participants*

There were in total 90 participants divided into groups of 30 subjects per condition (42 males and 48 females). All were university students with an average age of 23 years (ranging from 18 to 35 years).

### *Procedure*

Each subject was randomly assigned to one of the three experimental conditions and after being instructed played 9 training games. All subjects participated in all three parts of the experiment and were paid according to the number of points they have got during the experiment.

### *Dependent variables*

**Cooperation** is measured as the fraction of games in which subjects chose move *C* in the first part of the experiment. It is assumed that cooperation will be influenced by CI of the games, the context (CI range), and the dynamics of the playing.

**Cooperation ratings** (CR) are judgments subjects made in the second part of the experiment. These ratings were related to the likely move for a given game. In the analysis, these ratings are transformed in cooperativeness ratings. The lower is the scale value on the 7-point scale the higher is the perceived cooperativeness of the game and the higher is the CR. CR are expected to depend on games' CI and on context – the range of the CI of the games played in the first part of the experiment.

The research presented in this article was guided by the broad goal of studying deeper cognitive effects on how people make decisions in iterated PD game. More specifically, we wanted to check to what degree a CI judgment scale exists, how and when it is used by the participants and to what extent it is influenced by relevant context.

By 'context' in the present experiment we understand the specific CI range of the games in a given game sequence played by subjects (e.g. CI = 0.1, 0.3 and CI = 0.7, 0.9 are called low-range-CI and high-range-CI contexts). We expected to observe a change in the judgment scales about appropriate game moves due to this type of context. It was anticipated that subjects who played PD games in a low-range-CI context will underestimate the cooperativeness of the PD games and vice versa, subjects who played PD games in the high-range-CI will overestimate the cooperativeness of the PD games. Moreover, when priming with low- or high-range-CI game sessions, we expected a change in the whole subject's CI scale, including the full range of possible CI values.

### *PD games used in experiment*

The payoff matrices were randomly generated in order to avoid memory effects or big differences in the payoffs for games with the same CI that could favor different strategies (e.g. subjects could pay more attention to games with higher payoffs than to games with the same CI but with much smaller payoffs). Oskamp and Perlman [Oskamp and Perlman, 1965] claimed that the average payoff per trial ((T+R+P+S)/4, see Figure 1) is a very important factor with significant effect on the level of cooperation. Taking this into account, we generated the games so that T is between 22 and 78 points (mean 50), R was between 11 and 76 points (mean 41), P was between 1 and 66 points (mean 16). For simplicity we set S = 0. The mean average payoff per trial was 27 points (SD = 9 points). In order to make the subjects concentrate exclusively on the payoff table when making their choice, they were instructed to try to maximize their payoffs and not for instance to compete with the computer.

The game was presented to them in a formal and a neutral formulation to avoid as much as possible other factors and possible contexts. No cooperation or defection was mentioned in the instructions. Subjects were not informed about the existence of CI.

## 3. Results and Discussion

### *Subjects with different strategies with respect to CI*

In the first part of the experiment, we defined the context with respect to game sets with different CI range. However, CI is not a PD game characteristic obvious to the subjects. Although it is intuitive (it is reasonable to cooperate more when R is high and P and T are relatively low), there is no guarantee that all of the subjects were able to take advantage of it in their move choices.

As the data from the present experiment show, confirming well known previous results (see e.g. [Rapoport & Chammah, 1965]), there is a significant influence of CI on the cooperation rate in all three context conditions – subjects cooperate more in PD games with higher CI. However, if we look more closely at the data, not all of the subjects in each condition follow this trend. As a factor analysis showed, two groups of strategies can be singled out. For the first strategy (called further CI-based strategy) the dependence of cooperation with CI is a monotonously increasing function while for the second strategy (non-CI-based strategy) no such dependence is seen (see Figure 3). In the full-range-CI (control), low-range-CI and high-range-CI groups there were 12, 13 and 14 subjects, respectively, whose play was consistent with the CI-based strategy. The remaining subjects did not base their strategy on CI.

The mean cooperation, however, was not significantly different for the CI-based and non-CI-based strategies – 36% and 25% ($F(1, 28) = 3.8$, $p = 0.061$) for the full-range-CI group, 24% and 21% ($F(1, 28) = 0.18$, $p = 0.675$) for the low-range-CI group, and 43% and 42% ($F(1, 28) = 0.005$, $p = 0.944$) for the high-range-CI group, respectively.

The analysis of the non-CI-based strategies did not reveal any single simple strategy based on previous moves, game outcome or interaction with the computer. It is also possible that some of the subjects from the non-CI-based group paid attention to the general structure of the payoff matrix and not to the relative magnitudes of the payoffs thus eliminating the CI dependence from their moves.

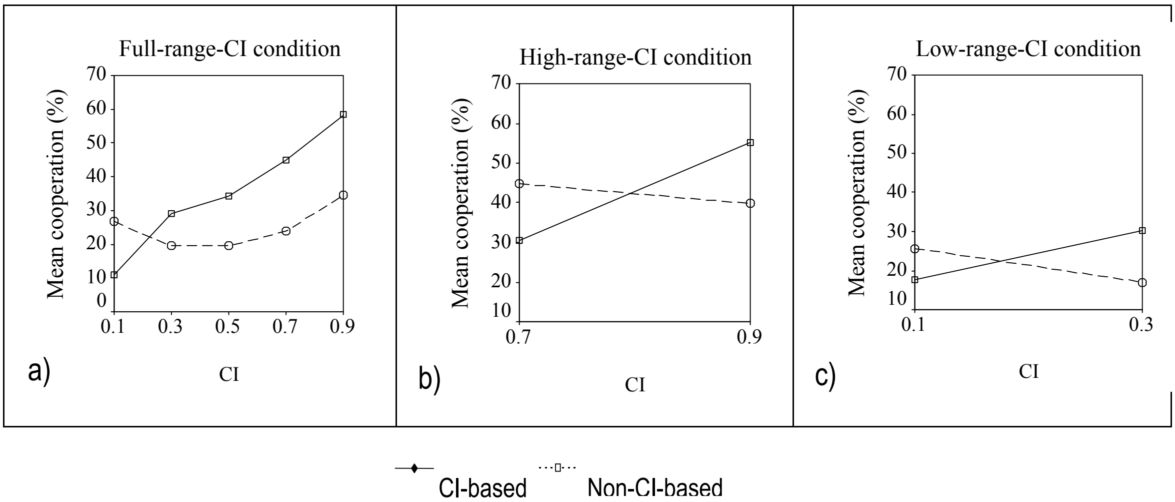


Figure 3: Mean cooperation (% of C choices), in part one of the experiment, for PD games with different CI for subjects with different strategies. a) Full-range-CI condition; b) High-range-CI condition; c) Low-range-CI condition

Whatever the strategy used, the question arises whether the subjects from this second group are sensitive at all to CI. The second part of the experiment shed some light to the answer of this question.

### *Context effects on cooperation ratings*

As stated earlier, our main goal in this paper is to check if the judgments about the cooperation ratings of PD games are influenced by the previously played games. We expected context (defined by the CI range of the games played by each subject group in the first part of the experiment) to influence cooperation rating in the second part of the experiment.

In order to perform this analysis, we computed mean cooperation ratings for the games with the same CI. These average cooperation ratings were analyzed in a repeated-measures analysis of variance with CI as a within-subjects factor and the experimental condition (full-range-CI (control) vs. low-range-CI vs. high-range-CI) as a between-subjects factor. The sphericity assumptions were not met, so the Hyunh-Feldt correction to the degrees of freedom was applied.

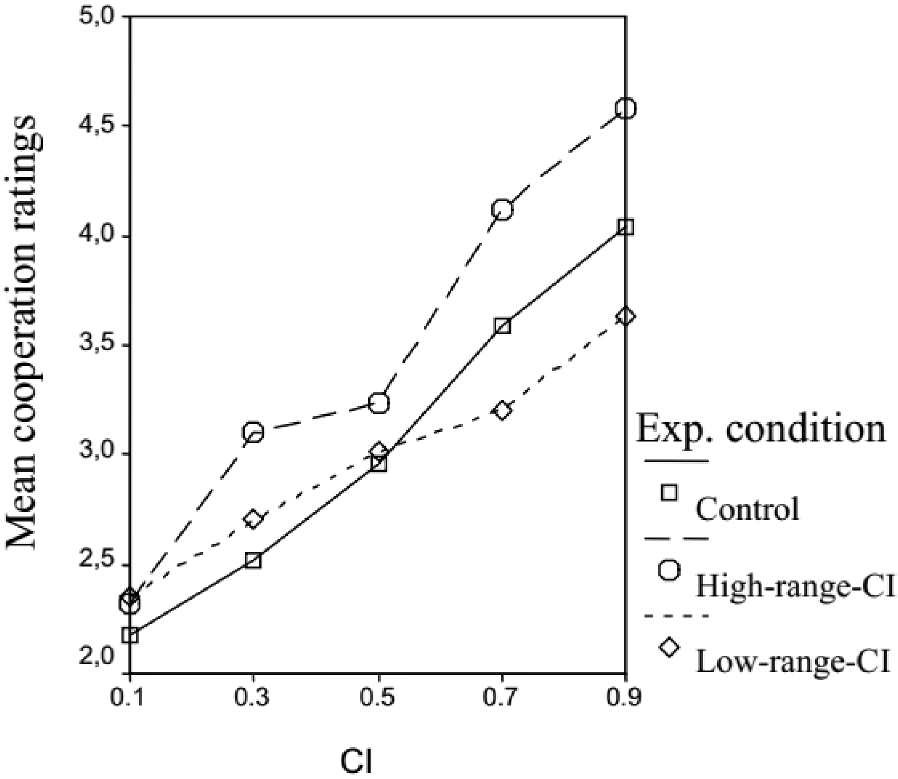


Figure 4: Comparison of the estimated mean cooperation ratings as a function of CI between the three experimental groups.

The interaction between CI and the experimental condition was found to be statistically significant – F(5, 227) = 2.59, p = 0.025 (see Figure 4). In order to compare the experimental groups for each level of CI, a post-hoc test was used. We found a significant difference in the cooperation ratings between the high-range-CI and the low-range-CI experimental conditions for CI = 0.7 (F(2, 87) = 4.98, p = 0.09) and CI = 0.9 (F(2, 87) = 4.1, p = 0.02).

These results confirm our main hypothesis about the influence of context on cooperation ratings.

Further, it is interesting to analyze what are the contribution to this effect coming from the two strategies delineated in each experimental condition – the CI-based and the non-CI-based strategies. To see this, we carried on the same analysis as for the whole experimental groups separately for each strategy subgroup (see Figure 5).

**CI-based strategy group.** The main effect of CI is significant ($F(3, 109) = 44.85$, $p < 0.001$). Subjects gave higher cooperation ratings with increasing CI (see Figure 5a). Although the main effect of the experimental group is not significant ($F(2, 36) = 2.247$, $p = 0.12$), there is a statistically significant interaction between CI and the experimental group ($F(6, 109) = 2.196$, $p = 0.048$). We found also a significant difference in the cooperation ratings between the high-range-CI and the low-range-CI conditions for CI = 0.7 ($F(2, 38) = 4.62$, $p = 0.016$) and CI = 0.9 ($F(2, 38) = 3.66$, $p = 0.036$). The subjects in the high-range-CI group gave higher overall cooperation ratings compared to the subjects in the low-range-CI group. This result is in accordance with our preliminary hypotheses. This effect is stronger for higher CI (0.7 and 0.9) and indiscernible for CI = 0.1. One possible explanation for the latter is that the strategy D is the dominant strategy for one-shot PD games and remains prevalent for iterated PD as well. The number of moves C is relatively small and is about 20% for low CI. This can lead to very small differences in cooperation for the different context conditions, which are beyond the sensitivity of the present experiment.

**Non-CI-based strategy group.** Surprisingly, in the non-CI-based strategy group, the main effect of CI was also significant ($F(3, 137) = 33.12$, $p < 0.001$). Subjects gave higher cooperation ratings with increasing CI as in the CI-based strategy group (see Figure 5b). However, neither the main effect of the experimental group ($F(2, 48) = 1.625$, $p = 0.208$) nor the interaction between CI and the experimental group ($F(6, 137) = 1.039$, $p = 0.402$) were significant. Thus, no context effect was observed for the non-CI-based group despite the fact that they took into account CI in their judgments.

This result can be explained by assuming that only the CI-based strategy group from part one of the experiment was influenced by the manipulation of the context (playing different sets of games with respect to CI). The non-CI-based group although sensitive to CI, as evinced by the judgment task in the second part of the experiment, didn’t pay or paid less attention to the payoff’s relative magnitudes and thus remained uninfluenced by the context.

In this way, it seems that the context effect observed in the experiment came mainly from subjects with the CI-based strategy in part one (see Figure 5a). The non-CI-based group was not influenced noticeably by the context. The latter, however, showed the same qualitative dependence of cooperation on CI and demonstrated that all subjects were sensitive to CI. In order to understand better this relation we analyze for each experimental group the difference between the two strategies in cooperativeness ratings.

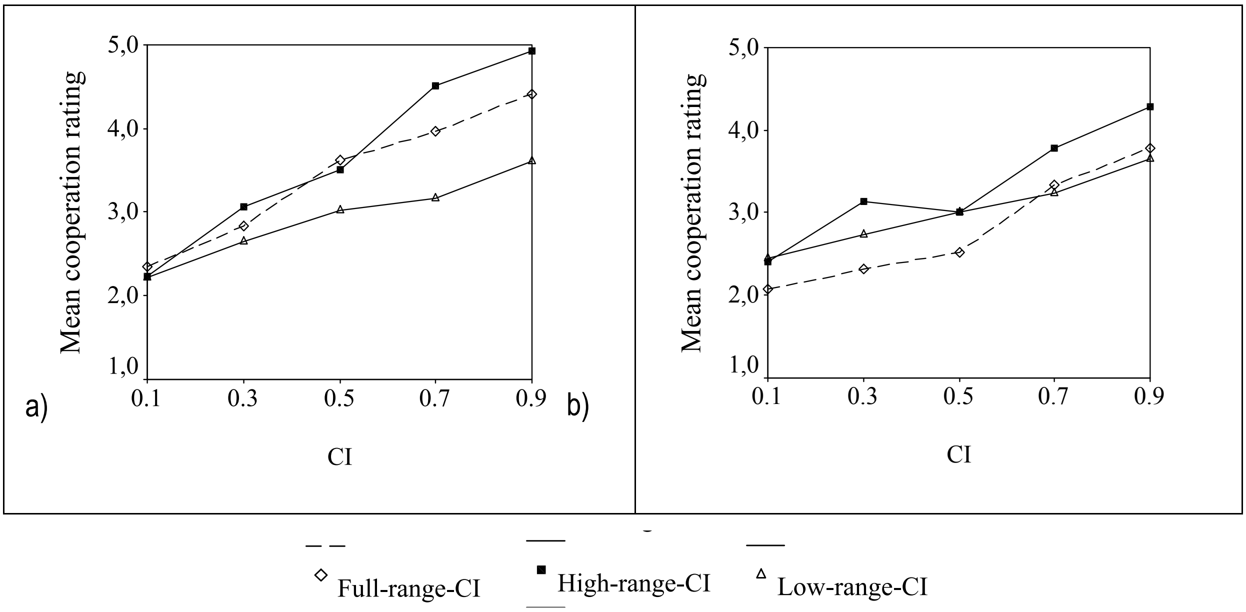


Figure 5: Mean cooperation ratings for PD games with different CI for each experimental condition: a) CI-based strategy subjects; b) non-CI-based subjects.

In Figure 6, the same data as the one plotted in Figure 5 is presented, but for each experimental condition.

In the full-range-CI condition, the CI-group gave more cooperative ratings than the non-CI-group ($F(1,28)=6.35$, $p = 0.018$). On the other hand, both groups of subjects show CI sensitivity in their judgments – they give higher ratings for games with higher CI. The effect of CI is significant ($F(3, 66) = 32.76$, $p < 0.001$) and the interaction between the CI and the strategy is not significant.

a)

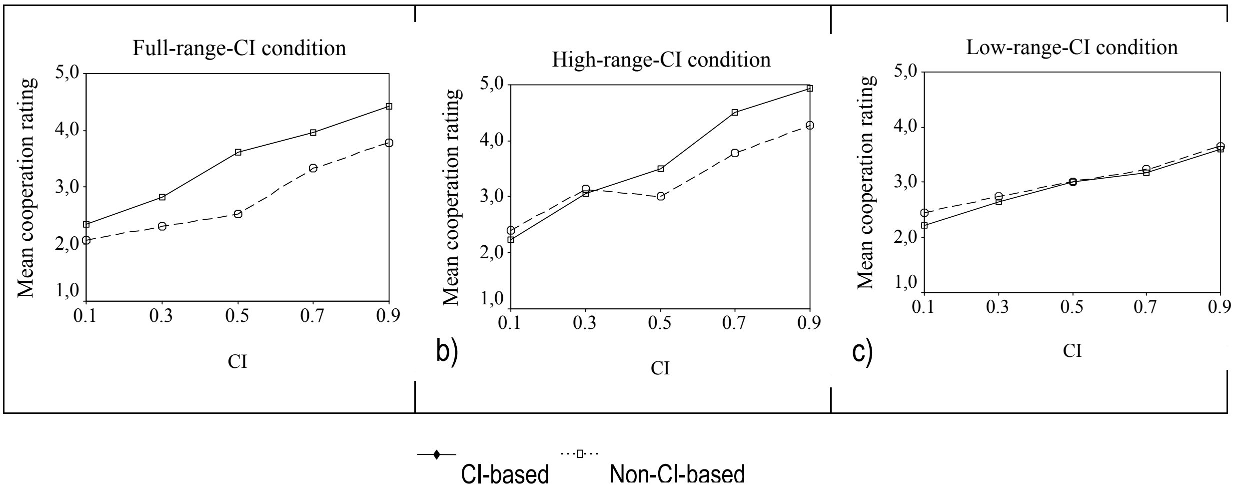


Figure 6: Mean cooperation ratings in part two of the experiment for PD games with different CI for subjects with different strategies. a) Full-range-CI condition; b) High-range-CI condition; c) Low-range-CI-Condition.

In high-range-CI and in the low-range-CI condition there is no significant difference in the cooperation ratings between the two strategy groups of subjects. Both groups of subjects show CI sensitivity in their judgments – they give higher ratings for games with higher CI. The effect of CI is significant ($F(3,79) = 37.85$, $p < 0.001$ and $F(3,68) = 11.6$, $p < 0.001$, respectively). The interaction between CI and the strategy is not significant.

Therefore, all subjects gave higher cooperation ratings with increasing CI. In this part of the experiment, they were not engaged in playing and the main basis for cooperation ratings was the payoff matrix.

It is interesting to note that in Figure 6, full CI scales can be seen even for the low-range-CI group and for the high-range-CI group, which have not seen the full CI range of games. Recently, the question of the existence of absolute scales has been discussed (see e.g. [Stewart et al., 2003]) and the case made that subjects do not have absolute scales.

***Multi-dimensional scaling***

In the third part of the experiment subjects had to divide 20 games into similarity groups with respect to the magnitude and structure of the payoffs. No context effect has been found in the grouping in the three experimental conditions. The similarity tables were strongly correlated ($r > 0.85$, $p < 0.001$) and the data have been analyzed together. The MDS revealed that at least three dimensions are needed to explain the grouping done by the subjects.

In Figure 7, a two-dimensional solution is presented, corresponding to the two most important dimensions. It shows clearly separated groups of games with the same CI. This result confirms that subjects effectively distinguish games with respect to their CI.

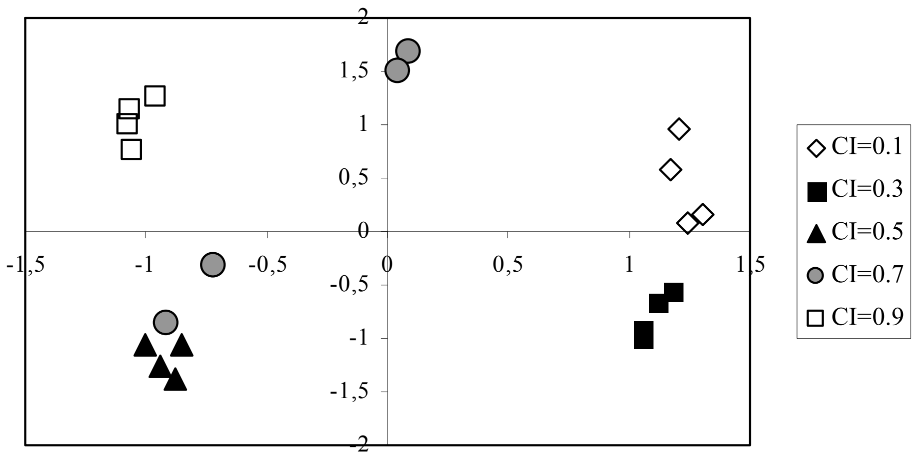


Figure 7: MDS results for games with different CI.

***Effect of CI on Cooperation***

It is largely accepted that when the CI increases the relative number of C choices also increase.

For each experimental condition, cooperation (the fraction of cooperative choices in %) was analyzed in a repeated-measures analysis of variance with CI as a within-subjects factor. The main effect of CI on cooperation was significant for the control condition, $F(4,116) = 11.43$, $p < 0.001$ and for the high-range-CI condition, $F(1,29) = 7.192$, $p = 0.012$. It was not significant for the low-range-CI condition.

In the control condition, although the main effect of CI was significant, planned contrasts showed that the cooperation increased only for PD games with CI = 0.9. In the low-range-CI condition, there was no significant difference in cooperation for games with CI = 0.1 and CI = 0.3. In the high-range-CI condition, the cooperation for games with CI = 0.9 was significantly higher than the one for games with CI = 0.7. It seems that the effect of CI is observed only for higher CI (0.9). When CI is between 0.1 and 0.7, there is no significant difference in cooperation.

There are several possible explanations of these results. One possibility may be that subjects cannot distinguish between CI lower or equal to 0.7. It seems that this is not the case as indicated by the results of MDS and by the fact that there was very strong effect of CI on CR subjects made. Another possibility is that cooperation is influenced in greater extend by other factors, such as the game dynamics and context.

**Effect of previous game on cooperation.** Performing this analysis, we wanted to test whether a particular player's move depends only on the game at hand (payoffs, structure etc.) or also on the previous moves and game outcome.

In Figure 8, the relationship between game outcome and next move is shown. When the previous game outcome was DD, CD or DC the cooperation was between 26 and 28%. However, in the case of a CC outcome the cooperation increased to 56 %, $\chi^2 = 208.3$, $p < 0.001$.

The increase in the cooperation when the previous game outcome was CC was more prominent in high-range-CI condition – from 32–38% (for all other game outcomes) to 68%. The increase in cooperation was also significant for the control condition (from 26–29% to 41%) and for the low-range-CI condition (from 20–21% to 44%).

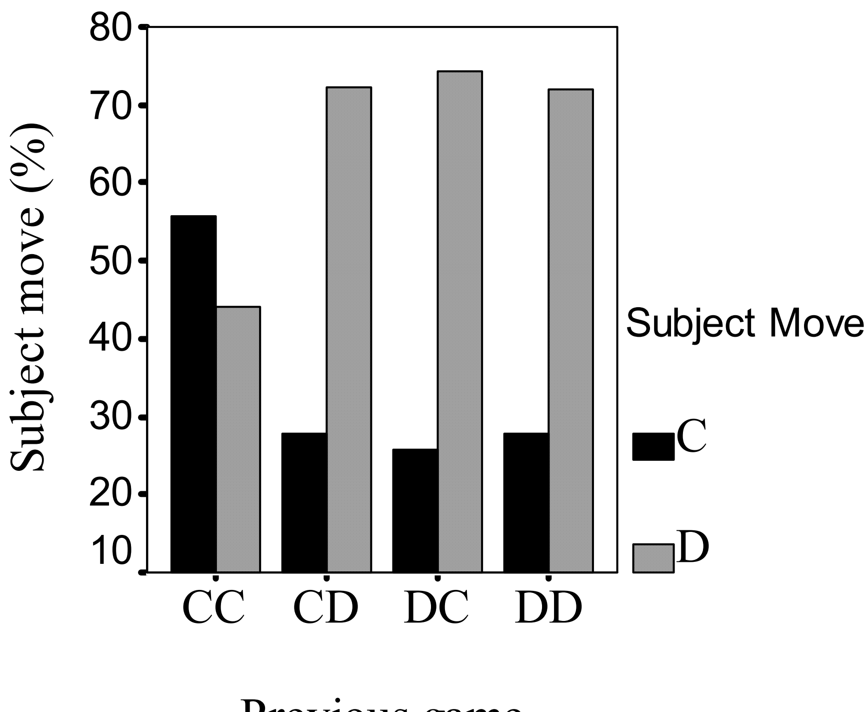


Figure 8: Effect of the previous game outcome on subjects' moves.

## 4. Conclusion

In this paper, we presented an experiment designed to investigate dynamical and context effects in iterated PD games. The initial hypotheses were confirmed largely. Context effects were observed both in subjects' choices in the first part of the experiment and in their cooperation ratings in the second.

In the second part of the experiment, significant differences between experimental conditions have been observed. Subjects participating in the low-range-CI condition gave lower cooperation ratings for PD games with CI equal to 0.7 or 0.9 than subjects participating in the high-range-CI condition. On the other hand, for the other values of CI no significant difference could be found. One possible reason is the fact that move D is the most probable (more than 70% of the cases) and we could not reach statistical significance although differences may have been present. A future experiment must shed light on this problem.

Probably these results mean that in the iterated play of PD games, there are strong dynamical context factors that influenced the subjects' decisions apart from CI of the current game. The most important of them was found to be the previous game outcome. Subjects made more choices that are cooperative after a game where both players have cooperated, compared to cases with different outcomes. Additionally, a tendency was observed in the first part of the experiment, that in the course of the game the cooperative choices decreased. This effect was most pronounced for the high-range-CI condition and shows an initial cooperative attitude, although the subjects played against a computer.

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The obtained results demonstrate the complexity of the cognitive processes involved in PD game playing and cooperativeness judgment. They support the conclusions that subjects are influenced by previous experience (context) in their judgment of the cooperativeness of PD games. Interestingly, subjects who did not take CI into account in their actual strategy choices were also influence by CI in their cooperation ratings. The finding that participants are sensitive to CI no matter how they play is supported by the MDS analysis. The fact that this sensitivity to the payoff structure is not seen in actual play is attributed to the dynamic of the play related to the moves of the opponent and the respective game outcomes which was evidenced by the found dependency on the previous game outcome.

## Acknowledgments

The paper is published with partial support by the ITHEA ISS (www.ithea.org), the ADUIS (www.aduis.com.ua), and the Central Fund for Strategic Development of the New Bulgarian University.


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## Authors' Information


***Maurice Grinberg, PhD –*** *Associate professor, Research Center for Cognitive Science, Department of Cognitive Science and Psychology, New Bulgarian University, 1618 Sofia, Bulgaria; e-mail: mgrinberg@nbu.bg*

*Major Fields of Scientific Research: decision making, cognitive modeling, experimental game theory.*

***Evgeniya Hristova, PhD*** *– Assistant professor, Research Center for Cognitive Science, Cognitive Science and Psychology Department, New Bulgarian University, 21 Montevideo str., Sofia, Bulgaria; e-mail: ehristova@cogs.nbu.bg*

*Major Fields of Scientific Research: Moral judgment, Social Dilemmas, Eye-tracking, Biosignal-based research*

# ECOLOGICAL AND ECONOMIC SECTOR INTERACTION MODELING WITHIN THE KYOTO PROTOCOL LIMITS FRAMEWORK

**O.Voloshyn, V.Kudin, A.Onyshchenko**

***Abstract.*** *A modified ecological input-output model is proposed in the paper. Greenhouse gas emissions limits set on Kyoto Protocol were taken into consideration. The model productivity existence conditions that provide economic and environmental indicators non-negativity were found. The mathematical apparatus that in case of branch structure changes determines the change in the main and auxiliary industries gross output is considered.*

***Keywords:*** *sustainable development, the Kyoto Protocol, an ecological and economic system, Leontief "input-output" model, Leontief-Ford "input-output" model, simulation modeling.*

***ACM Classification Keywords****: I. Computing Methodologies – I.6. Simulation and modeling – I.6.5. Model Development –Modeling Methodologies.*

## Introduction

Contemporary theoretical and practical economy prospective analysis demonstrates growing trend in consideration of social factors and life support on Earth on a global scale. This tendency is expected to be a major trend in terms of the global economy and to significantly determine international economic relations in the nearest future. In terms of world economy globalization and international economic relations, providing world society complete future is coming in the foreground. Therefore, consideration of environmental factors in macroeconomics has greatly increased. Furthermore, environmental component role, place and organisation were rased as a specific problem.

Therefore, developing a new conceptual approach to environmental resource as a current economic category becomes especially important. This new ecological and economic concept should be based on international economic relations, finding optimal ways for intergovernmental cooperation on environmental protection, resource conservation and low-waste technologies.

The Kyoto Protocol to the United Nations Framework Convention on Climate Change was the first intergovernmental agreement aimed to protect the environment by using economic instruments [KYOTO]. It was signed in 1997 by 84 states and establishes a procedure for greenhouse gases emissions reducing (primarily carbon dioxide). Their accumulation is recognized to be the cause of a major ecological problem - global warming. According to the Kyoto Protocol, the main polluters are industrialized countries. Therefore, they are committed to reduce the greenhouse gas emissions amount by 8% on the average compared to 1990.

The Kyoto Protocol also has international cooperation economic mechanisms. They declare that the climate effects do not depend on greenhouse gases emission locations and greenhouse gases concentrations in the atmosphere do not affect humans directly. These mechanisms are called "The Kyoto Protocol flexibility mechanisms" that refers to flexibility in choosing locations and facilities. The Protocol provides three economic mechanisms [Mechanisms].

**International emission trading** - the country obligation in not exceeding the set level of emissions for a particular reporting period. Each country is provided with national quotas on emissions. If the country does not use its quota fully, it has the right to emit an “extra part” to other countries.

"**Joint implementation" projects** - CO2 reduction cost varies for different countries. Thus, the country with quantitative commitments may finance projects on greenhouse gases reduction in another country with quantitative obligations. The resulting implementation of such projects are called "emission reduction units" and can be transferred to the investing party to offset its liabilities.

**The clean development mechanism** - countries with quantitative commitments are certified with emission reduction credits for financing projects related to the greenhouse gas emissions reduction in the countries without quantitative commitments.

Worlds’ community concern is stimulated by the real threat of a global warming and different countering prices in different countries. Reducing greenhouse gas emissions is a complicated process. Moreover, different conditions for their implementation and diverse effects on climate change vary from country to country. This makes a process of taking joint decisions ambiguous. For the first time, it is about creating a fundamentally new market sector, that directly affects the planet's atmosphere. It is clear that participants behavior rules and competition in this sector have features that require detailed analysis.

Implementation of the Kyoto Protocol requires a broad range of interdisciplinary sciences cooperation. Economic encouragement as a basic principle for solving environmental problems deserves particular attention. Studying the Kyoto Protocol economy requires an integrated and systematic approach [Voloshin, 2010].

## Objectives

A number of issues related to state participation in the Kyoto Protocol, raises the need for environmental services market volume estimation, potential partners' identification and an economic strategy development that would identify priorities for each economic mechanism, their application proportions for the purpose of attracting environmental investments.

A special role in solving the fundamental problems of nature is environmental expenditures spendings justification. Taking into account the socio-economic impact and geographical distribution, these problems belong to input-output models as well as to regional and sectoral models.

Historically, the first and the simplest inter-sectoral industrial relations mathematical model was the Leontief's "input-output" model.

Let us put into consideration direct material costs coefficients matrix $A = (a_{ij})$, gross output column vector $X = (X_1, X_2, \dots X_n)^T$ and final production column vector $Y = (Y_1, Y_2, \dots Y_n)^T$. Here is the balance model in a matrix form [Leontief, 1986]:

$$X = AX + Y. \qquad (1)$$

The system of equations (1) is called an input-output economic-mathematical model (Leontief model).

The methodological basis for constructing balance models that take into account the environmental management serves as an expanded reproduction theory. At a present times the reproduction process, along with industrial relations, wealth and human resources reproduction necessarily includes natural resources and environment restoration.

An "input-output" model design and implementation based on environmental and economic balance scheme. It involves modern science fundamental problems solutions. The list includes development of reliable methods for predicting environmental parameters and its' quality criteria. They have to able to provide a quantitative measurement for human needs satisfaction level in a clean and natural diversity.

The list also includes creating science-based methods for determining the economic damage from pollution and modelling natural systems' various components interaction whereas taking into account natural and anthropogenic factors and conditions.

Thus, there is a need to build an environmental and economic model, that would include the Kyoto commitments implementation cost. Economic and environmental indexes nonnegativity raises the balance model productivity question. It is associated with technological matrix model. Changing the ecological and economic system sectorial structure is reflected in matrix coefficients and in turn it affects production volume and requires new algorithms development These algorithms have to define solution without solving the model equations.

## Research results

The difficulty and factors variety in the national economy for greenhouse gas emissions reduction problems requires its deeper consideration in the context of existing production fields (economic activities). In leads to Kyoto Protocol implementation expenditure inclusion and pollution allocation among them. In this regard, we are considering greenhouse gas emissions limits costs in the structure of main production areas as:

$$\begin{cases} x_1 = A_{11}x_1 + A_{12}x_2 + Cy_2 + y_1, \\ x_2 = A_{21}x_1 + A_{22}x_2 - y_2, \end{cases} \qquad (2)$$

where $x_1 = \left(x_1^1, x_2^1, \ldots, x_n^1\right)^T$ – production volumes column vector;

$x_2 = \left(x_1^2, x_2^2, \ldots, x_m^2\right)^T$ – destroyed pollutants volumes column vector;

$y_1 = \left(y_1^1, y_2^1, \ldots, y_n^1\right)^T$ – final products volumes column vector;

$y_2 = \left(y_1^2, y_2^2, \ldots, y_m^2\right)^T$ – uncompensated pollution volumes column vector;

$A_{11} = \left(a_{ij}^{11}\right)_1^n$ – square matrix of direct costs production coefficients $i$ per production unit $j$;

$A_{12} = \left(a_{ig}^{12}\right)_{i,g=1}^{n,m}$ – rectangular matrix production costs $i$ per destroying pollutants unit $g$;

$A_{21} = \left(a_{kj}^{21}\right)_{k,j=1}^{m,n}$ – rectangular matrix of pollutants release $k$ per output unit $j$;

$A_{22} = \left(a_{kg}^{22}\right)_{1}^{m}$ $-k$ pollutants release per unit of destroying pollutants $g$ square matrix.

$Cy_2$ – costs that are related to greenhouse gas emissions (ie greenhouse gas emissions maintenance costs, including a payment for allowances);

$C = \left(c_{ig}^{12}\right)_{i,g=1}^{n,m}$ – production costs $i$ per unit of pollutant emissions $g$ rectangular matrix;

In vector-matrix form model (2) can be represented as:

$$\begin{pmatrix} x_1 \\ x_2 \end{pmatrix} = \begin{pmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + \begin{pmatrix} E_1 & C \\ 0 & -E_2 \end{pmatrix} \begin{pmatrix} y_1 \\ y_2 \end{pmatrix} \tag{3}$$

where $E_1$ and $E_2$ – identity matrixes.

The first equation reflects the economic balance - the industry's gross output distribution by primary and auxiliary production consumption, final consumption of primary production and costs associated with Kyoto Protocol commitments implementation. The second equation reflects the greenhouse gases physical balance as the emissions amount, resulting from the primary and auxiliary production activities of the main and auxiliary industries, and their uncompensated volumes.

The variable model (3) economic content requires nonnegative values consideration. This is closely linked to the balance model performance issue. This leads to the question of the production system functioning that can provide intermediate consumption, the final product positive production volumes and fulfillment of stated limits on greenhouse gas emissions.

In order to study solutions nonnegativity issue, let us express $x_2$ from the second equation and put it into the first:

$$x_1 = (E_1 - A_1)^{-1} \left( y_1 + Cy_2 - A_{12} (E_2 - A_{22})^{-1} y_2 \right),$$

where $A_1 = A_{11} + A_{12} (E_2 - A_{22})^{-1} A_{21}$ – $n$-th order square matrix.

Let us also express $x_1$ from the first equation and put it into the second:

$$x_2 = (E_2 - A_2)^{-1} \left( A_{21} (E_1 - A_{11})^{-1} y_1 + A_{21} (E_1 - A_{11})^{-1} Cy_2 - y_2 \right),$$

where $A_2 = A_{22} + A_{21} (E_1 - A_{11})^{-1} A_{12}$ – $m$ - th order square matrix.

Thus, the formal solution of a system (3) can be written as:

$$\begin{pmatrix} x_1 \\ x_2 \end{pmatrix} = \begin{pmatrix} (E_1 - A_1)^{-1} & (E_1 - A_1)^{-1} \left( A_{12} (E_2 - A_{22})^{-1} - C \right) \\ (E_2 - A_2)^{-1} A_{21} (E_1 - A_{11})^{-1} & (E_2 - A_2)^{-1} \left( E_2 - A_{21} (E_1 - A_{11})^{-1} C \right) \end{pmatrix} \begin{pmatrix} y_1 \\ -y_2 \end{pmatrix}.$$

According to the methodology proposed in [Lyashenko, 1999, 2009], [Onyshhenko, 2011] let us generalize the “performance” concept in case of block matrices with nonnegative elements:

$$A = \begin{pmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{pmatrix} \geq 0 . \qquad (4)$$

We will assume that nonnegative block matrix is productive if the matrixes $A_{11}$, $A_{12}$, $A_1$ and $A_2$ are productive. Matrix $A_1$ and $A_2$ productivity means the main and auxiliary production profitability for the full production cycle and for the full greenhouse gas emissions destruction cycle. If matrixes $A_{11}$, $A_{12}$, $A_1$ and $A_2$ are productive, then the matrixes

$$(E_1 - A_{11})^{-1} \geq 0 ,\ (E_2 - A_{22})^{-1} \geq 0 ,\ (E_1 - A_1)^{-1} \geq 0 ,\ (E_2 - A_2)^{-1} \geq 0$$

exist and consist of nonnegative elements.

Block matrix (3) performance does not guarantee the system (3) solutions nonnegativity. Let us analyze the expressions for $x_1$ and $x_2$. From system (3) we obtain

$$x_1 = (E_1 - A_{11})^{-1} (A_{12} x_2 + C y_2 + y_1).$$

It case that $x_2 \geq 0$, $y_1 \geq 0$, $y_2 \geq 0$ the condition $x_1 \geq 0$ is executed.

Thus, a necessity and sufficiency condition for nonnegative model (3) solutions in case of block matrix (4) productivity and at $y_1 \geq 0$, $y_2 \geq 0$ will be $x_2 \geq 0$ condition, that

$$(E_2 - A_2)^{-1} \left( A_{21} (E_1 - A_{11})^{-1} y_1 + A_{21} (E_1 - A_{11})^{-1} C y_2 - y_2 \right) \geq 0.$$

From the last inequality we obtain a sufficiency condition for the nonnegative solutions existence:

$$A_{21} (E_1 - A_{11})^{-1} (y_1 + C y_2) \geq y_2,$$

that can be replace by even more strict sufficiency condition:

$$A_{21} (y_1 + C y_2) \geq y_2.$$

The last inequality means that for main and auxiliary production functioning sufficiency condition is not exceeding the unutilized greenhouse gas emissions amount over the full greenhouse gas emissions. They are arising from the final product manufacturing and service costs that are held under the Kyoto Protocol.

Let us consider the problem of determining how the gross output and greenhouse gases utilization volumes vectors would change if technology matrix coefficients would change, including the environmental standards strengthening and the need to increase spending on Kyoto Protocol obligations fulfillment. For example, suppose that in the technological matrixes $A_{11}$, $A_{12}$, $A_{21}$, $A_{22}$, $C$ one or more elements undergo changes.

Let us determine how the change affects the $x_1$ and $x_2$ vectors value. For this purpose, the procedure proposed in [Voloshin, Kudin, 2013, 2015].

The model (3) can be also represented as:

$$Au = C. \tag{5}$$

where $A = \begin{pmatrix} E_1 - A_{11} & -A_{12} \\ -A_{21} & E_2 - A_{22} \end{pmatrix}\begin{pmatrix} x_1 \\ x_2 \end{pmatrix}$ , $u = \begin{pmatrix} x_1 \\ x_2 \end{pmatrix}$ – $(n+m)$ -dimensional vector, $C = \begin{pmatrix} E_1 & C \\ 0 & -E_2 \end{pmatrix}\begin{pmatrix} y_1 \\ y_2 \end{pmatrix}$, $E_1$, $E_2$ – corresponding dimension block unit matrixes, $0$ – block zero matrix.

Let us also consider the system perturbations (in matrixes $A_{11}$, $A_{12}$, $A_{21}$, $A_{22}$, $C$ elements) to linear algebraic equations system (5):

$$\bar{A}u = \bar{C}. \tag{6}$$

Where $A$ , $C$ - are corresponding perturbed matrix. Let us suppose that for the system (5) the basic solution and inverse matrix were found. Then there is the following theorem [Kudin, 2007].

**Theorem 1.** There are the following ratio for vectors normal restrictions expansion coefficients on matrix basic lines, inverse matrices elements, basic solutions and restriction residuals in two related basic solutions:

$$\bar{\alpha}_{rk} = \frac{\alpha_{rk}}{\alpha_{lk}},\ \bar{\alpha}_{ri} = \alpha_{ri} - \frac{\alpha_{rk}}{\alpha_{lk}}\alpha_{li},\ r = \overline{1, n+m},\ i = \overline{1, n+m},\ i \neq k. \tag{7}$$

$$\bar{e}_{rk} = \frac{e_{rk}}{\alpha_{lk}},\ \bar{e}_{ri} = e_{ri} - \frac{e_{rk}}{\alpha_{lk}}\alpha_{li},\ r = \overline{1, n+m},\ i = \overline{1, n+m},\ i \neq k. \tag{8}$$

$$\bar{u}_{0j} = u_{0j} - \frac{e_{jk}}{\alpha_{lk}}\Delta_l,\ j = \overline{1, n+m}. \tag{9}$$

$$\bar{\Delta}_k = -\frac{\Delta_l}{\alpha_{lk}},\ \bar{\Delta}_r = \Delta_r - \frac{\alpha_{rk}}{\alpha_{lk}}\Delta_l,\ r = \overline{1, n+m},\ r \neq k. \tag{10}$$

The matrix condition for being basis when entering the normal vector $a_l$ restrictions $a_l u \leq c_l$ for $k$-y basic matrix position $A$ is the inequality fulfillment: $\alpha_{lk} \neq 0$.

Based on the reduced ratio we can build algorithmic scheme of study (6) (when the model has changes). The algorithm will be based on simplex method ideology [Voloshyn, Kudin, 2015], involving some iterative process features. In particular, the transition from the system (6) to the system (5) will be carried consecutively by relevant perturbed lines ($i, i+1, i+2, ..., i+i_0$) replacement.

This means that the normal vectors hyperplanes that form the basis matrix lines and the corresponding inverse matrix will be replaced by appropriate “perturbed” normal vectors. Following basic solutions and inverse matrixes will be recalculated based on simplex relations (7)-(10). While maintaining the basic properties on replacement iterations, system (6) solution would be found by $i_0$ iterations. The result is a new base solution and the inverse matrix.

Based on the following information we can present a new algorithm for new solution determination in case of the basic matrix elements perturbation. This approach allows to determine changes in the gross output volume when ecological and economic model (3) technological matrixes were changed.

**Step 1.** Let us find the initial system (5) solution and the inverse block matrix $A^{-1}$.

**Step 2.** Matrix $A$ undergoes perturbation in $a_{kj}$ element: $\overline{a}_{kj} = a_{kj} + a'_{kj}$.

**Step 3.** Let us determine the coefficient $\alpha_{ek} = 1 + a'_{kj} \cdot e_{jk} \neq 0$, where $e_{jk}$ – corresponding element for matrix $A^{-1}$.

**Step 4.** Let us find the new column vector $\overline{e}_k = \dfrac{e_k}{\alpha_{ek}}$ for matrix $A$.

**Step 5.** Let us determine the residual for the element perturbed line: $a'_{kj}$ : $\Delta_e = \overline{\Delta}_k = a'_{kj} \cdot u_{0j}$, where $u_{0j}$ is a $j$-th component for $u_0$.

**Step 6.** Let us find a new solution based on the following correlation: $\overline{u}_0 = u_0 - \overline{e}_k \cdot \Delta_e$.

Let us illustrate on conditional data the proposed algorithm in case of technological inter-branch changes. Let the ecological and economic model (3) technological matrix coefficients have the following values:

$$A_{11} = \begin{pmatrix} 0.2 & 0.1 \\ 0.3 & 0.2 \end{pmatrix},\ A_{12} = \begin{pmatrix} 0.1 & 0.2 \\ 0.2 & 0.2 \end{pmatrix},\ A_{21} = \begin{pmatrix} 0.1 & 0.3 \\ 0.2 & 0.3 \end{pmatrix},\ A_{22} = \begin{pmatrix} 0.2 & 0.3 \\ 0.3 & 0.1 \end{pmatrix}.$$

Greenhouse gas emissions maintenance costs matrix, sectoral final release vector and greenhouse gas emissions restrictions vector respectively:

$$C = \begin{pmatrix} 0.3 & 0.2 \\ 0.1 & 0.5 \end{pmatrix},\ y_1 = \begin{pmatrix} 12 \\ 23 \end{pmatrix},\ y_2 = \begin{pmatrix} 5 \\ 8 \end{pmatrix}.$$

Let us verify the performance condition for ecological and economic system in the case of numerical data. Block matrix $A$

$$A = \begin{pmatrix} 0.2 & 0.1 & 0.1 & 0.2 \\ 0.3 & 0.2 & 0.1 & 0.2 \\ 0.1 & 0.3 & 0.2 & 0.3 \\ 0.2 & 0.3 & 0.3 & 0.1 \end{pmatrix}$$

is productive because it is sufficient as a technological matrix for Leontiefs' type balance models. We should also note that model (3) performance is sufficient what is proven by inequality $A_{21}(y_1 + Cy_2) \geq y_2$:

$$\begin{pmatrix} 9.76 \\ 11.27 \end{pmatrix} \geq \begin{pmatrix} 5 \\ 8 \end{pmatrix}.$$

Here is the algorithm steps 1-6.

1. Let us find the system solution and the inverse technology matrix: $u_0 = \begin{pmatrix} 38.17 \\ 60.43 \\ 32.67 \\ 30.62 \end{pmatrix}$,

$$A^{-1} = \begin{pmatrix} 1.79 & 0.73 & 0.6 & 0.76 \\ 1.08 & 2.0 & 0.74 & 0.93 \\ 1.04 & 1.32 & 1.99 & 1.19 \\ 1.1 & 1.27 & 1.04 & 1.99 \end{pmatrix}.$$

2. We assume that in model (3) $a_{21}^{11} = 0.3$ element undergoes perturbation. It increases for $0.1$. This means second field production costs increase per unit of the first sector. Therefore, $\bar{a}_{21} = 0.3 + 0.1 = 0.4$.

3. Let us find $\alpha_{lk} = \bar{\alpha}_{kk} = 1 + 0.1 \cdot a_{12}^{-1} = 1 + 0.1 \cdot 0.74 = 1.074$.

4. Let us determine the column vector: $\bar{e}_2 = \begin{pmatrix} 0.73 \\ 2.0 \\ 1.32 \\ 1.27 \end{pmatrix} / 1.074 = \begin{pmatrix} 0.68 \\ 1.86 \\ 1.23 \\ 1.18 \end{pmatrix}$.

5. Let us calculate perturbed line residual: $\Delta_l = \bar{\Delta}_2 = 0.1 \cdot 38.17 = 3.817$.

6. The new solution is obtained: $\bar{u}_0 = \begin{pmatrix} 38.17 \\ 60.43 \\ 32.67 \\ 30.62 \end{pmatrix} - 3.817 \cdot \begin{pmatrix} 0.68 \\ 1.86 \\ 1.23 \\ 1.18 \end{pmatrix} = \begin{pmatrix} 35.57 \\ 53.33 \\ 27.97 \\ 26.12 \end{pmatrix}$.

Solution analysis brings us to the following conclusions. In terms of the ecological and economic system (3): second branch unit release costs increase for one first branch unit leads to a 1st and 2nd material production gross output decrease by 2.6 and 7.1 standard units respectively. It also leads to greenhouse gas volume utilization decrease of 1st and 2nd type for 4.7 and 4.5 standard units respectively.

## Conclusion

In the modern civilization system there is a need to take into account environmental factors. This causes further production activities consideration within a single socio-ecological-economical system. An important requirement for its existence is the need to balance between the interests of these subsystems. An effective tool is a balance method and corresponding methods, such as a model proposed in this article. It takes into account costs for projects aimed to reduce greenhouse gas emissions.

Performance conditions and determining the total industrial releases volume algorithm in case of technological branch structure changes were established for model effectiveness. Further studies would be appropriate in the field of additional economic and environmental constraints inclusion as well as changes in classical assumptions about the technological structure of the proposed model.

## Acknowledgements

The work is published with the financial support of the project ITHEA XXI Institute of Information Theory and Applications FOI ITHEA Bulgaria www.ithea.org Association and the creators and users of intellectual systems ADUIS Ukraine www.aduis.com.ua.

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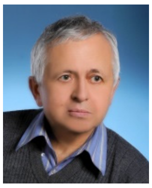
## Authors Information

*Oleksii Voloshyn - Dr. Sc., Professor, Kyiv National Taras Shevchenko University,*

*Faculty of Computer Sience and Cybernetics ; e-mail: olvoloshyn@ukr.net*

*Research interests: decision-making theory, decision support systems, information technology, expert systems, mathematical economics, fuzzy analysis, e-learning*

*Vladimir Kudin - Dr. Sc., Professor, Kyiv National Taras Shevchenko University; Faculty of*

*Information Technology; e-mail: V_I_Kudin@mail.ru*

*Research interests: optimization techniques, systems analysis, computational method, decision-making, mathematical economics*

*Andriy Onyshchenko – Dr. Sc., Professor, Kyiv National Taras Shevchenko University;*

*Faculty of Information Technology; e-mail: onyshchenko@yandex.ru*

*Research interests: ecological-economical modelling, sustainable development, Kyoto Protocol, Paris Agreement, mathematical economics*

# CLASSIFICATION OF INFORMATION RESOURCES CREATION PROJECTS OF PROJECT-ORIENTED ENTERPRISES

**Yehorchenkova Nataliia, Yehorchenkov Oleksii, Kataieva Yevheniia**

***Abstract**: the study is to suggest to apply project approach to the creation and use of information resource of project-oriented enterprises. Modern researches in information resources management are showed. The models classification of information resources management in accordance with the project approach and provision in different areas of project and operation management of the project-oriented enterprise are developed. Signs by which we classify models are presented.*

***Keywords**: information resources, project management, projects classification.*

***ACM Classification Keywords**: K.6.1 − Project and People Management*

## Introduction

Today the limited number of approaches is used in the information resources management to their creation and use. In most cases, these issues are considered as part of information technology from the standpoint of the process approach - “how to process information”. Although the process of creating any resource, including information resource, should begin with the question “And what is it for?”, “For whom or for what is this resource?” “What does it give?”, “How much it costs to receive it?”, “Where to get it?”, “What time it is received?”, etc. All of these issues are usually considered as part of the project approach, not the process approach. Answers to these questions can only be obtained with effective project management system that creates an information resource, not just information technology. Therefore, narrowing view of the information that is seen in technologies, constricts process of the information support of managers, which in turn leads to low-quality and ineffective inform the participants of the project and operation activities. This in turn leads to many problems in the coordination and adoption of various decisions, lack of training meetings, the long search for the right information.

Therefore, the paper proposes to apply the project approach to the issue of creation and use of information resource in project-oriented enterprises. The essence of this approach to resource management is the creation and use of this resource is considered as the project implementation with all the attributes and components of the control system. After all the creation and use of any information resource demands to plan actions (integration and project content management), organize services work, monitor, consider the risks, information communications, human resources, sometimes - procurement, etc. Further, such projects will be called Creation and provision of information resource projects.

## Analysis of the latest research and publications

Today there are a lot of studies that focus on the management of information resources [1- 10].

For example, in the paper [7] are introduced the features of a new class of information systems creation - systems of the enterprise information resources management. Disclosed advantages and features of this system and described its application for higher education in Ukraine. Demonstrated structure, algorithms and features of realization of information resource management at Taras Shevchenko National University of Kyiv.

The paper [8] is devoted to solving the problem of creating intelligent management methods of enterprises information resources.

The paper [9] presents a prototype approach for the design and use of training material that provides significant advantages to both the designer-strategic planner (knowledge – content reusability and semantic web enabling) and the user-manager (semantic search, knowledge navigation and knowledge dissemination). The approach is based on externalizing domain knowledge in the form of ontology-based knowledge networks (i.e. training scenarios serving specific training needs) so that it is made reusable.

The authors [10] showed the role of information resources as one of the factors of production, their distinctive features, the need for management within the enterprise, and developed a scheme for the conversion process of information resources. In the first stage a man acquires the information to his needs (information is the subject of work), in the second stage he uses the accumulated knowledge, information, production takes place (resource is the work tool).

## Main part

**Definition 1 Project of creation and provision of information resource (PCPIR)** - this is information-creating project, which purpose is to meet the information needs of users by creating and providing information resource in a convenient way.

The research allowed to classify models of information resources management in accordance with the proposed project approach and provision in different areas of project management and operations of the project-oriented enterprise. Table 1 shows the characteristics for which models classification is performed.

All of the signs should be used selectively, depending on the functional tasks and functional roles that use information resources in the management of project and operational activities of the enterprise. But most importantly, work with information resource should be done with using management models that are adapted to these classes. Such models allow to formally operate processes of resource management, which in turn will make decisions that lead to optimal and quasi-optimal actions to manage projects and programs.

Consider the model of information resource management in the context of the presented classes. This context is required because the forms of information resources specifies the data that best meet essential of management of project and operational activities of the enterprise.

Table 1. **Classification features of projects of creation and providing information resources**

| N | Classification feature | Project class | Description |
|---|---|---|---|
| 1. | **The duration of projects of creating and providing an information resource** | Short-term | Project duration does not exceed the limit time |
| | | Long-term | Project duration exceeds the limit time |
| 2. | **The urgency of creating and providing an information resource** | Operational | A project that originally was not planned, but the need to implement it explained the unpredictable situation in the enterprise activity. |
| | | Planned | A project, which caused a predictable |

| | | | |
|---|---|---|---|
| | | | situation on the creation of an information resource |
| **3.** | **The complexity of creating and providing an information resource** | Simple | It represents set of actions to create an information resource by one project participant |
| | | Complex | It represents set of actions to create an information resource by more than one project participant |
| **4.** | **The kind of an information resource (PCPIR product)** | Standards | The documented rules that regulate the project and operation activities of the enterprise. |
| | | Permission documentation | The documents, which give the right to perform business activities. |
| | | Plan | The document, which defines the sequence of actions to achieve the objectives of the project and operating activities of the enterprise. |
| | | Order | Official authority order. |
| | | Report | Official notification provided for a certain issue, which is based on the involvement of documentary evidence. |

| | | | |
|---|---|---|---|
| 5. | **By way of creation of an information resource** | Automatic | An information resource is created in the information systems environment, without the involvement of people. |
| | | Traditional | An information resource is created by employees of the project oriented enterprise or external persons without use of computers. |
| | | Automated | An information resource is created by the complex interaction between employees of the project oriented enterprise or external persons and computer technologies. |
| 6. | **По формі надання інформаційного ресурсу** | Text | - Analytic note.<br>- Table.<br>- List.<br>- Definition (rule). |
| | | Diagram | - Histogram.<br>- Chart.<br>- Diagram.<br>- 3D image. |
| | | Graph | - Workflow.<br>- Network graph.<br>- Tree graph (hierarchical graph).<br>- Bipartite graph.<br>- Semantic network. |

| | | | |
|---|---|---|---|
| | | Figure | - Map.<br>- Arbitrary drawing.<br>- Photo. |
| | | Mixed | It is a form of representation that includes various types of information resources visualization. |

These features form a set of class PCPIR. Any need for information for project management will depend on the situation in the project, in the enterprise, in the project management system. In turn, such a situation will form the values for these attributes for information management system of the enterprise. This will specify the PCPIR class and develop project realization templates in this class. A set of templates will create some project management methodology for creating and providing an information resource. In this case, each PCPIR is included at the same time in separate classes for each of the given signs and in the intersection of classes (subclasses) that generated by set of all features (Figure 1.).

There are 1200 subclasses with the proposed classification. It is clear that the PCPIR control system should be sufficiently complex, multidimensional, based on strong methodological basis to meet the needs of project-oriented enterprises in the information resources management. But it is impossible to create a system that contains a set of management practices for each of the subclasses. Therefore, the task of creating an effective management system is to bring together subclasses in such groups, which are used for the same methods and controls PCPIR.

To solve the problem of creating a system of management PCPIR we first need to formalize the given PCPIR classification, to identify management classes and to create appropriate methods for implementing management functions on the basis of created PCPIR management classes.

On the basis on given classifications we need to develop projects models for individual classes. The purpose is to determine the information intersections of these classes from the viewpoint of creating the management system with identical methods and means.

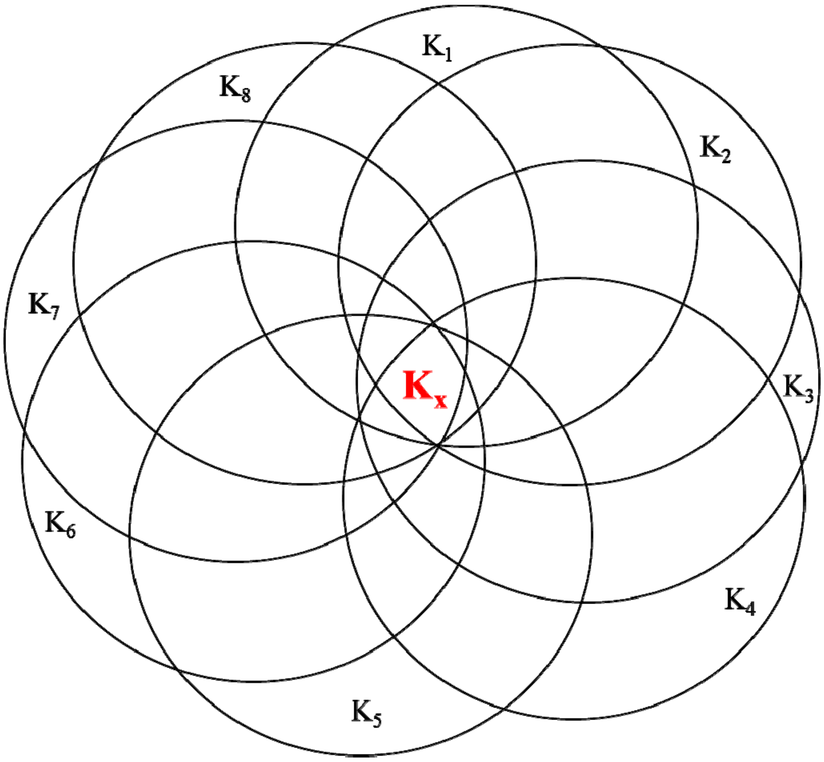



**Figure 1. PCPIR subclasses**

## Conclusions

Classification of creation and provision of information resource projects will allow to develop a management model. Each model will be presented by different tools of implementation project management functions. And this models can be used to control many subclasses PCPIR.

These models will give the opportunity to optimize the functions of planning, organization and control processes necessary to request, creation and provision of information resources of project-oriented enterprise, which will increase the efficiency of its project and operation activities.

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## Authors' Information

***Yehorchenkov O.V.*** *– PhD, associate professor of the department of geoinformatics, Taras Shevchenko National University of Kyiv, Kyiv; e-mail: alexee@ukr.net*

***Yehorchenkova N.I.*** *–PhD, associate professor, doctoral student of the technology management department, Taras Shevchenko National University of Kyiv, Kyiv; e-mail: realnata@ukr.net*

*Kataieva Y.I.– PhD, associate professor, associate professor of department of software of automated systems, Cherkasy State Technological University, e-mail: kataevae@ukr.net*

# AN APPROACH FOR TRAINING DATA REDUCTION USING BILINEAR FORM OPTIMIZATION

**Vasily Ryazanov**

***Abstract**: An approach for solving the problem of dataset reduction is considered. The problem of selection an optimal subset of features and objects is an important task for every classification algorithm. Having smaller and more informative dataset one can perform training operation faster and study data visually. However nowadays most of algorithms select features and objects separately and are based on statistical or logical base. In this paper a method for training set reduction is presented. Using votes for each class in calculation estimation algorithm a bilinear form is constructed. Having optimized bilinear form one can find an optimal subset for features and objects at once. In order to fasten optimization a technique for linear local optimization is proposed. During bilinear form optimization one can select an optimal iteration with smaller dataset and acceptable classification quality. Prospects of this approach are confirmed by a series of experiments on various practical tasks.*

***Keywords**: classification, data mining, supervised learning, dataset reduction, bilinear form.*

***ACM Classification Keywords**: I.2.4 ARTIFICIAL INTELLIGENCE Knowledge Representation Formalisms and Methods – Predicate logic, I.5.1 PATTERN RECOGNITION Models – Deterministic, H.2.8 Database Applications, Data mining.*

## 1. Introduction

Currently interest in the problem of minimizing training data, i.e. the selection of smaller informative training subsets, is growing.

Performance of present algorithms depends on solving the problem of an adequate description of objects and classes, with the smaller object-feature space, the optimization problems arising in training are solved easier and more accurate. Therefore, the task of reducing the training information is always of great interest.

With training data increasing some classifiers can physically lose the ability to process the data and construct the prediction, so data reduction can solve even this problem. Smaller tables also allow experts to examine directly and visualize data, thereby to find new patterns.

Current methods of minimizing the data are mostly built to optimize the number of features. To solve this problem algorithms based on information theory and correlation [Lei Yu et al., 2003] are often used. They introduce criteria based on entropy, statistical heuristics, and study the mutual features correlation. Algorithms of feature selection based on logical methods (binary trees, logical regularities) are also widely spread today. For example, in [Norbert Jankowski et al., 2005] the classical approach SSV (Separability Split Value) to ranking criteria is proposed: the importance of the feature is higher, the more frequently it occurs in the casting tree nodes and sooner it happens on a partition. Methods based on alternately adding and removing features, and then validation on test sample [P. Pudil et al., 1994], are also popular. Their disadvantages include a durable working time, random during searching for the optimum, as well as dependence on the validation set.

Despite a somewhat less attention to the domain of objects selection, this problem is no less important during classification. In many cases simple empirical search for anomalies, as well as filtering objects by some criteria in order to exclude clearly irrelevant objects are used. There are approaches based on the k-nearest neighbors algorithm [P. Hart, 1968], as well as other algorithms such as SVM or genetic algorithms.

To get the maximum knowledge from the data, objects and features should be examined in combination. Thus prerequisites for creating algorithm of complex data optimization occur.

In this paper the formulation and approach of the problem of the simultaneous reduction of feature and object descriptions are proposed. The task is to select a subset of informative features and objects, reducing the sample size while preserving quality close to the original.

A modification of 'calculation estimation' algorithm [Zhuravlev, 1978] is used as base approach. Vectors $\mathbf{x} = (x_1, x_2, ..., x_n)$, which has the same dimension as number of features and $\mathbf{y} = (y_1, y_2, ..., y_m)$, which has equal size to number of objects are introduced. Parameters $x_i, y_i \in [0,1] \forall i$ denote features and objects importance.

Next, after classification of test data, linear functions of the object estimations for their own and others' classes, are transformed to the bilinear form $F(\mathbf{x}, \mathbf{y})$. Maximizing this criteria, one obtain the optimal vectors $\mathbf{x}$ and $\mathbf{y}$, corresponding to the optimal subsample of the original data.

This paper also proposes a local optimization algorithm of bilinear functional, having a linear complexity in the neighborhood of $O^2$ from the starting point. Usage of this criterion allow to speed up the optimization process.

## 2. Initial notations and problem statement.

Consider the following standard problem recognition by precedents. Let there is a set $M$ of objects $\mathbf{z}$, defined with their feature descriptions. For simplicity assume that $\mathbf{z} \in R^n$ . The set is $M = \bigcup_{i=1}^{l} K_i, K_i \cap K_j = \varnothing, i \neq j$ , with classes $K_i, i = 1, 2, ..., l$ . Information of this partition is given by training sample $Z = \{\mathbf{z}_i, i = 1, 2, ..., m\}$ , which consists of representatives of each class: $Z = \bigcup_{i=1}^{l} K_i^*, K_i^* \subset K_i$ , $\left|K_i^*\right| = n_i$ . The task is assigning $\forall \mathbf{z} \in R^n$ to one of the classes.

Let's consider "Calculation Estimation" – baseline classification algorithm [Zhuravlev, 1978], which modification was used in this paper. It is considered that all training objects $Z = \{\mathbf{z}_i, i = 1, 2, ..., m\}$ are divided into $l$ disjoint classes. A natural $k, 1 \leq k \leq n$ is fixed. Sample $\mathbf{z}$ is compared to all the objects from the training above all subsets of features $\Omega \subseteq \{1, 2, ..., n\}, |\Omega| = k$ , having length $k$ to calculate the "degree of proximity" of the object to each of the classes: $\Gamma_i(\mathbf{z}) = \frac{1}{\mathrm{n}_i} \sum_{\mathbf{z}_t \in K_i} \sum_{\Omega:|\Omega|=k} B_\Omega(\mathbf{z}_t, \mathbf{z})$ .

Where the proximity function between two objects is defined as follows: $B_\Omega(\mathbf{z}_t, \mathbf{z}) = \begin{cases} 1, & \left|z_{tj} - z_j\right| \leq \varepsilon_j, \forall j \in \Omega, \\ 0, & \text{otherwise.} \end{cases}$ .

In [Zhuravlev, 1978] it is shown that $\Gamma_i(\mathbf{z}) = \frac{1}{\mathrm{n}_i} \sum_{\mathbf{z}_t \in K_i} C^k_{d(\mathbf{z}_t, \mathbf{z})}$ , where $d(\mathbf{z}_t, \mathbf{z}) = \left|\{j : \left|z_{tj} - z_j\right| \leq \varepsilon_j, j = 1, 2, ..., n\}\right|$ . Here $\varepsilon_j, j = 1, 2, ..., n$ - are parameters. Typically, they are set as $\varepsilon_j = \frac{2}{m(m-1)} \sum_{\substack{u,v=1,2,...,m \\ u>v}} \left|z_{uj} - z_{vj}\right|, j = 1, 2, ..., n$ . After calculating values $\Gamma_i(\mathbf{z}), i = 1, 2, ..., l$ the object $\mathbf{z}$ is marked as having class $K_j$ , having maximum score: $\Gamma_j(\mathbf{z}) > \Gamma_i(\mathbf{z}), i, j = 1, 2, ..., l, i \neq j$ . Otherwise, a rejection of the classification of the object $\mathbf{z}$ occurs.

Let's introduce the vector parameters $\mathbf{x} = (x_1, x_2, ..., x_n)$ called "feature weights" and the parameters $\mathbf{y} = (y_1, y_2, ..., y_m)$ called "sample weights".

Next modify the CE algorithm and it's scores $\Gamma_j(\mathbf{z})$ for test object $\mathbf{z}=(z_1,z_2,...,z_n)$ to the class $K_j$ having added parameters $\mathbf{x},\mathbf{y}$: $\Gamma_j(\mathbf{z})=\frac{1}{|K_j|}\sum_{\mathbf{z}_\nu\in K_j} y_\nu \sum_{\Omega\in\Omega_A}(\sum_{i\in\Omega} x_i)B_\Omega(\mathbf{z}_\nu,\mathbf{z})$, where $|K_j|$ - number of objects in the class $K_j$, $\Omega$ - a reference set (subset of attributes) form a plurality of reference sets $\Omega_A$ of CE algorithm, $B_\Omega(\mathbf{z}_\nu,\mathbf{z})$ - the proximity of the object $\mathbf{z}$ to the training object $\mathbf{z}_\nu$ on the support set. One can show that $\Gamma_j(\mathbf{z})=\frac{1}{|K_j|}\sum_{\mathbf{z}_i\in K_j} y_i(\sum_{t\in J(\mathbf{z},\mathbf{z}_i)} x_t)C^{k-1}_{d(\mathbf{z},\mathbf{z}_i)-1}$ where $J(\mathbf{z},\mathbf{z}_i)=\{\nu:|z_{i\nu}-z_\nu|\le\varepsilon_\nu,\nu=1,...,n\}$, $d(\mathbf{z},\mathbf{z}_i)=|J(\mathbf{z},\mathbf{z}_i)|$, $k,\varepsilon_1,\varepsilon_2,...,\varepsilon_n$ - some of the parameters of the recognition algorithm. In such a setting various subsets of $k$ signs represent all the support sets.

Let's introduce an aggregated functional that will characterize the generalized classification quality. For this let's sum all the scores for "own" classes with a positive coefficient $\tau_1$ and sum all the scores for "foreign" classes with coefficient $\tau_2$. Without loss of generality one can set $\tau_1=1,\tau_2=-t$.

The final functional will be following: $f(\mathbf{x},\mathbf{y},t)=\sum_{\alpha=1}^{l}\sum_{\mathbf{z}'_\tau\in K_\alpha}\Gamma_\alpha(\mathbf{z}'_\tau)-t\sum_{\alpha=1}^{l}\sum_{\mathbf{z}'_\tau\notin K_\alpha}\Gamma_\alpha(\mathbf{z}'_\tau)$. One can easy show that it is a bilinear form on the parameters $x_1,x_2,...,x_n,y_1,y_2,...,y_m$.

So, the following optimization problem is considered:

$$f(\mathbf{x},\mathbf{y},t)=\sum_{i=1}^{n}\sum_{j=1}^{m}c_{ij}(t)x_i y_j\to\max_{\mathbf{x}\in X,\mathbf{y}\in Y}$$

Two types of areas $X$ and $Y$ can be considered during optimization of this functional: $1\ge x_i\ge 0, i=1,2,...,n, 1\ge y_j\ge 0, j=1,2,...,m,$ or $x_i\in\{0,1\}, i=1,2,...,n, y_j\in\{0,1\}, j=1,2,...,m$, for continuous and discrete case. In the second case, the choice of parameters $x_1,x_2,...,x_n,y_1,y_2,...,y_m$ means choosing a sub-table from training table. Here $t$ serves as a parameter that is not involved in the optimization process directly.

## 3. Local step of optimization.

Consider the proposed method of local optimization algorithm. Fix some $t = t_0 = const$ . Then the functional takes the following form:

$$f(\mathbf{x},\mathbf{y},t_0) = \sum_{i=1}^{n}\sum_{j=1}^{m} c_{ij}(t_0)x_i y_j = F(\mathbf{x},\mathbf{y}) = \sum_{i=1}^{n}\sum_{j=1}^{m} C_{ij}x_i y_j \to \max_{\mathbf{x}\in X,\mathbf{y}\in Y}$$

Let $\tilde{\mathbf{x}} = (\tilde{x}_1,...,\tilde{x}_n) \in \{0,1\}, \tilde{\mathbf{y}} = (\tilde{y}_1,...,\tilde{y}_m) \in \{0,1\}$ is a current point in the process of optimization, $d(\mathbf{x},\tilde{\mathbf{x}})$ is the Hamming distance between vectors. Introduce the following notation: $O_{k_x k_y}(\tilde{\mathbf{x}},\tilde{\mathbf{y}}) = \{\mathbf{x},\mathbf{y} : d(\mathbf{x},\tilde{\mathbf{x}}) = k_x, d(\mathbf{y},\tilde{\mathbf{y}}) = k_y\}$ , i.e. $O_{k_x k_y}(\tilde{\mathbf{x}},\tilde{\mathbf{y}})$ is the set of vectors $\mathbf{x},\mathbf{y}$ that they differ in exactly $k_x$ feature vectors and $k_y$ object vectors. Denote:

$$F^{20}(\tilde{\mathbf{x}},\tilde{\mathbf{y}}) = \max_{O_{20}(\tilde{\mathbf{x}},\tilde{\mathbf{y}})} F(\mathbf{x},\mathbf{y}),\ \ F^{02}(\tilde{\mathbf{x}},\tilde{\mathbf{y}}) = \max_{O_{02}(\tilde{\mathbf{x}},\tilde{\mathbf{y}})} F(\tilde{\mathbf{x}},\mathbf{y}),\ \ F^{11}(\tilde{\mathbf{x}},\tilde{\mathbf{y}}) = \max_{O_{11}(\tilde{\mathbf{x}},\tilde{\mathbf{y}})} F(\mathbf{x},\mathbf{y})$$

$$u_j(\mathbf{x}) = \sum_{i=1}^{n} C_{ij}x_i,\ \ v_i(\mathbf{y}) = \sum_{j=1}^{m} C_{ij}y_j$$

Next, show that each of the values $F^{20}(\tilde{\mathbf{x}},\tilde{\mathbf{y}}), F^{02}(\tilde{\mathbf{x}},\tilde{\mathbf{y}}), F^{11}(\tilde{\mathbf{x}},\tilde{\mathbf{y}})$ can be calculated with $O(n+m)$ time , so, the step of local extremum search in $O^2(\tilde{\mathbf{x}},\tilde{\mathbf{y}})$ has linear complexity with respect to the sum of number of features and number of objects. Consider three possible cases

1) $\mathbf{x},\tilde{\mathbf{y}} \in O_{20}(\tilde{\mathbf{x}},\tilde{\mathbf{y}})$ , where $x_i = \tilde{x}_i, i \notin \{i_1,i_2\}$ . It's obvious that $x_i \in \{0,1\}, i \in \{i_1,i_2\}$ . This implies:

$$\Delta F(\mathbf{x},\tilde{\mathbf{y}}) = F(\mathbf{x},\tilde{\mathbf{y}}) - F(\tilde{\mathbf{x}},\tilde{\mathbf{y}}) = v_{i_1}(\tilde{\mathbf{y}})(x_{i_1} - \tilde{x}_{i_1}) + v_{i_2}(\tilde{\mathbf{y}})(x_{i_2} - \tilde{x}_{i_2})$$

$$\varphi_1 = \min_{\mathbf{x},\tilde{\mathbf{y}}\in O^2(\tilde{\mathbf{x}},\tilde{\mathbf{y}})} \Delta F(\mathbf{x},\tilde{\mathbf{y}})$$

2) Similarly, when $\tilde{\mathbf{x}},\mathbf{y} \in O_{02}(\tilde{\mathbf{x}},\tilde{\mathbf{y}})$ , $y_i = \tilde{y}_i, i \notin \{i_1,i_2\}$ , $y_i \in \{0,1\}, i \in \{i_1,i_2\}$

$$\Delta F(\tilde{\mathbf{x}},\mathbf{y}) = F(\tilde{\mathbf{x}},\mathbf{y}) - F(\tilde{\mathbf{x}},\tilde{\mathbf{y}}) = u_{i_1}(\tilde{\mathbf{x}})(y_{i_1} - \tilde{y}_{i_1}) + u_{i_2}(\tilde{\mathbf{x}})(y_{i_2} - \tilde{y}_{i_2})$$

$$\varphi_2 = \min_{\tilde{\mathbf{x}},\mathbf{y}\in O^2(\tilde{\mathbf{x}},\tilde{\mathbf{y}})} \Delta F(\tilde{\mathbf{x}},\mathbf{y})$$

Obviously, the search of $\varphi_1$ and $\varphi_2$ values has complexity $O(n+m)$ .

3) Third case where $\mathbf{x},\mathbf{y} \in O_{11}(\tilde{\mathbf{x}},\tilde{\mathbf{y}})$

$$x_i = \begin{cases} \tilde{x}_i, & i \neq i_1, \\ 1 - \tilde{x}_i, & \text{otherwise.} \end{cases} \quad y_i = \begin{cases} \tilde{y}_i, & i \neq i_2, \\ 1 - \tilde{y}_i, & \text{otherwise.} \end{cases}$$

where $i_1, i_2$ is an arbitrary fixed coordinate pair. In this case:

$$\Delta F(\mathbf{x},\mathbf{y}) = F(\mathbf{x},\mathbf{y}) - F(\tilde{\mathbf{x}},\tilde{\mathbf{y}}) = v_{i_1}(\tilde{\mathbf{y}})(x_{i_1} - \tilde{x}_{i_1}) + u_{i_2}(\tilde{\mathbf{x}})(y_{i_2} - \tilde{y}_{i_2}) + C_{i_1 i_2}(x_{i_1} - \tilde{x}_{i_1})(y_{i_2} - \tilde{y}_{i_2})$$

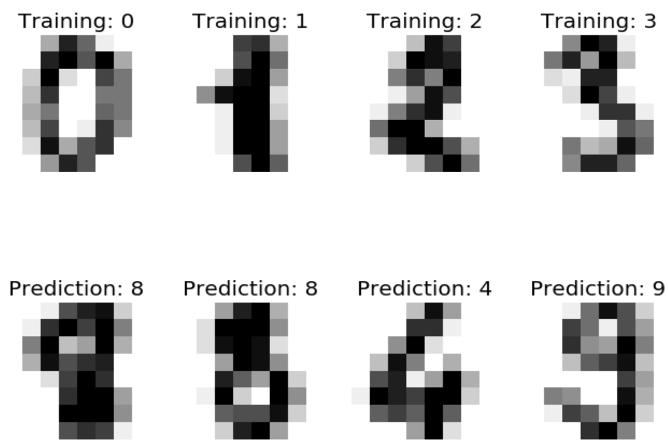
$$\Delta F(\mathbf{x},\mathbf{y}) \le v_{i_1}(\tilde{\mathbf{y}})(x_{i_1} - \tilde{x}_{i_1}) + u_{i_2}(\tilde{\mathbf{x}})(y_{i_2} - \tilde{y}_{i_2}) + \max_{i_2} \left| C_{i_1 i_2} \right| = \Delta_1 F(\mathbf{x},\mathbf{y})$$

$$\Delta F(\mathbf{x},\mathbf{y}) \le v_{i_1}(\tilde{\mathbf{y}})(x_{i_1} - \tilde{x}_{i_1}) + u_{i_2}(\tilde{\mathbf{x}})(y_{i_2} - \tilde{y}_{i_2}) + \max_{i_1} \left| C_{i_1 i_2} \right| = \Delta_2 F(\mathbf{x},\mathbf{y})$$

Obviously, in this case the bust of all $\Delta_1 F(\mathbf{x},\mathbf{y}), \Delta_2 F(\mathbf{x},\mathbf{y})$ values and search for the optimum has complexity $O(n+m)$. In the case $\mathbf{x},\mathbf{y} \in O^1(\tilde{\mathbf{x}},\tilde{\mathbf{y}})$ the complexity is linear for obvious reasons. Finally, the total complexity of the algorithm is $O(n+m)$.

## 4. Results of numerical experiments

In this paper we tested the approach on different datasets. The first considered set is named "Digits" and was taken from scikit-learn [Pedregosa et al., 2011] database. It is dedicated to the problem of handwritten digits classification. The set consists of 1797 objects that represent 8x8 black-and-white pictures of numbers. Thus, each object has 64 features – color intensity at each pixel. All objects are divided into 10 classes.

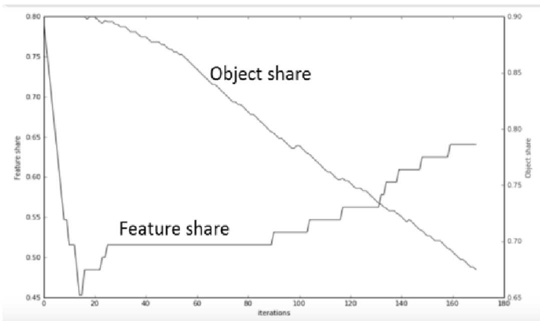



During the experiment, the dependency of classification quality (accuracy, or share of correctly recognized objects) on the $F$ value, and share of saved features and objects, with different parameters $t$ was considered.

During each experiment a certain proportion of the component feature and object vectors are set as 0. Next, a greedy optimization process described above is run. The local step each time shifts to the most optimal point of the neighborhood. Below, on the left graph 3 plots are shown: share of new table to the old, quality of the classifier while training on the reduced data, and $F$ - the value of optimized functional at certain optimization iteration. On the right side the proportion of saved attributes and objects in each iteration is shown.

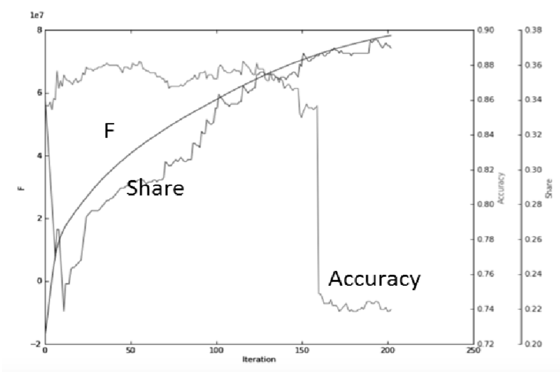
Experiment 1, $\frac{\sum x_i}{|x_i|} \approx 0.8$ , $\frac{\sum y_i}{|y_i|} \approx 0.9, t = 0.23$:


Accuracy, F and Table Share

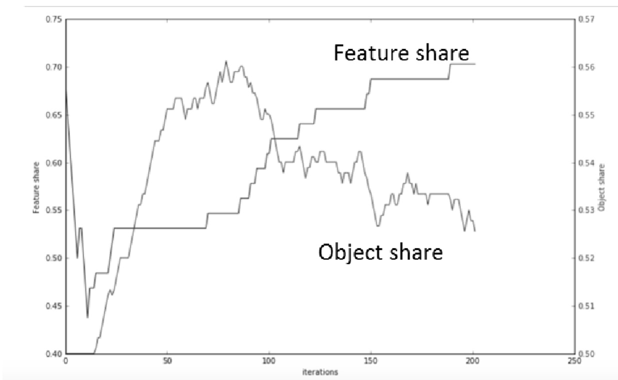



Feature share and object share

Experiment 2, $\frac{\sum x_i}{|x_i|} \approx 0.67$ , $\frac{\sum y_i}{|y_i|} \approx 0.5, t = 0.23$:

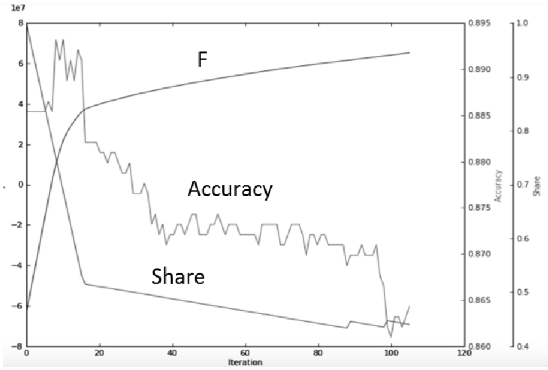



Accuracy, F and Table Share

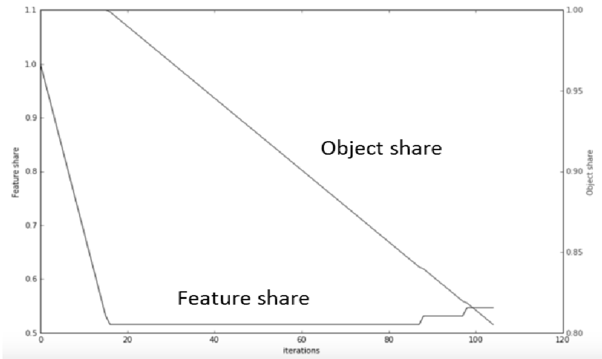



Feature share and object share

Experiment 3, $\frac{\sum x_i}{|x_i|} = 1$, $\frac{\sum y_i}{|y_i|} = 1, t = 0.23$:




Accuracy, F and Table Share



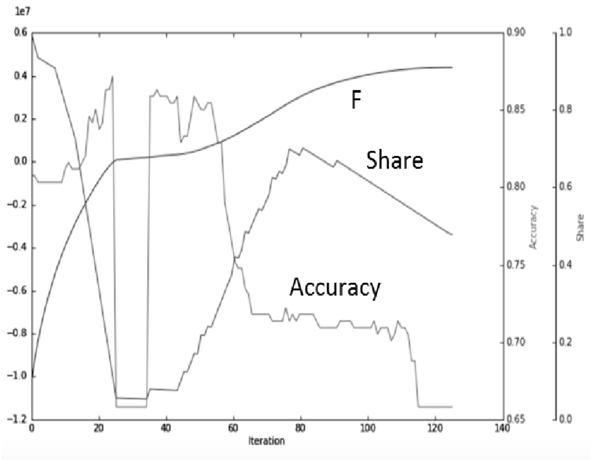

Feature share and object share

Following patterns can be seen during each experiment: after a certain number of iterations, an optimal sub-sample appears, which size is substantially smaller comparing to the original and at the same time the quality of the classification decreases slightly or even increases. Considering the right plot one can see that objects and features are examined by the algorithm simultaneously.

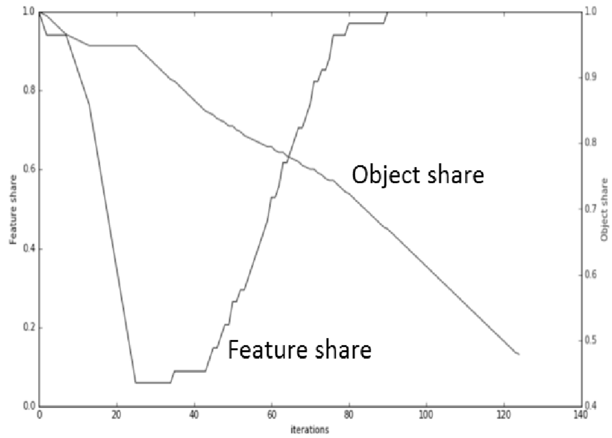
The second problem called "ionosphere", is taken from the repository [Lichman, 2013]. A system of 16 high-frequency antennas explores the properties of the ionosphere. The task is to distinguish between two types of signals - "good", having free electrons and carrying useful information of the structure of the ionosphere and "bad", which pass through the ionosphere without reflection. The electromagnetic signals are characterized by a set of 17 pulsations, each of which has two attribute, so the number of features equals 34. Two tables are given – training and validating, in each of the tables approximately 200 objects of each class persist.

The experiment also demonstrates simultaneous selection of attributes and objects and in search of an optimal iteration, also accuracy is risen comparing to baseline and training table size is significantly reduced both in number of features and the number of objects.

Experiment 4, $\frac{\sum x_i}{|x_i|}=1$ , $\frac{\sum y_i}{|y_i|}=1, t=4$ :




Accuracy, F and Table Share

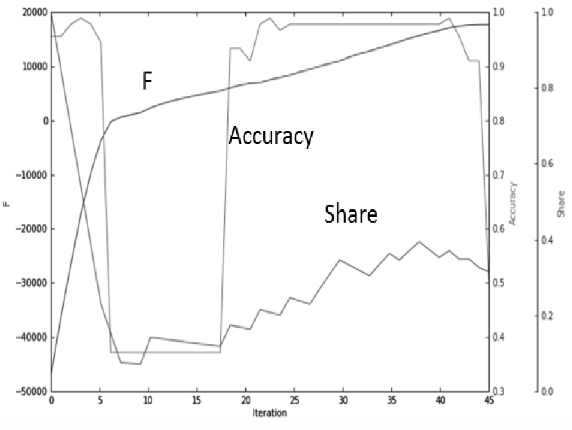



Feature share and object share

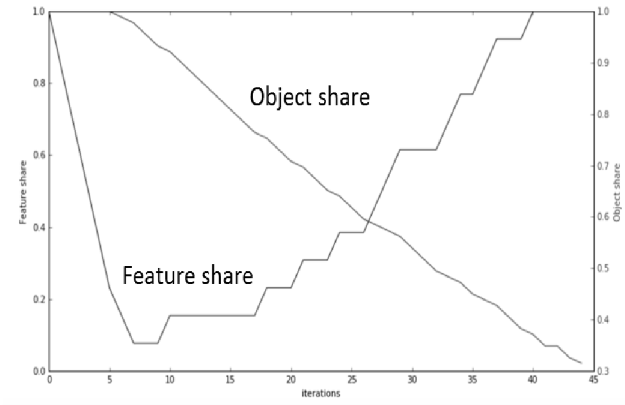
And the last of the tasks - the problem of classifying wines by chemical analysis. Sample objects are the result of chemical analysis, expressed in the 13 symptoms, such as alcohol content, malic acid, magnesium, and other hue. The table is divided into 3 classes corresponding to 3 grades of wine made from grapes grown in the same region of Italy.

Similarly to the previous classification problem quality is improved by reducing the training sample. In the last two experiments, an interesting pattern appears - at some iteration the quality drops sharply and then returns to the original values. This is due to the removal "by mistake" some important features, and then returning them back to the task.

Experiment 5, $\frac{\sum x_i}{|x_i|}=1, \frac{\sum y_i}{|y_i|}=1, t=3.3$:




Accuracy, F and Table Share




Feature share and object share

## 5. Acknowledgements

This work was supported by program RFBR № 16-31-00443 mol_a.

## 6. Conclusion

These experiments demonstrate the ability of the algorithm to solve its initial task - simultaneous selection of features and objects, thereby it leads to training set reduction and improves the quality of the classification. This result was obtained on different data and different starting parameter options.

It should also be noted that the proposed method of local optimization is a cheap procedure, thereby it allows to search for optimal subsamples faster, accelerating the speed of learning.

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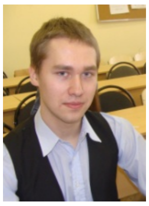
## Authors' Information



***Vasily Ryazanov*** – *PhD student; Moscow Institute of Physics and Technologies, Russia, 141700, Moscow reg., Dolgoprudny, Institutsky per. 9; e-mail: vasyarv@mail.ru*

*Major Fields of Scientific Research: Data Mining, Missing Data, Multiclass Classification*

# A METHOD FOR EVALUATION OF INFORMATIONAL SERVICES - STEP 3: RANK-BASED MULTIPLE COMPARISON

**Krassimira Ivanova, Krassimir Markov, Stefan Karastanev**

***Abstract***: *Enhancing the hardware power does not cause linear enhancing of the informational services' performance. To discover the value of growth one has to test both source and enhanced systems running equal or similar services. If we need to discover the growth of services' performance for different computers' configurations we have to have common basis for comparing one software service with those of other systems which are tested on different computer configurations. In papers [Ivanova et al 2016a; Ivanova et al 2016b] the first and second steps of a method for solving such problem were presented. In this paper we outline the third step of the method. This step consists of the analysis of experiments: rank-based multiple comparison. All examples in the paper are based on results from real experiments presented in the [Markov et al, 2015].*

***Keywords***: *Evaluation of informational services; Analysis of experiments: Rank-based multiple comparison.*

***ACM Classification Keywords***: *H.3.4 Systems and Software - Performance evaluation (efficiency and effectiveness); H.3.5 Online Information Services.*

## Introduction

Enhancing the hardware power does not cause linear enhancing of the informational services' performance. To discover the value of growth one has to test both source and enhanced systems running equal or similar services. If we need to discover the growth of services' performance for different computers' configurations we have to have common basis for comparing one software service with those of other systems which are tested on different computer configurations. In papers [Ivanova et al 2016a; Ivanova et al 2016b] the first and second steps of a method for solving such problem were presented. In this paper we outline the third step of the method. This step consists of the analysis of experiments: rank-based multiple comparison. All examples in the paper are based on results from real experiments presented in the [Markov et al, 2015].

The problem which has to be solved is to discover the growth of software performance for different computers' configurations if we have common basis for comparing one software system with same or other systems which are tested on different computer configurations. Enhancing the hardware power does not cause linear enhancing of the software performance. To discover the value of growth one has to test both source and enhanced systems running equal or similar software. Practically, the computers have different characteristics and operational systems. In addition, the target computers and operational systems may be not available for experiments but some benchmarks may be published.

As running example we use the problem to compare loading times for given datasets for different software systems in the next conditions:

- Program system **X** is tested on two computer configurations: **U** and **W**, where **W** is enhanced configuration in respect of **U**; program system **Y** is tested on different computer configuration **V** of the same class and similar characteristics as **U**. We have testing couples **(X,U)**, **(X,W)**, and **(Y,V)**;
- Computer configurations **U** and **W** are not available for testing and all work has to be done on computer configuration **V**;
- **X** has published results from tests on **U** by dataset **S1** with **|S1|** instances and on **W** with similar dataset **S2** with **|S2|** instances; **Y** is tested on configuration **V** by datasets **S1** and **S2**;
- Loading times are respectively: $L_{(X,U,S1)}$, $L_{(X,W,S2)}$, $L_{(Y,V,S1)}$, $L_{(Y,V,S2)}$.

The problem we have to solve is: "What will be the loading time of system **Y** if it will be run on computer configuration **W** with dataset **S2**?" i.e. $L_{(Y,W,S2)} = ?$.

The methodology for solving this problem consists of three steps:

1. Computing the hardware proportionality constants;
2. Computing the software systems' performance and proportionality constants;
3. Analysis of experiments: Rank-based multiple comparison.

Further in this paper we describe the third point of methodology - Analysis of experiments: Rank-based multiple comparison. The experiments are based on real systems, data sets, and real as well as published benchmarks.

## Experiments

We will compare a real RDF-data storing system **R** [RDFArM, 2015] with three other similar real RDF-stores:

- **V** [Virtuoso, 2013];
- **J** [Jena, 2016];
- **S** [Sesame, 2015],

Systems **V**, **J**, and **S** are tested by Berlin SPARQL Bench Mark (BSBM) team and connected to it research groups [Becker, 2008; BSBMv2, 2008; BSBMv3, 2009].

We provided experiments with *middle-size RDF-datasets*, based on selected real datasets from DBpedia [DBpedia, 2007a; DBpedia, 2007b] and artificial datasets created by BSBM Data Generator [BSBM DG, 2013; Bizer & Schultz, 2009].

The real middle-size RDF-datasets which we used consist of DBpedia's homepages and geocoordinates datasets with minor corrections [Becker, 2008]:

- ***H.nt*** (200,036 instances; 24 MB) Based on DBpedia's homepages.nt dated 2007-08-30 [DBpedia, 2007a]. 3 URLs that included line breaks were manually corrected (fixed for DBpedia 3.0);
- ***G.nt*** (447,517 instances; 64 MB) Based on DBpedia's geocoordinates.nt dated 2007-08-30 [DBpedia, 2007b]. Decimal data type URI was corrected (DBpedia bug #1817019; resolved).

The RDF stores feature different indexing behaviors: **S** automatically indexes after each import, while SDB and **V** allow for selective index activation which cause corresponded limitations or advantages. In order to make load times comparable, the data import by [Becker, 2008] was performed as follows:

- ***H.nt*** was imported with indexes enabled;
- ***G.nt*** was imported with indexes enabled.

In the case with **R** no parameters are needed. The data sets were loaded directly from the source N-triple files.

The artificial middle-size RDF-datasets are generated by BSBM Data Generator [BSBM DG, 2013] and published in N-triple as well as in Turtle format [BSBMv1, 2008; BSBMv2, 2008; BSBMv3, 2009]. We converted Turtle format in N-triple format using “rdf2rdf” program developed by Enrico Minack [Minack, 2010].

We have use four BSBM datasets – 50K, 250K, 1M, and 5M. Details about these datasets are summarized in following Table 1.

Table 1. Details about used artificial middle-size RDF-datasets

| **Name of RDF-dataset:** | **B50K** | **B250K** | **B1M** | **B5M** |
|---|---|---|---|---|
| Exact Total Number of Instances: | 50,116 | 250,030 | 1,000,313 | 5,000,453 |
| File Size Turtle (unzipped) | 14 MB | 22 MB | 86 MB | *1,4 GB* |

## Loading of B50K

**R** has loaded all **50116** instances from **B50K** for about **113 seconds** (112851 ms) or average time of **2.3 ms** per triple.

Number of Subjects in this dataset was S=4900; number of relations R=40; and number of objects O=50116.

This means that practically we had 40 layers with 4900 NL-locations (containers) which contain 50116 objects. The loading time' results from our experiment and [Bizer & Schultz, 2008] are given in Table 2.

Computer configurations and corresponded to them coefficients were given in [Ivanova et al, 2016a].

Benchmark configuration used by [Bizer&Schultz, 2008] is **Configuration B**.

Our benchmark configuration is **Configuration K**.

The loading times proportionality formula is

$$\mathbf{L}_{(R,B,S2)} = \mathbf{L}_{(R,K,S2)} * \mathbf{R}_{R,K,B}, \text{ and } \mathbf{R}_{R,K,B} = \mathbf{0.025729};$$

and we compute final loading time as follow: 113 * 0.025729= **2.91 sec**.

Table 2. Benchmark results for B50K

| system | loading time in seconds |
|---|---|
| **S** | 3 |
| **J** SDB | 5 |
| **V** | 2 |
| **R** | **3** |

From Table 2 we may conclude that **V** has the best loading time for **B50K. R** has same loading time as **S** and 40% better performance than **J**.

**Loading of H.nt**

**R** has loaded all **200036** instances from ***H.nt*** for about **727 seconds** (727339 ms) or average time of **3.6 ms** per triple. More detailed information is given in Table 3. Every row of this table contains data for storing of one hundred thousand instances. Total stored instances were 200036 and Table 3 contains three rows.

Table 3. Results for loading times of H.nt by **R**

| part | instances stored | ms for all | ms for one | Subjects | Relations | Objects |
|---|---|---|---|---|---|---|
| 1 | 100000 | 360955 | 3.6 | 100000 | 1 | 100000 |
| 2 | 100000 | 366275 | 3.7 | 100000 | 1 | 100000 |
| 3 | 36 | 109 | 3.0 | 36 | 1 | 36 |
| **Total:** | **200036** | **727339** | **3.6** | **200036** | **1** | **200036** |

Number of Subjects in this dataset was S=200036; number of relations R=1; and number of objects O=200036.

This means that practically we had only one layer with 200036 NL-locations (containers) which contain the same number of objects. The loading time' results from our experiment and [Becker, 2008] are given in Table 4.

Benchmark configuration used by [Becker, 2008] is **Configuration A**.

Our benchmark configuration is **Configuration K**.

The loading times proportionality formula is

$$\mathbf{L_{(R,A,S2)}} = \mathbf{H_{AK}}*\mathbf{L_{(R,K,S2)}}, \text{ where } \mathbf{H_{AK}} = \mathbf{3.125};$$

and we compute final loading time as follow: 727 x 3.125 = **2271.875** sec.

Table 4. Benchmark results for H.nt

| system | loading time in seconds |
|---|---|
| **V** | 1327 |
| **J V1** | 5245 |
| **J V2** | 3557 |
| **J V3** | 9681 |
| **S** | 2404 |
| **R** | **2272** |

From Table 4 we may conclude that **V** has the best time (about 42% better result than **R**); **R** has about 5% better time than **S** and 36% better time than **J** (we take in account only the best results of compared systems, in this case – **J**).

### Loading of B250K

**R** has loaded all **250030** instances from **B250K** for about **575 seconds** (575069 ms) or average time of **2.3 ms** per triple.

More detailed information is given in 0. Every row of this table contains data for storing of one hundred thousand instances. Total stored instances were 250030 and 0 contains three rows.

Table 5. Results for loading times of B250K by **R**

| part | instances stored | ms for all | ms for one | Subjects | Relations | Objects |
|---|---|---|---|---|---|---|
| 1 | 100000 | 238525 | 2.4 | 19854 | 6 | 100000 |
| 2 | 100000 | 228854 | 2.3 | 26505 | 22 | 100000 |
| 3 | 50030 | 107690 | 2.1 | 14525 | 22 | 50030 |
| **Total:** | **250030** | **575069** | **2.3** | **60884** | **22** | **250030** |

Number of Subjects in this dataset was S=60884; number of relations R=22; and number of objects O=250030.

This means that practically we had 22 layers with 60884 NL-locations (containers) which contain 250030 objects. The loading time' results from our experiment and [BSBMv2, 2008] are given in Table 6.

Benchmark configuration used by [BSBMv2, 2008] is **Configuration B**.

Our benchmark configuration is **Configuration K**.

The loading times proportionality formula is

$$\mathbf{L_{(R,B,S2)}} = \mathbf{L_{(R,K,S2)}} * \mathbf{R_{R,K,B}}, \text{ and } \mathbf{R_{R,K,B}} = \mathbf{0.025729};$$

and we compute final loading time as follow: 575 x 0.025729= **14.79 sec**.

Table 6. Benchmark results for B250K

| system | loading time in seconds |
|---|---|
| **S** | 19 |
| **J** TDB | 13 |
| **V** TS | 05 |
| **V** RDF views | 09 |
| **V** SQL | 09 |
| **R** | **14.79** |

From Table 6 we may conclude that **V** has 66% and **J** has 12% better performance than **R**. **R** has 22% better performance than **S**.

**Loading of G.nt**

**R** has loaded all 447517 instances from **G.nt** for about 1110 seconds (1110415 ms) or average time of 2.5 ms per triple.

More detailed information is given in Table 7 Every row of this table contains data for storing of one hundred thousand instances. Total stored instances were 447517 and Table 7 contains five rows.

Table 7. Results for loading times of G.nt by **R**

| part | instances stored | ms for all | ms for one | Subjects | Relations | Objects |
|---|---|---|---|---|---|---|
| 1 | 100000 | 244453 | 2.4 | 34430 | 6 | 100000 |
| 2 | 100000 | 246747 | 2.5 | 34909 | 6 | 100000 |
| 3 | 100000 | 245530 | 2.5 | 33863 | 6 | 100000 |
| 4 | 100000 | 248198 | 2.5 | 33678 | 6 | 100000 |
| 5 | 47517 | 47517 | 2.6 | 16095 | 6 | 47517 |
| **Total:** | **447517** | **1110415** | **2.5** | **152975** | **6** | **447517** |

Number of Subjects in this dataset was S=152975; number of relations R=6; and number of objects O=447517.

This means that practically we had six layers with 152975 NL-locations (containers) which contain 447517 objects, i.e. some containers in some layers are empty. The loading time' results from our experiment and [Becker, 2008] are given in **Error! Reference source not found.** and **Error! Reference source not found.**.

Benchmark configuration used by [Becker, 2008] is **Configuration A**.

Our benchmark configuration is **Configuration K**.

The loading times proportionality formula is

$$\mathbf{L_{(R,A,S2)}} = \mathbf{H_{AK}}^*\mathbf{L_{(R,K,S2)}}, \text{ where } \mathbf{H_{AK}} = \mathbf{3.125};$$

and we compute final loading time as follow: 1110 x 3.125= **3468.75 sec**.

Table 8. Benchmark results for G.nt

| system | loading time in seconds |
|---|---|
| **V** | 1235 |
| **J V1** | 6290 |
| **J V2** | 3305 |
| **J V3** | 9640 |
| **S** | 2341 |
| **R** | **3469** |

From Table 8 we may conclude that **R** has the worst performance (we take the best time of **J**). **V** has 64%, **S** has 33%, and **J** has 5% better performance.

## Loading of B1M

**R** has loaded all **1000313** instances from **B1M** for about **2349 seconds** (2349328 ms) or average time of **2.3 ms** per triple.

More detailed information is given in Table 9. Every row of this table contains data for storing of one hundred thousand instances. Total stored instances were 1000313 and Table 9 contains 11 rows. This table has new structure. It contains number of stored instances to corresponded part including it and in separate columns the time for storing the last 100000 instances and average time for one triple from this part.

Table 9. Results for loading times of B1M by **R**

| part | instances stored | ms for all | ms for one | ms for last 100000 | ms for one | Subjects | Relations | Objects |
|---|---|---|---|---|---|---|---|---|
| 1 | 100000 | 241099 | 2.4 | 241099 | 2.4 | 6859 | 22 | 100000 |
| 2 | 200000 | 480265 | 2.4 | 239166 | 2.4 | 14363 | 29 | 200000 |
| 3 | 300000 | 714453 | 2.4 | 234188 | 2.3 | 24365 | 29 | 300000 |
| 4 | 400000 | 962994 | 2.4 | 248541 | 2.5 | 34366 | 29 | 400000 |
| 5 | 500000 | 1194344 | 2.4 | 231350 | 2.3 | 44368 | 29 | 500000 |
| 6 | 600000 | 1423665 | 2.4 | 229321 | 2.3 | 54370 | 29 | 600000 |
| 7 | 700000 | 1655420 | 2.4 | 231755 | 2.3 | 64324 | 40 | 700000 |
| 8 | 800000 | 1892074 | 2.4 | 236654 | 2.4 | 73799 | 40 | 800000 |
| 9 | 900000 | 2116590 | 2.4 | 224516 | 2.2 | 83269 | 40 | 900000 |
| 10 | 1000000 | 2348501 | 2.3 | 231911 | 2.3 | 92729 | 40 | 1000000 |
| 11 | 1000313 | 2349328 | 2.3 | 827 | 2.6 | 92757 | 40 | 1000313 |

Number of Subjects in this dataset was S=92757; number of relations R=40; and number of objects O=1000313.

This means that practically we had 40 layers with 92757 NL-locations (containers) which contain 1000313 objects. The loading time' results from our experiment and [BSBMv2, 2008; BSBMv3, 2009] are given in Table 10.

Benchmark configuration used by [BSBMv2, 2008; BSBMv3, 2009] is **Configuration B**.

Our benchmark configuration is **Configuration K**.

The loading times proportionality formula is

$$\mathbf{L_{(R,B,S2)}} = \mathbf{L_{(R,K,S2)}} * \mathbf{R_{R,K,B}}, \text{ and } \mathbf{R_{R,K,B}} = \mathbf{0.025729};$$

and we compute final loading time as follow: 2349 x 0.025729 = **60.437421 sec**.

Table 10. Benchmark results for B1M

| system | loading time in min:sec | |
|---|---|---|
| | (a) [BSBMv2, 2008] | (b) [BSBMv3, 2009] |
| **S** | 02:59 | 03:33 |
| **J** TDB | 00:49 | 00:41 |
| **J** SDB | 02:09 | - |
| **V** TS | 00:23 | 00:25 |
| **V** RV | 00:34 | 00:33 |
| **V** SQL | 00:34 | 00:33 |
| **R** | **01:00** | **01:00** |

From Table 10 we may conclude that **V** has 62% and **J** has 32% better performance than **R**. **R** has 67% better performance than **S**.

## Loading of B5M

**R** has loaded all **5000453** instances from **B5M** for about **11704 sec.** (11704116 ms) or average time of **2.3 ms** per triple.

Number of Subjects in this dataset was S=458142; number of relations R=55; and number of objects O=5000453.

This means that practically we had 55 layers with 458142 NL-locations (containers) which contain 5000453 objects. The loading time' results from our experiment and [Bizer & Schultz, 2008] are given in Table 12.

More detailed information is given in Table 11. Every row of this table contains data for storing of one hundred thousand instances. Total stored instances were 5000453 and Table 11 contains 51 rows.

This table contains number of stored instances to corresponded part including it and in separate columns the time for storing the last 100000 instances and average time for one triple from this part.

Table 11. Results for loading times of B5M by **R**

| part | instances stored | ms for all | ms for one | ms for last 100000 | ms for one | Subjects | Relations | Objects |
|---|---|---|---|---|---|---|---|---|
| 1 | 100000 | 250023 | 2.5 | 250023 | 2.5 | 5463 | 22 | 100000 |
| 2 | 200000 | 506660 | 2.5 | 256637 | 2.6 | 7973 | 22 | 200000 |
| 3 | 300000 | 751254 | 2.5 | 244594 | 2.4 | 10471 | 22 | 300000 |
| 4 | 400000 | 983196 | 2.5 | 231942 | 2.3 | 12974 | 22 | 400000 |
| 5 | 500000 | 1227104 | 2.5 | 243908 | 2.4 | 22353 | 29 | 500000 |
| 6 | 600000 | 1468063 | 2.4 | 240959 | 2.4 | 32357 | 29 | 600000 |
| 7 | 700000 | 1708663 | 2.4 | 240600 | 2.4 | 42360 | 29 | 700000 |
| 8 | 800000 | 1956034 | 2.4 | 247371 | 2.5 | 52363 | 29 | 800000 |
| 9 | 900000 | 2190644 | 2.4 | 234610 | 2.3 | 62366 | 29 | 900000 |
| 10 | 1000000 | 2430043 | 2.4 | 239399 | 2.4 | 72369 | 29 | 1000000 |
| 11 | 1100000 | 2666041 | 2.4 | 235998 | 2.4 | 82372 | 29 | 1100000 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 12 | 1200000 | 2910230 | 2.4 | 244189 | 2.4 | 92375 | 29 | 1200000 |
| 13 | 1300000 | 3143529 | 2.4 | 233299 | 2.3 | 102377 | 29 | 1300000 |
| 14 | 1400000 | 3371618 | 2.4 | 228089 | 2.3 | 112381 | 29 | 1400000 |
| 15 | 1500000 | 3605136 | 2.4 | 233518 | 2.3 | 122384 | 29 | 1500000 |
| 16 | 1600000 | 3838139 | 2.4 | 233003 | 2.3 | 132387 | 29 | 1600000 |
| 17 | 1700000 | 4070830 | 2.4 | 232691 | 2.3 | 142390 | 29 | 1700000 |
| 18 | 1800000 | 4298155 | 2.4 | 227325 | 2.3 | 152393 | 29 | 1800000 |
| 19 | 1900000 | 4527367 | 2.4 | 229212 | 2.3 | 162396 | 29 | 1900000 |
| 20 | 2000000 | 4758030 | 2.4 | 230663 | 2.3 | 172399 | 29 | 2000000 |
| 21 | 2100000 | 4985698 | 2.4 | 227668 | 2.3 | 182402 | 29 | 2100000 |
| 22 | 2200000 | 5212742 | 2.4 | 227044 | 2.3 | 192405 | 29 | 2200000 |
| 23 | 2300000 | 5439692 | 2.4 | 226950 | 2.3 | 202408 | 29 | 2300000 |
| 24 | 2400000 | 5685347 | 2.4 | 245655 | 2.5 | 212043 | 40 | 2400000 |
| 25 | 2500000 | 5922328 | 2.4 | 236981 | 2.4 | 221512 | 40 | 2500000 |
| 26 | 2600000 | 6155331 | 2.4 | 233003 | 2.3 | 230972 | 40 | 2600000 |
| 27 | 2700000 | 6391610 | 2.4 | 236279 | 2.4 | 240447 | 40 | 2700000 |
| 28 | 2800000 | 6630417 | 2.4 | 238807 | 2.4 | 249912 | 40 | 2800000 |
| 29 | 2900000 | 6855511 | 2.4 | 225094 | 2.3 | 259371 | 40 | 2900000 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 30 | 3000000 | 7078545 | 2.4 | 223034 | 2.2 | 268831 | 40 | 3000000 |
| 31 | 3100000 | 7305979 | 2.4 | 227434 | 2.3 | 278290 | 40 | 3100000 |
| 32 | 3200000 | 7533928 | 2.4 | 227949 | 2.3 | 287754 | 40 | 3200000 |
| 33 | 3300000 | 7773608 | 2.4 | 239680 | 2.4 | 297240 | 40 | 3300000 |
| 34 | 3400000 | 8006782 | 2.4 | 233174 | 2.3 | 306704 | 40 | 3400000 |
| 35 | 3500000 | 8239629 | 2.4 | 232847 | 2.3 | 316145 | 40 | 3500000 |
| 36 | 3600000 | 8464536 | 2.4 | 224907 | 2.2 | 325609 | 40 | 3600000 |
| 37 | 3700000 | 8693202 | 2.3 | 228666 | 2.3 | 335077 | 40 | 3700000 |
| 38 | 3800000 | 8919248 | 2.3 | 226046 | 2.3 | 344557 | 40 | 3800000 |
| 39 | 3900000 | 9150254 | 2.3 | 231006 | 2.3 | 354009 | 40 | 3900000 |
| 40 | 4000000 | 9383912 | 2.3 | 233658 | 2.3 | 363472 | 40 | 4000000 |
| 41 | 4100000 | 9616120 | 2.3 | 232208 | 2.3 | 372924 | 40 | 4100000 |
| 42 | 4200000 | 9850090 | 2.3 | 233970 | 2.3 | 382383 | 40 | 4200000 |
| 43 | 4300000 | 10073842 | 2.3 | 223752 | 2.2 | 391847 | 40 | 4300000 |
| 44 | 4400000 | 10305832 | 2.3 | 231990 | 2.3 | 401308 | 40 | 4400000 |
| 45 | 4500000 | 10536619 | 2.3 | 230787 | 2.3 | 410763 | 40 | 4500000 |
| 46 | 4600000 | 10769997 | 2.3 | 233378 | 2.3 | 420233 | 40 | 4600000 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 47 | 4700000 | 11004030 | 2.3 | 234033 | 2.3 | 429699 | 40 | 4700000 |
| 48 | 4800000 | 11242836 | 2.3 | 238806 | 2.4 | 439169 | 40 | 4800000 |
| 49 | 4900000 | 11474107 | 2.3 | 231271 | 2.3 | 448643 | 40 | 4900000 |
| 50 | 5000000 | 11702852 | 2.3 | 228745 | 2.3 | 458099 | 40 | 5000000 |
| 51 | 5000453 | 11704116 | 2.3 | 1264 | 2.8 | 458142 | 55 | 5000453 |

Benchmark configuration used by [Bizer & Schultz, 2008] is **Configuration B**.

Our benchmark configuration is **Configuration K**.

The loading times proportionality formula is

$$\mathbf{L_{(R,B,S2)}} = \mathbf{L_{(R,K,S2)}} * \mathbf{R_{R,K,B}}, \text{ and } \mathbf{R_{R,K,B}} = \mathbf{0.025729};$$

and we compute final loading time as follow: 11704 * 0.025729= **301.13** sec.

Table 12. Benchmark results for B5M

| system | loading time in seconds |
|---|---|
| **S** | 1988 |
| **J** | 1053 |
| **V** | 609 |
| **R** | **301** |

From Table 12 we may conclude that **R** has best loading time (better about 85% than **S**, 71% than **J**, and 51% than **V**).

## Experiments with large datasets

We provided experiments with real large datasets which were taken from DBpedia's homepages [DBpedia, 2007c] and Billion Triple Challenge (BTC) 2012 [BTC, 2012].

The real dataset from DBpedia's ***I.nt*** (15,472,624 instances; 2.1 GB) is based on DBpedia's *infoboxes.nt* dated 2007-08-30 [DBpedia, 2007c]. 166 instances from the original set were excluded because they contained excessively large URIs *(> 500 characters)* that caused importing problems with **V** (DBpedia bug #1871653). **R** has no such limitation. **I.nt** was imported with indexes initially disabled in **V**. Indexes were then activated and the time required for index creation time was factored into the import time. In the case with **R** no parameters are needed. The datasets were loaded directly from the source file.

The RDF stores feature different indexing behaviors: **S** automatically indexes after each import, while SDB and **V** allow for selective index activation.

Artificial large datasets are taken from Berlin SPARQL Bench Mark (BSBM) [Bizer & Schultz, 2009; BSBMv3, 2009; BSBMv5, 2009; BSBMv6, 2011]. Details about the benchmark artificial datasets are summarized in the following Table 13:

Table 13. Details about artificial large RDF-datasets

| Number of Instances | 25M | 100M |
|---:|---:|---:|
| Exact Total Number of Instances | 25000244 | 100000112 |
| File Size Turtle (unzipped) | *2.1 GB* | 8.5 GB |

## Loading of I.nt

**R** has loaded all 15 472 624 instances from **I.nt** for about 43652 seconds (43652528 ms) or average time of 2.8 ms per triple.

Detailed information is not given here because of the size of the table with results. Every row of this table contains data for storing of one hundred thousand instances and total number of stored instances is 15,472,624 and table contains 155 rows.

Number of Subjects in this dataset was S=1354298; number of relations R=56338; and number of objects O=15472624.

This means that practically we had 56338 layers with 1354298 NL-locations (containers) which contain 15472624 objects, i.e. some containers in some layers are empty. The loading time' results from our experiment and [Becker, 2008] are given in Table 14.

Benchmark configuration used by [Becker, 2008] is **Configuration A**.

Our benchmark configuration is **Configuration K**.

The loading times proportionality formula is

$L_{(\mathbf{R},A,S2)} = H_{AK}{*}L_{(\mathbf{R},K,S2)}$, where $H_{AK} = 3.125$;

and we compute final loading time as follow: 43652 x 3.125= **136412.5** sec.

Table 14. Benchmark results for I.nt

| system | loading time in seconds |
|---|---:|
| **V** | 7017 |
| **J Variant 1** | 70851 |
| **J Variant 2** | 73199 |
| **J Variant 3** | 734285 |
| **S** | 21896 |
| **R** | **136412** |

From Table 14 we may conclude that **R** has the worst loading time. **V** is 95%, **S** is 84%, and **J** is 48% better than **R** (we take in account only the best results of compared systems).

### Loading of B25M

**R** has loaded all **25000244** instances from **B25M** for about **56488** seconds (56488509ms) or average time of **2.3** ms per triple.

Number of Subjects in this dataset was S=2258132; number of relations R=112; and number of objects O=25000244.

This means that practically we had 112 layers with 2258132 NL-locations (containers) which contain 25000244 objects, i.e. some containers in some layers are empty.

The loading time' results from our experiment and [Bizer & Schultz, 2009; BSBMv3, 2009] are given in Table 15.

Benchmark configuration used by [Bizer & Schultz, 2009; BSBMv3, 2009] is **Configuration B**. Our benchmark configuration is **Configuration K**.

The loading times proportionality formula is

$$\mathbf{L_{(R,B,S2)}} = \mathbf{L_{(R,K,S2)}} * \mathbf{R_{R,K,B}}, \text{ and } \mathbf{R_{R,K,B}} = \mathbf{0.025729}.$$

We compute final loading time as follow: 56488*0.025729= **1453.38** sec.

Table 15. Benchmark results for B25M

| system | loading time in seconds |
|---|---|
| **S** | 44225 |
| **J** TDB | 1013 |
| **J** SDB | 14678 |
| **V** TS | 2364 |
| **V** RV | 1035 |
| **V** SQL | 1035 |
| **R** | **1453** |

From Table 15 we may conclude that **J** (with 30%) and **V** (with 29%) are better than **R**. **R** has 97% better performance than **S**.

## Loading of B100M and BSBM 200M

**R** has loaded all **100000112** instances from **B100M** for about **229344** seconds (229343807 ms) or average time of **2.3** ms per triple.

Number of Subjects in this dataset was S=9034046; number of relations R=341; and number of objects O=100000112.

This means that practically we had 341 layers with 9034046 NL-locations (containers) which contain 100000112 objects, i.e. some containers in some layers contain more than one object. The loading time' results from our experiment and [Bizer & Schultz, 2009; BSBMv3, 2009] are given in Table 16.

Benchmark configuration used by [Bizer & Schultz, 2009; BSBMv3, 2009] is **Configuration B**.

Our benchmark configuration is **Configuration K**.

The loading times proportionality formula is

$$\mathbf{L}_{(R,B,S2)} = \mathbf{L}_{(R,K,S2)} * \mathbf{R}_{R,K,B}, \text{ and } \mathbf{R}_{R,K,B} = \mathbf{0.025729}.$$

We compute final loading time as follow:

229344 * 0.025729 = **5900.79** sec.

Table 16. Benchmark results for B100M

| system | loading time in seconds |
|---|---|
| **S** | 282455 |
| **J** TDB | 5654 |
| **J** SDB | 139988 |
| **V** TS | 28607 |
| **V** RV | 3833 |
| **V** SQL | 3833 |
| **R** | **5901** |

From Table 16 we may conclude that **V** is 35% better than **R** and **J** is 4% better than **R**. **R** is 98% better than **S**.

## Analysis of experiments: Rank-based multiple comparison

We have provided experiments with middle-size and large RDF-datasets, based on selected datasets from DBpedia's homepages and Berlin SPARQL Bench Mark (BSBM) to make comparison with published benchmarks of known RDF triple stores. Result from Rank-based multiple comparison is discussed below.

We used the Friedman test to detect statistically significant differences between the systems [Friedman, 1940]. The Friedman test is a non-parametric test, based on the ranking of the systems on each dataset. It is equivalent of the repeated-measures ANOVA [Fisher, 1973]. We used Average Ranks ranking method, which is a simple ranking method, inspired by Friedman's statistic [Neave & Worthington, 1992]. For each dataset the systems are ordered according to the time measures and are assigned ranks accordingly. The best system receives rank 1, the second – 2, etc. If two or more systems have equal value, they receive equal rank which is mean of the virtual positions that had to receive such number of systems if they were ordered consecutively each by other.

Let *n* is the number of observed datasets; *k* is the number of systems.

Let $_i r_j$ be the rank of system *j* on dataset *i*. The average rank for each system is calculated as

$$R_j = \frac{1}{n}\sum_{i=1}^{k} r_j^i \cdot$$

The null-hypothesis states that if all the systems are equivalent than their ranks $R_j$ should be equal. When null-hypothesis is rejected, we can proceed with the Nemenyi test [Nemenyi, 1963] which is used when all systems are compared to each other. The performance of two systems is significantly different if the corresponding average ranks differ by at least the critical difference

$$CD = q_\alpha \sqrt{\frac{k(k+1)}{6N}}$$

where critical values $q_\alpha$ are based on the Studentized range statistic divided by $\sqrt{2}$. Some of the values of $q_\alpha$ are given in Table 17 [Demsar, 2006].

Table 17. Critical values for the two-tailed Nemenyi test

| **systems** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |
|---|---|---|---|---|---|---|---|---|---|
| $q_{0.05}$ | 1.960 | 2.343 | 2.569 | 2.728 | 2.850 | 2.949 | 3.031 | 3.102 | 3.164 |
| $q_{0.10}$ | 1.645 | 2.052 | 2.291 | 2.459 | 2.589 | 2.693 | 2.780 | 2.855 | 2.920 |

The results of the Nemenyi test are shown by means of critical difference diagrams.

Experiments which we will take in account were presented in corresponded tables of above as follow (Table 18):

Table 18. Information about tests and results

| **test No:** | **results** |
|---|---|
| 1 | Table 2 |
| 2 | Table 4 |
| 3 | Table 6 |
| 4 | Table 8 |
| 5a | Table 10 |
| 5b | Table 10 |
| 6 | Table 12 |
| 7 | Table 14 |
| 8 | Table 15 |
| 9 | Table 16 |

Benchmark values from our 12 experiments and corresponded published experimental data from BSBM team are given in Table 19 Published results do not cover all table, i.e. we have no values for some cells. To solve this problem we will take in account only the best result for given system on concrete datasets (Table 20). **S** had no average values for tests 10a and 10b. Because of this we will not use these test in our comparison. They were useful to see the need of further refinement of **R** for big data.

The ranks of the systems for the ten tests are presented below in Table 21.

Table 19. Benchmark values for middle size datasets

| **system** | **TEST** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5a** | **5b** | **6** | **7** | **8** | **9** |
| **R** | 3 | 2272 | 14.79 | 3469 | 60 | 60 | 301 | 136412 | 1453 | 5901 |
| **S** | 3 | 2404 | 19 | 2341 | 179 | 213 | 1988 | 21896 | 44225 | 282455 |
| **V** | 2 | 1327 | | 1235 | | | 609 | 7017 | | |
| **V** TS | | | 05 | | 23 | 25 | | | 2364 | 28607 |
| **V** RDF | | | 09 | | | | | | | |
| **V** SQL | | | 09 | | 34 | 33 | | | 1035 | 3833 |
| **V** RV | | | | | 34 | 33 | | | 1035 | 3833 |
| **J** SDB | 5 | | 13 | | 129 | | 1053 | | 14678 | 139988 |
| **J** TDB | | | | | 49 | 41 | | | 1013 | 5654 |
| **J V1** | | 5245 | | 6290 | | | | 70851 | | |
| **J V3** | | 3557 | | 3305 | | | | 73199 | | |
| **J V2** | | 9681 | | 9640 | | | | 734285 | | |

Table 20. Chosen benchmark values for middle size datasets

| | **TEST** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **system** | **1** | **2** | **3** | **4** | **5a** | **5b** | **6** | **7** | **8** | **9** |
| **R** | 3 | 2272 | 14.79 | 3469 | 60 | 60 | 301 | 136412 | 1453 | 5901 |
| **S** | 3 | 2404 | 19 | 2341 | 179 | 213 | 1988 | 21896 | 44225 | 282455 |
| **V** | 2 | 1327 | 05 | 1235 | 23 | 25 | 609 | 7017 | 1035 | 3833 |
| **J** | 5 | 3557 | 13 | 3305 | 49 | 41 | 1053 | 70851 | 1013 | 5654 |

Table 21. Ranking of tested systems

| **system** | **ranks for the tests** | | | | | | | | | | **average rank** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5a** | **5b** | **6** | **7** | **8** | **9** | |
| **R** | 2.5 | 2 | 3 | 4 | 3 | 3 | 1 | 4 | 3 | 3 | **2.85** |
| **S** | 2.5 | 3 | 4 | 2 | 4 | 4 | 4 | 2 | 4 | 4 | **3.35** |
| **V** | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | **1.2** |
| **J** | 4 | 4 | 2 | 3 | 2 | 2 | 3 | 3 | 1 | 2 | **2.6** |

All average ranks are different. The null-hypothesis is rejected and we can proceed with the Nemenyi test. Following [Demsar, 2006], we may compute the critical difference by formula:

$$CD = q_{\alpha}\sqrt{\frac{k(k+1)}{6N}}$$

where $q_{\alpha}$ we take as $q_{0.10}$ = 2.291 (from Table 17 [Demsar, 2006; Table 5a]); *k* will be the number of systems compared, i.e. *k*=4; N will be the number of datasets used in benchmarks, i.e. N=10. This way we have:

$$CD_{0.10} = 2.291 * \sqrt{\frac{4*5}{6*10}} = 2.291 * \sqrt{\frac{20}{60}} = 2.291 * 0.577 = 1.322$$

We will use for critical difference $CD_{0.10}$ the value 1.322.

At the end, average ranks of the systems and distance to average rank of the first one are shown in Table 22.

Table 22. Average ranks of systems and distance to average rank of the first one

| place | system | average rank | Distance between average rank of the every system and average rank of the first one |
|---|---|---|---|
| **1** | **V** | **1.2** | **0** |
| **2** | **J** | **2.6** | **1.4** |
| **3** | **R** | **2.85** | **1.65** |
| **4** | **S** | **3.35** | **2.15** |

The visualization of Nemenyi test results for tested systems is shown on Figure 1.

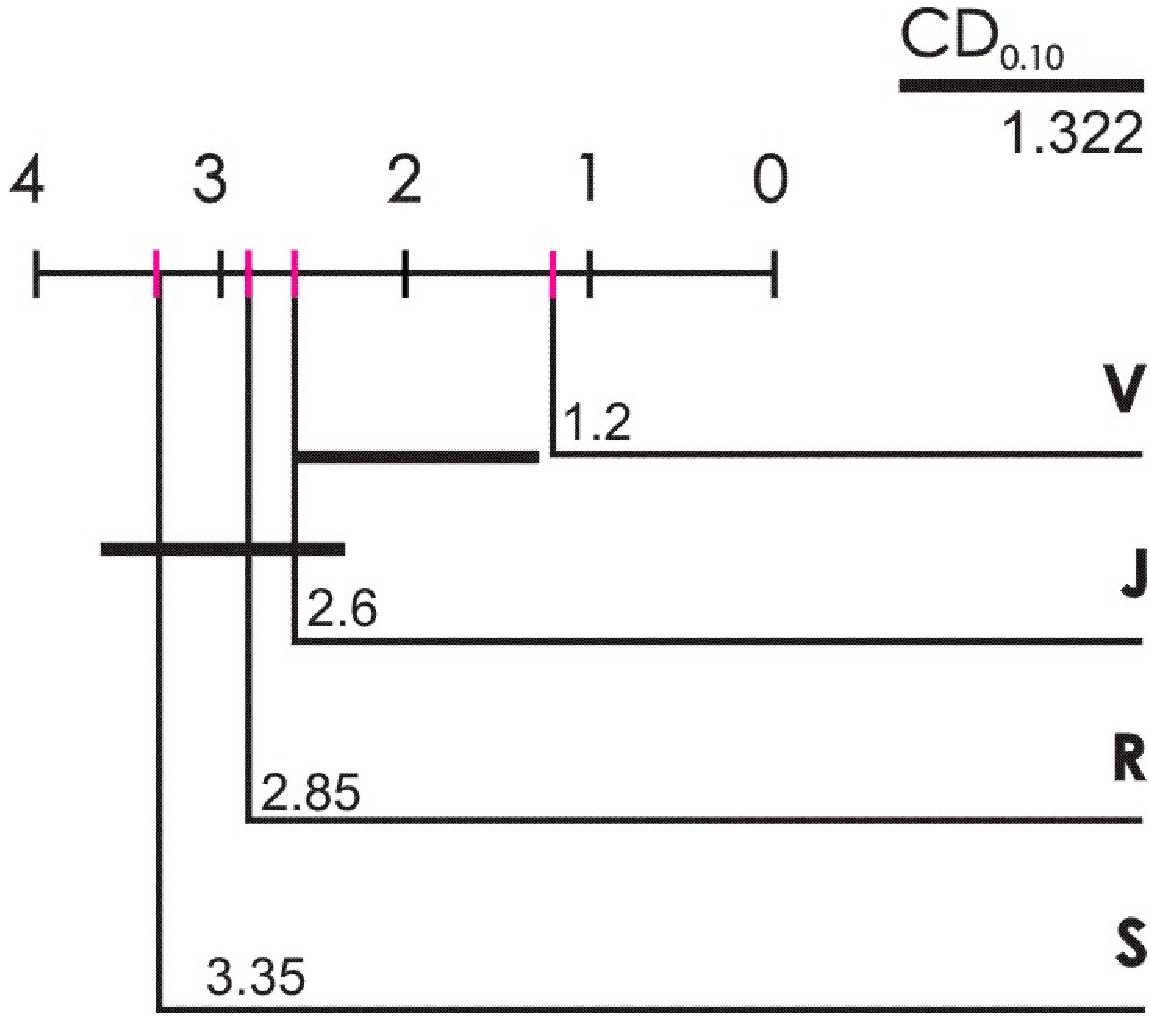



Figure 1. Visualization of Nemenyi test results

Analyzing these experiments we may conclude that **R** is at critical distances to **J** and **S**. **R** is nearer to **J** than to **S**. **R**, **J**, and **S** are significantly different from **V**.

## Conclusion

We have presented results from series of experiments which were needed to estimate the storing time of NL-addressing for middle-size and very large RDF - datasets.

We described the experimental storing models and special algorithm for NL-storing RDF instances. Estimation of experimental systems was provided to make different configurations comparable. Special proportionality constants for hardware and software were proposed. Using proportionality constants, experiments with middle-size and large datasets become comparable.

Experiments were provided with both real and artificial datasets. Experimental results were systematized in corresponded tables. For easy reading visualization by histograms was given.

Experimental results will be analyzed in the next chapter.

The goal experiments for NL-storing of middle-size and large RDF-datasets were to estimate possible further development of NL-ArM. We assumed that its "software growth" will be done in the same grade as one of the known systems like **V**, **J**, and **S**. In the next chapter we will analyze what will be the place of NL-ArM in this environment but already we may see that NL-addressing have good performance and NL-ArM has similar results as **J** and **S**.

**Acknowledgement**

The paper is published with partial support by the Project "Methods for modeling and evaluation of informational services" of the University of Telecommunications and Posts, Sofia, Bulgaria.

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## Authors' Information

***Krassimira Ivanova*** – *Assoc. prof. Dr.; University of Telecommunications and Posts, Sofia, Bulgaria; Institute of Mathematics and Informatics, BAS, Bulgaria; e-mail: krasy78@mail.bg ;*

***Major Fields of Scientific Research:*** *Software Engineering, Business Informatics, Data Mining, Multidimensional multi-layer data structures in self-structured systems*

***Krassimir Markov*** – *Institute of Mathematics and Informatics, BAS, Acad. G.Bontchev St., bl.8, Sofia-1113, Bulgaria; e-mail: markov@foibg.com*

***Major Fields of Scientific Research****: General theoretical information research, Multi-dimensional information systems; Software Engineering, Business Informatics, Data Mining.*

***Stefan Karastanev*** – *Assist. prof.; Institute of Mechanics, BAS, Bulgaria; e-mail: stefan@imbm.bas.bg*

***Major Fields of Scientific Research:*** *Software Engineering, Data Processing and Mining, Data structures in information systems.*

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