Filip the Catalyst

(Instead of) "Laudatio"

Why "Instead of"? At least for six reasons; thus, a conventional "Laudatio" would be rather:

a) *Hardly possible* for a career that braves any standard. Which Filip should be praised in a limited journal space? Except the young specialist in industrial automation who disappeared soon because a large palette of personalities were grafted onto, all other professional facets – from IT expert to transdisciplinary researcher and from manager to university professor – are long-lasting, rich and diverse.

b) *Irrelevant or even boring.* What should be emphasized? Positions, titles, books, papers, classes, success stories? The long lists would do their job as usual: instead of illustrating quality, they would smother it; in short, the trees hide the forest.

c) *Either parochial or snobbish.* Indeed, giving the reasons for awarding him the Honoris Causa Degree in Sibiu a few years ago would sound sectorial or insular, whereas trying to present his role in the academic life of Chişinău would sound arrogant, since the readers know it much better. In any case it would distort: either by omission or by unbalanced focus.

d) *Strange.* For a dynamic personality, still far from the scientific apex, the occasion given by an age divisible by ten is forced to coexist with the usual references to an "Opera Omnia". It sounds Procrustean.

e) *Redundant.* In this very journal much more competent authorities have done it in a high-level manner.

f) *Biased.* For more than a quarter-century, Florin Gheorghe Filip was crucial for my evolution; hence, I lack the minimal detachment necessary to become an acceptable *Laudator* in its earliest mediaeval meaning.

Therefore, this pseudo-Laudatio is a fuzzy blend of acknowledgment, confession, and feelings. Albeit most of the assertions below (and above too!) are my opinions, covering them with the umbrella of "feelings" gives two benefits: no need to justify them, no risk to be assessed as exaggerated. I should use this double freedom, rare for a scientific environment.

Why "the Catalyst"? Again for six reasons; the hypostasis of catalyst was chosen because it is:

a) *Unknown.* The main cause is Filip himself: he filled the public interest with so many reports where he was *actor* – mostly protagonist – that those about his role as *catalyst* could hardly get some attention.

b) *Seemingly uninteresting.* It is perceived somehow as a "second hand" scientific activity. For instance, in 1998 after being declared the IT person of the year in Europe, nobody cared that a young teaching assistant from Sibiu was able to participate at a prestigious international conference only due to Filip's decisive scientific and financial support. So what?

c) *Vital.* While in chemistry the catalyst only increases the rate of a reaction, in scientific research the catalyst is vital, I dare to say it is a *sine qua non* condition for the reaction to emerge. Indeed, exaggerating metaphorically, without a catalytic Pygmalion, few "professional Galateas" can carve themselves out of a promising yet lifeless block of scientific ivory.

d) *Powerful Amplifier.* The leverage effect of scientific catalyse is huge, mainly when the catalyst is as polyvalent and tireless as Florin Filip was since he became scientist in 1976. As a result, the paper published in 1980 by Pergamon Press had four colleagues as co-authors. Now there are probably almost a thousand IT professionals owing their take-off to his catalyse. (Only in Sibiu – including also the "third generation" – we are about thirty.)

   The last two reasons are caused by personal links.

e) *The author is involved.* It begun in the early 80's when Florin Filip was one of the few colleagues from Bucharest and Timişoara who guided my first steps into the challenging realm of real-time programming (simple, giving me a seminal book by Per Brinch Hansen). And the process is lasting (I could mention at least ten other areas/ moments/issues where he catalysed decisively my career – but not the generated *reaction* should be focused on, here it is about the *catalyst*).

f) *The paper is involved too.* A few months ago, this pseudo-Laudatio was supposed to be an epilogue to the preceding paper but very soon it turned the other way around: the paper was concocted almost as prolegomena to the virtues of "scientific catalyse": the research described was not developed but triggered by Filip (simple again although "scientific catalyse" avant la lettre: he gave me the idea of the "Prigogine niche").

Hoping that these reasons persuaded that any reference to any hypostasis of a polyvalent character has nothing to do with his age, I dare to sketch a micro-portrait of "Filip the Catalyst" – albeit a possible quite distorted one, since it is shaped from inside a very prolonged catalytic process:

The main impression (in its both connotations: "impact" and "feeling") is that the cardinal catalyse macrofeature is *naturalness*, decomposable in four related but distinct features: *spontaneity* (mostly it is his initiative), *openness* (if suitable, a brief *pro and con* analysis), *effortlessness* (nothing seems easier), *modesty* (don't mention it). Our first paper written together – and my first paper accepted in a conference outside Romania – is a relevant example: he asked the organizers to transfer the invitation from him to me and to give me a substantial financial help (conference fee plus accommodation), gave me some names of faculty members to start a collaboration, and finally ... forgot to insert it into his paper list (at least, I hope that it was no other reason!). (*Nota bene*: it was just after I left the institute where he was general manager.)

What is behind the scenes of this seamless picture? A research feature important for all scientific areas but imperative for an "IT Catalyst" is "*Feeling the Zeitgeist*". As essential Zeitgeist-component, the "e-Zeitgeist" is most deceptive because of its tremendous dynamics; to absorb it, two pillars are mandatory: a solid professional status and a superior intellectual texture. You can be successful in incremental research lacking the second or even a good professor lacking the first, but never a Filip-like catalyst. In his case the first is obvious but the second is hidden (by the way, how many IT specialists do you know who are able to talk in six languages about Scandinavian poetry?). Does it matter? It does. Whereas for any researcher a *violon d'Ingres* (I hate the word "hobby") acts as an intellectual amplifier, for a catalyst it is an intrinsic ingredient of the scholarly structure. (Moreover, to perceive Prigogine-niches, the violin must be replaced by an orchestra.) In short, the easiness of a Filip-like catalyse is an illusion because the inexorable foundation stays hidden in the following (over)simplified implication chain: catalyse → IT excellence → Prigogine-niches → transdisciplinarity $\rightarrow$ anthropocentric perspective $\rightarrow$ e-Zeitgeist $\rightarrow$ Zeitgeist $\rightarrow$ intellectual excellence. Furthermore, in this tempting blend Florin Filip instilled a rather rare constituent: *tolerance*. He paid always attention to the subtle difference between catalyse and prescription. (The last inside example: despite the fact that he was the acknowledged first violin in our long teamwork, he tolerated – in the best meaning of this word – most of my minoritarian and heterodox opinions about, for instance, the sunset of object-orientation or the role of agents in decision support systems).

Certainly, like in every alchemic endeavour, there are a great deal of esoteric elements involved in the catalyse process. Maybe, even more in the catalyst persona. I enjoyed trying to unveil some of them.

Thank you *Computer Science Journal of Moldova* for giving me the opportunity.

Thank you *Florin Gheorghe Filip* for giving me the reasons.

Boldur-Eugen Bărbat

We are proud to be side by side

It is very difficult to speak about Svetlana Cojocaru. We don't think that each evocation is sufficiently appropriate to her real nature, character and activity.

Let us try to represent point by point some traits which characterize her personality.

In the first place is fidelity. Let us bring only one example. Starting with the third year at the University she activates with Institute of Mathematics and Computer Science (IMCS).

Don't forget that she is a lady with all the ensuing consequences. Being faithful she at the same time likes everything that is new, she wishes changes and diversity. Being directed at post graduate study she didn't accept the proposed theme but had chosen the theme to her taste. Her first researches were in the domain of formal grammars. Natural language processing was her choice in the framework of collaboration with Romanian Academy of Sciences. From 1990 she successfully continues to obtain the results which are highly appreciated by specialists in corresponding domain.

It is natural that Romanian language is the object of these researches funded by national and international projects. In a few years, not abandoning natural language she joins in the project on computational algebra in the framework of the program with Sweden Royal Academy. The projects lasted consecutively for 12 years. From these researches the interest in intelligent interfaces came out. It became the theme of her second (doctor in habilitation) theses. She has the gift to inspire colleagues (including the youth) with her interests. She leads several post graduates trying to explore new directions and domains together with them. Now she takes part in the researches concerning Decision Support System development in ultrasonography.

Along with the publications in prestigious publishers as Springer, Thomson, Elsevier etc she has 3 monographs, and they are from different domains: compiler construction, problems of informational society creation, computational algebra.

We want to make the unbiassed representation and not the panegyric, so let us go on with purely human qualities.

Her sense of beauty is so pronounced, that it is felt by any visitor of IMCS (the hall, offices, conference hall, library are finally the products of her delicate taste). In academic circles the IMI is well-known not only for scientific results of its researchers, but for various expositions of pictures and photography art as well, and S.Cojocaru being one of the organizers of these vernissages.

Many initiatives promoted in IMCS are the products of insistency of our colleague.

Nobody can tell that holding the official posts in IMCS (scientific secretary from 1999 and vice director from 2005) she gained the authority by something else than by her competency and ability to convince those who didn't feel from the very beginning the reason for which some idea is promoted. Each of us benefited from her help and useful advices. Her vision is always characterized by lucidity and competence.

We think that she also will be amazed when reading, that risk is inherent in herself, the risk which has its origin in intuition or, better to say, in correct appreciation of the situation.

Whether consciously or not (and consciously nevertheless) she is associated with a cat with its remarkable traits of tenderness and insistency in achieving the goal. The evidence is her collection of cats-souvenirs each of which has its own temper and something which is similar to the proprietress.

We see our colleague in the prime of life with plans for new achievements, with insistency in their implementation, with kindness in relations with colleagues.

The editorial board of CSJM knows the broad activity of Svetlana Cojocaru in publishing the journal the initiator of which she was and the promoter of which she is from 1993, being its editor and the author as well.

We wish ourselves continuous activity together with herself, and we wish her heartily many long years, happiness and new achievements.

Editorial board of ,,Computer Science Journal of Moldova"

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Functional FX-bar Projections of the (Romanian) Verbal Group and Sub-Groups on the Syntactic-Semantic Interface*

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Abstract

The aim of this paper is to investigate the syntactic / semantic substructures (called subgroups) of the Romanian verbal group (VG) [12], or verbal complex [25], starting with the achievements in the literature, and melted into the device of direct and inverse functional projection within FX-bar theory [7]. The paper examines several problems and their solutions for the syntactic-semantic theories of VG, as discussed in some fundamental papers, and we offer our explanation on the involved syntactic phenomena, the emphasis falling on the VG substructures (verbal subgroups, VSGs), VSG boundaries and composition within VG, direct and inverse FX-bar projections of VG, VG parsing, lexical semantics and intensional / extensional logic representations of the Romanian (verbal or nominal) predicate.

Keywords: functional FX-bar theory; verbal group; verbal subgroups; Romanian predicate and predication; intensional / extensional semantics; clause-level parsing.

1 Introduction

The aim of this paper is to investigate the syntactic / semantic substructures of the Romanian *verbal group* (VG), or *verbal complex* [1], [25], [16], starting from the instruments and current achievements in the literature, and melted into the device of (direct and inverse) FX-bar projections and theory [4], [5], [6], [7], [8], [12], [13]. Since [8]

*This is a revised and improved version of the paper [13] we separated within the verbal group (VG) the so-called *default verbal group*, denoted then as *verbal group kernel* (VGK), that substructure of VG which may commute with its proper, '*outside*' adverb, and does not enclose this modifier. The same VG / VGK substructure has been described in more detail as the *inside* part of the *verbal complex* [1], with its *inside* (special) adverbs (mai, cam, prea, și, tot) and *outside* negations and adverbs. In the present paper, the proper syntactic / semantic *substructures* of VG (together with VGK) shall be called *verbal subgroups* (VSG*s*).

Examples of VGs [10], [11]. VGK is represented in parentheses, included in VG; the unaccentuated pronouns (pronominal clitics) are in *italics*: " nu că (nu *mi-l* va mai și plăti) greu; (nu-*i* cunoșteam); (*li se* cereau) ; (*își* mai recăpătase) ; (Ai consultat) ; (ar fi simțit) ; (*i se* așternea) ; (să *se* întâmple) ; (nu *se* putea abține); (n-*o* putea lua); (Nu *i*-ar fi trecut); (să poată afla); (să *te* intimideze); (să *vă* văd lucrând) ".

As [1] remarks rightfully, VG provides both an *outside* ($\mathbf{nu}_1$) *negation* and an *inside* ($\mathbf{nu}_2$) *negation* (*e.g.* $\mathbf{nu}_1$ să $\mathbf{nu}_2$ te duci), which can be interpreted as outside VG and inside VGK *quantifiers*. Similarly, there exist as VG *inside modifiers* the *special adverbs* (mai, cam, prea, și, tot), and the proper, VG *outside adverbs* (nu_1 să nu_2 te $\mathbf{tot}_2$ duci $\mathbf{imediat}_1$). The structure of VGK as the "inside" of VG, with a *syntactic head* (the *tense auxiliary*, bearing the number and person, when present lexically) and a *semantic one* (the *predicational head verb*, often called also the matrix, or lexical, or embedded verb), with clitics 'inside' and semantic (direct) arguments 'outside') the VGK, this verbal structure is playing an essential role in the development of the *lexical predication*.

VG may be seen as the 'last' shell of VGK, while the contents of VGK may be interpreted as the *clause-shadow* (of the regular clause) that projects itself onto the clause, as well as representing the projection(s) of the lexical-semantic head bearing the *predicationality feature* (*e.g.* [8]), using *diathesis transformations* and *semantic diathesis functions* associated with semantic restrictions on predication arguments (see [16], [23], [24], [1], [21]). Furthermore, along with its finite or non-finite *predicational* head, the VG may contain (some) other verbs, including tense and passive auxiliaries, semi-auxiliaries, and restructuring (*modal*, *aspectual*, *motion*) verbs. Our goal is to investigate the VG syntactic-semantic substructures (Verbal SubGroups – VSG*s*), the relationship VG-predication-predicate, and whether a VG contains a single or a multiple predicate (thus clause, thus potential discourse segment).

This paper will examine several problems and their solutions for the syntactic theories of VG, as discussed in some fundamental papers such as [25], [16], [1], [21], and we shall try to offer our approach on the involved syntactic phenomena, the emphasis falling on the lexical semantics and intensional / extensional logic representations, our interests being mainly oriented towards VG parsing, VG substructures (VSG*s*), VSG composition and their FX-bar projections, VG phonology and (local) prosody [25; Chap.9], [14], [15].

1.1 The Classical Predication vs. Lexical Predications

The *classical predication* pair (Subject, Predicate) can be viewed as just *one of the facets* of the VG (verbal complex) whose semantic head bears the *predicationality feature* PREDF [8], the other ones, equally righted as "classical predications", being instantiated by the predicational verb (lemmatized form), endowed with clitic(s) as affixed inflexion(s), which are obligatory present when their valence-commanded arguments are personalized or focused (*i.e. theta*-disordered), doubled or not by the corresponding semantic arguments. Thus, the classical predication pair corresponds to the subject theta-role of "actor" or "actant", while the other "classical" predications may associate, valence-driven, the theta-roles of "patient" and/or "receiver" and/or "addressee" to semantic arguments (but not adjuncts!). All these are commanded (or not) by the presence (or absence) of the PREDF predicational feature, assigned at the *lexical level*, to the semantic head in VG.

In a *first move*, the classical predication pair (Subject, Predicate) should be reduced to the pair (Subject, PREDF_verb) corresponding to the *theta*-role of "actor" or "actant" in the valence-driven SUBCAT (or ARG-ST vector [26]), with 1 to 3 semantic arguments. It is important to specify that there exist normally at least two SUBCAT lists: $\text{SUBCAT}_{oblic\_order}$, containing the syntactic arguments of the PREDF_verb, in the order of increasing obliqueness, and $\text{SUBCAT}_{theta\_order}$, enclosing the arguments in the *theta*-order (or *systemic* order) for the valence-based arguments of PREDF_verb. Usually, (only) *for the active voice* and a normal semantics of predicationality, these arguments should coincide.

In a *second move*, to this first classical predication are added, equally righted in the *theta*-semantics, the following similar "classical" predications (Figure 1):

$$(\text{SUBJ}_{Obliqueness=0}, \text{PREDF\_Verb}\begin{bmatrix} [VG \quad Tense\_Aspect] \\ \textbf{\textit{Semantic\_Diathesis}}(\text{SUBJ, OBJD, OBJI}) \\ = (\theta(\text{SUBJ}), \theta(\text{OBJD}), \theta(\text{OBJI})) \\ Agreement(\text{SUBJ}, \ Inflection\_\text{VG}) \end{bmatrix})$$

$$(\text{OBJD}_{Obliqueness=1}, \text{PREDF\_Verb}\begin{bmatrix} [VG \quad Tense\_Aspect] \\ \textbf{\textit{Semantic\_Diathesis}}(\text{SUBJ, OBJD, OBJI}) \\ = (\theta(\text{SUBJ}), \theta(\text{OBJD}), \theta(\text{OBJI})) \\ Agreement(\text{OBJD}, \ Clitic\text{OBJD\_VG}) \end{bmatrix})$$

$$(\text{OBJI}_{Obliqueness=2}, \text{PREDF\_Verb}\begin{bmatrix} [VG \quad Tense\_Aspect] \\ \textbf{\textit{Semantic\_Diathesis}}(\text{SUBJ, OBJD, OBJI}) \\ = (\theta(\text{SUBJ}), \theta(\text{OBJD}), \theta(\text{OBJI})) \\ Agreement(\text{OBJI}, \ Clitic\text{OBJI\_VG}) \end{bmatrix})$$

Figure 1. All the extended, valence-based 'classical' predications

In Figure 1, SUBJ, OBJD, OBJI represents the syntactic categories of subject and direct arguments (direct and oblique complements), respectively. The ***Semantic_Diathesis*** function, depending on the valence-value of the predicational verb at the lexicon level, *links* (in the sense of *linking theory* [28]) the grammatical (syntactic) arguments SUBJ, OBJD, OBJI (sometimes, OBJD2 at the shallow level) to their semantic, *theta roles* (*e.g.* Actant, Patient, Addressee etc.) θ(SUBJ),

θ(OBJD), θ(OBJI). The *Agreement* function establishes anaphoric local bindings between the verb inflection and its object (pronominal) clitics, on one hand, and the syntactic (SUBJ, OBJD, OBJI) arguments, respectively, on the other hand.

These are the new 'traditional' predications, with their real engine, *viz.* the *predicational feature* PREDF, installed on the (lexical) verb head of the verbal group VG. Similarly, non-finite forms of PREDF verbs may be associated to those N*s* (Nouns called *nominalizations*) and/or A*s* (Adjectives or Adverbs) that bear the feature PREDF.

In the 'classical' predications above, clitics may lack when the semantic arguments are of *non-person* or *non-animate* nature but are lexically present. This does not change the 'equivalence' of these newly devised valence-based predications. Such an interpretation of the VG structure has consequences in establishing the FX-bar (direct and inverse) VG projections (see the outlined solutions considered in the subsection 2.2 devoted to the problem of VG local structure and its FX-bar projections).

The problem of 'classical' *predication*(s) in HPSG theory [2], or the problem of the *special* role of the *subject* in the SUBCAT list of HPSG [26; Chap.9] are solved in the linguistic feature structures in Figure 1 above as follows: the feature *Semantic_Diathesis*(SUBJ, OBJD, OBJI) is not an elementary (atomic) feature value but a *function*, defined as follows: the input of the function is the VG shallow, *syntactic diathesis*, represented by the above mentioned $\text{SUBCAT}_{obliq\_order}$, while the output (value) of the function is the VG *semantic diathesis*, *viz.* $\text{SUBCAT}_{theta\_order}$ list. This solution forces the subject-*actor* and the subject-*least_oblique_element* (or grammatical subject) to take each one its own right place, in the right (possibly distinct) ordering.

Briefly, the *values* of the function *Semantic_Diathesis* are established as follows: the input value is represented by the tense and syntactic diathesis resulted from the VG shallow parsing. The output, or the value of the *Semantic_Diathesis* function, is obtained from the lexicon, where the head verb (*predication*) meaning is represented by specific standard lists of semantic arguments corresponding to the valence of that specific predicational category, and the syntactic diathesis is transformed into a certain particular list of semantic arguments corresponding to the tense, diathesis, and predicational meaning of that (verb) category. (See the mechanism of *dt* and *sd* functions in subsections 2.2 and 2.3, defined to make operational the FX-bar direct and inverse projections of VGK.)

In Figure 2 of the FX-bar scheme for *local structures*, the local (single-event) levels X0-X1-X2 express the *clause predication* depending on basic, lexical categories (V, N, A), while the levels CL0-CL1-CL2 express logical or (*second-order*) *predicational relations* on simple clauses.

1.2 Handing Down the Predication from Syntax into Lexis

The feature that we called *Predicationality* [8] borne at the *lexical* (even *lexicon*) level by the major lexical categories N, V, A, corresponds to what in the literature is called (more frequently, among other labels) as the *deverbal* property, or *deverbality*, of these categories. For an extended survey and analysis of this notion and its syntactic-semantic consequences, see [8]. We avoid the term *deverbality* because its meaning is *not necessarily specific* to V*s* since this essential lexical-semantics feature is *equally shared* by V*s*, N*s* and A*s*! Moreover, there are (classes of) verbs which do not bear this property, *e.g.* the *copulative* ones. The feature of *Predicationality* is assigned to those finite or non-finite V*s*, N*s* (often called *nominalizations*), and A*s*, whose meaning involves a *process* event or *process* name. We abbreviated this feature as PRED(dication)F(eature), with two main values, PROC(cess) and STAT(e) (or EXIST).

We are mainly interested by those major categories providing a first-order predicational feature, thus associated with first-order predicates whose arguments are noun groups (NG*s*) and not new finite VG*s* or VSG*s*. This is the *straight* or *canonical* type of predication, since there also exist second-order predications, *e.g.* as those assigned modal, inchoative, semi-auxiliary (or "restructuring" [25], *i.e. modal*, *aspectual*, *motion*) verbs. Thus it is important not only the valence (number of arguments) of a predicational category but also the sort-type of these arguments.

The classical notion of *predication* is known to be the pair (*Subject*, *Predicate*), an essentially *syntactic concept* meant to support the finite clause (proposition) structure. The predicate, either synthetic or analytic, encloses both *process* verbs and *state* verbs (the latter case for the nominal predicate) indiscernibly, despite the fact that only process (predicational) verbs entail a semantic argument-based syntactic distribution, corresponding to a proper *valence*. Furthermore, the feature of *predicationality* (or *deverbality*) is equally shared not only by process verbs but also by nominals N*s* and modifiers A*s* that are (in terms of lexical semantics) siblings of the corresponding predicational verbs, these non-verbal categories having a *similar syntactic distribution* of semantic arguments, with the same valence as their predicational, verbal counterparts.

Thus, the feature of *predicationality*, as a *lexical semantics* quality, is not necessarily related to the predicate (which is a syntactic construction): in the *nominal predicate*, the copulative verb is not a predicational one. The same goes for the auxiliaries incorporated within the VG, whose tense is based on compound syntactic constructions. This does not exclude, in the *nominal predicate*, that the *predicative nominal* (as semantic head of the construction) bears the feature of predicationality. *E.g.*, the predicative nominals *explanation*, *marking*, *receiving* etc. (which are *predicational nouns*) in the nominal predicates of the clauses *This is John's explanation* (*marking, receiving...*) *of the notion* ... .

These reasons support the idea of *handing down* the notion of *predication* from its classical, *syntactic* level, to the *lexical*, word level of *representation* and *analysis*. The lexical semantics feature of *predicationality* (PREDF) has sometimes a contextual usefulness since the same word may, or may not, bear the feature PREDF, the process meaning depending on its contextual use. For instance, the noun *building* in languages such as English, French, Romanian, may have both the meaning of a process, with [PREDF +] (or simply, PREDF), and the meaning of an object (in this case, the process result), with [PREDF –]

(or STAT, or EXIST, or simply NPREDF values).

2 FX-bar Schemes and the Predicational Feature

We propose in Fig. 2 the following general FX-bar scheme [11] for (local and global) clause-level and RST discourse structures [22]. This FX-bar scheme is using the SCD marker classes and their graph-type hierarchy, an essential instrument to represent clause-level syntactic-semantic structures and to establish their (local and global level) dependencies, including VG as the representative structure for the *verbal predicate* and (finite) clause. In the same time, there exist *global structures* whose constructive bricks are not necessarily the finite-clause but the rhetorical *discourse-segment* of the RST discourse theory [22]. The dashed lines in Fig. 2 represent the special cases when a discourse segment is a proper subclause span and when a discourse segment splits a clause.

Compared to the version of FX-bar scheme exposed in [11], the *novelty* of *this* FX-bar scheme consists in the syntactic presence of traces I, J, K that corresponds to the valence of the VG semantic head, and embodies the (local) anaphoric agreement (and *linking* relations [28]) between VG and its *theta*-semantics *direct arguments* (*Agent*, *Patient-Object*, and *Receiver-Recipient*). The index I represents *the inflexion* of a semantic or syntactic verb head in VG that is in concord with the grammatical subject of the clause, while J and K, when lexically (overt) present, are *pronominal clitics.* Comprising the VG *direct-argument* (or *linking*) *indices* within the VG syntax represents an effective need in VG FX-bar projection and comes into play when applying the *linking algorithms* [28], fortifying the idea of viewing VG as the *clause-shadow* structure.

2.1 FX-bar Direct and Inverse Projections of VG

In the next subsection 2.2 we introduce *diathesis transformations* and *semantic diathesis functions* as useful tools in describing the *lexical*

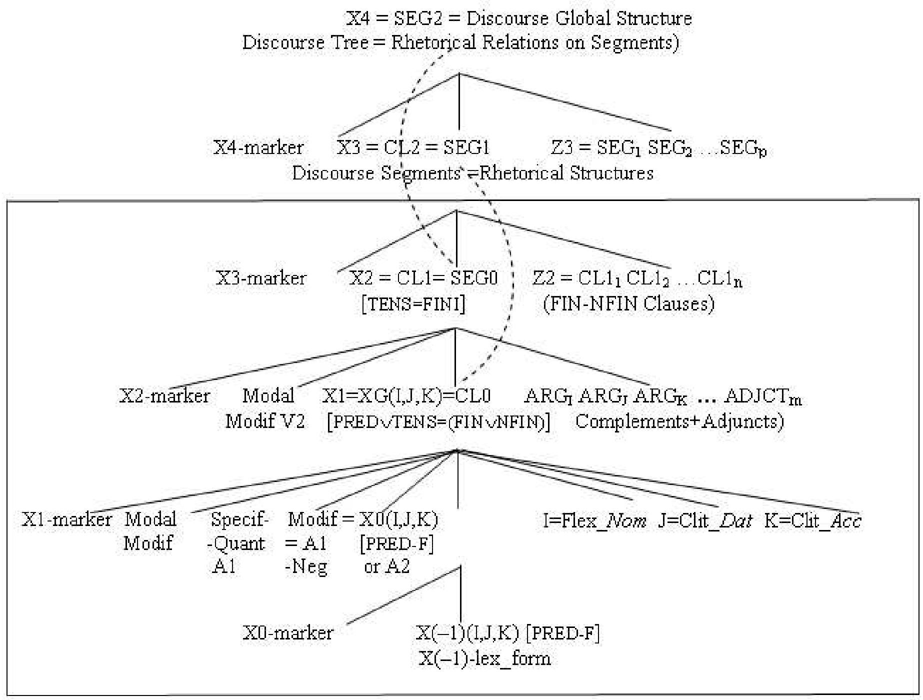


Figure 2. Global (clause and discourse) level FX-bar Scheme

predication metamorphosis from syntactic (shallow) diathesis to semantic diathesis as a top-down and bottom-up movement, from text to lexicon and backward. This mechanism may also be understood as procedures of direct and inverse FX-bar projection procedures of VG toward its (predicational) semantic head and to the clause, derived from the diathesis analysis (as in [20]), stated as solutions to the following VG FX-bar projection (Figure 2) problems:

FX-bar(VG): The problem of FX-bar direct projection of VG: To show how the *clause-shadow* information (see above) incorporated into VG is (directly) FX-bar projected into a (finite or non-finite) regular clause.

FX-bar^{-1}(VG): The problem of FX-bar inverse projec-

tion of VGK: To obtain an improved linguistic mechanism by which a *predicational category* (from the lexicon) is FX-bar projected on VG (VGK). This means to establish the FX-bar *inverse projection* Fx-bar^{-1}(VG) for VG, *i.e.* the morphologic-phonologic-syntactic-semantic restrictions on the (predicational) semantic head of VG that are necessary (and sufficient) to retrieve the VG (or VGK) *local* structure through FX-bar (direct) projection of its semantic head. The two projection functions are outlined in Figure 3.

The FX-bar inverse projection associates to VG a number of (possibly covert) *semantic heads*, corresponding to the meaning(s) of the lexical head entry, each semantic head observing the set of *sd* and *dt* functions and values, along with phonologic, lexical, morphologic, syntactic and semantic restrictions at lexical level on arguments, clitics, doubling etc. [29].

This is the starting point in the process of *text generation task*, when the first requirement is to generate one or several adequate VGs, satisfying the *planning* restrictions. For clause analysis / generation, the parsed VG (as *clause-shadow*) or the obtained VG(s) is FX-bar projected into one (or more) finite or non-finite clause(s), with its (their) arguments, constructed lexically from diathesis computations and linguistic restrictions.

2.2 Diathesis Transformations and Semantic Diathesis Functions

The definition given to the diatheses considers either the syntactic rapport between the subject and the verb complement(s), as arguments of the same predicational head category, either an ontological rapport between the action and its author, or even both realities. [3; p.87–91] distinguishes between active, passive, impersonal reflexive, and dynamical reflexive diatheses, according to the importance given by the speaker to the action presented. [19; p. 464] considers the realities between the syntactic positions (subject – verb – complement) and their semantic correspondences, (actant-process-patient). [17; p. 13–22] takes into account for the diathesis definitions, the reflection at the semantic level of the verb of the extralinguistic rapport subject-action-object, meaning both the syntactic rapport verb-subject and the verb-complement one.

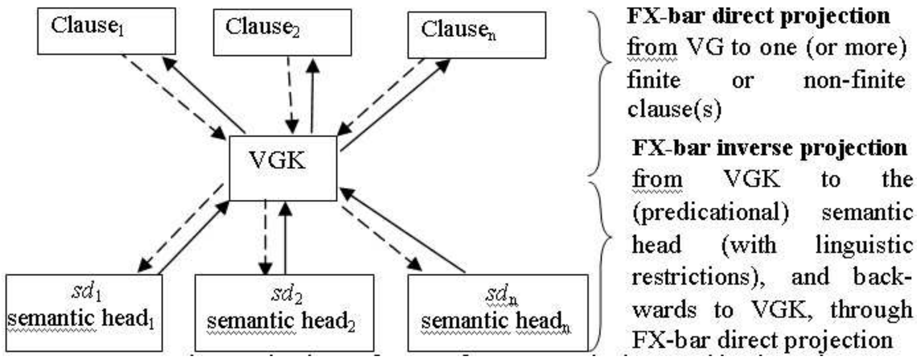


Figure 3. FX-bar projections of VGK, from text to lexicon and backwards

We try to solve the above mentioned problems of FX-bar direct and inverse projections for VG / VGK by defining *diathesis transformations* and *semantic diathesis functions*, following mainly the *semantic diatheses* (active, passive, reflexive, reciprocal, impersonal, and dynamic) developed in [20; p. 85–115]. The information sources for the projection processes are **(a)** VG / VGK parsing on one side, from which one can extract VG tense, syntactic (shallow) diathesis, (predicational or not) semantic head, clitics, quantifiers, internal and external (proper) modifiers, modalizers (Figure 3). With these elements, one moves down towards lexicon, where one should find **(b)** the second source of information: the valence (arity), type (sort, *e.g.* NG, VG, clause) of the VG semantic head, the *diathesis transformations*, and the values of the *semantic diathesis functions*. Necessary (and sufficient, if possible) constraints can be specified to ensure the uniqueness of the FX-bar projection(s), either *direct* or *inverse*, of a *semantic head*, through a VG, into a (finite) clause, and the reverse [8]. These constraints are similar to those met in *local linking algorithms* [28], including the diathesis (ARGLIST) transformations, *i.e.* VG semantic diatheses related to the TFA (Topic-Focus Articulation) ordering of clause arguments [18], [14].

The following Table 1 shows the mappings of the argument lists within the syntactic / semantic diathesis metamorphosis.

Table 1. Diathesis transformations from syntactic to semantic argument lists

SynD **SemD**	**Active**	**Passive**	**Reflexive**
Active	*dt*([A1, A2, (A3)**]) ↓↑ * [A1, A2, (A3)]	∅	*dt*([A1≡ReflPron, A2, ∅]) (analysis) ↓↑ (generation) [A1, A2, ∅]
Passive	∅	*dt*([A1, A2, (A3)]) ↓↑ [A2, A1, (A3)]	*dt*([A1, A2≡ReflPron, (A3)]) ↓↑ [X1***, A1≡A2, (A3)]
Reflexive	∅	∅	*dt*([A1, A2≡A1, ∅]) ↓↑ [A1, A2≡A1, ∅]
Reciprocal	∅	∅	*dt*([A1≡ReflPron, (A2), ∅]) ↓↑ A1≡{X1,X2} {[X1, A2, X2], [X2, A2, X1]}
Impersonal	∅	∅	*dt*([(A1)≡ReflPron, (A2), ∅]) ↓↑ [X1, (A1), (A2)]
Dynamic	∅	∅	*dt*([(A1)≡ReflPron, (A2), ∅]) ↓↑ [(A1)≡X1, (A2), ∅]

*↓↑ = analysis "↓" and "↑" generation tasks;

**(A_n) = argument optionally present;

***X = uninstantiated variable introduced to support semantically an argument;

The notation "(A1)≡ReflPron" means that the argument A1 is optionally present, the reflexive pronoun is overt (lexically present), and (clitic) doubling is possible.

The notation "*dt*([(A1)≡ReflPron, (A2), ∅]) ↓↑[X1, (A1), (A2)]" means that the *semantic_diathesis* function *sd*(category, clitics, syntactic_diathesis, valence) is applied to the *Reflexive* diathesis list [(A1)≡ReflPron, (A2), ∅], the result being the semantic *Impersonal* diathesis list [X1, (A1), (A2)] (see Table 1).

The *diathesis transformation* functions $dt(\mathrm{List}_0) = dt_1 = \mathrm{List}_1$ map the list of syntactic (grammatical, shallow) arguments (corresponding to $\mathrm{SUBCAT}_{obliq\_order}$), into the list of semantic arguments corresponding to $\mathrm{SUBCAT}_{theta\_order}$. The result of transforming a syntactic diathesis into a semantic one is not a unique operation, and Table 1 gives the general *dt* functions, as a mapping of the *three* syntactic diatheses into the *six* semantic ones, and backwards. For a lexicon entry, the *semantic diathesis functions* take the form:

sd(category, clitics, syntactic_diathesis, valence) = $\{dt_1,\ dt_2,\ \ldots\ dt_n\}$, (n = $1 \div 6$), where $dt_1 = dt(\mathrm{List}_0)$, $dt_2 = dt(\mathrm{List}_1)$, $dt_3 = dt(\mathrm{List}_2)$, ..., accordingly to the lexical semantics meanings (*readings*) derived from the VG head category and additional information resulted from the VG parsing.

2.3 Diathesis Computing within FX-bar Projections of VG[1]

As already mentioned in subsection 2.2, the semantic diathesis function is defined as *sd*(category, clitics, syntactic_diathesis, valence) = $\{dt_1,\ dt_2,\ \ldots\ dt_n\}$, n = $1 \div 6$.

Using the verb *a-se-uita (to look at)* as example, the computation of *dt* and *sd* function values is realized in the following steps, derived from the operation sequence of FX-bar direct and inverse projections:

Step1. Extracting an *a-se-uita* derived VGK from a *concrete* but *arbitrary* clause that encloses it;

Step2. Handing down to the lexicon, with the semantic head of that VGK;

Step3. Computing the *sd* and the *dt* function values;

Step4. Retrieval of the same VGK as FX-bar projection of (one of the meanings of) *a-se-uita* semantic head, associated with the semantic diathesis computed values of *dt* and *sd* functions;

Step5. FX-bar projection of the VG into the n possible clause types, n corresponding to the *number* of (diathesis transformation) *dt* functions.

After choosing a VGK from an arbitrary clause in the text, VGK is completely parsed, being obtained the VG extracted semantic head,

[1] The analysis of this subsection may also be found in [RevRoum06]

tense, syntactic diathesis, clitics etc. The next move is to step down with the VGK semantic head at the lexicon level, where the semantic diathesis transformations and restrictions are located. In our case, the following *sd* function value:

sd(*se-uita*, ReflPron_*se*, reflexive, 2) = {active, reflexive, impersonal} = = {dt_1, dt_2, dt_3}

has to be found, meaning that the reflexive syntactic diathesis of *a-se-uita (to–look–at)* can be translated into the *active, reflexive, and impersonal* semantic diatheses. From the above *sd* values, using Table 1, one can compute the following values of *dt* functions:

dt_1(*reflexive*) = *active* ⇔ dt_1([A1≡ReflPron, A2, Ø]) ↓↑ [A1, A2, Ø]
dt_2(*reflexive*) = *reflexive* ⇔ dt_2([A1, A2≡A1, Ø]) ↓↑ [A1, A2≡A1, Ø]
dt_3(*reflexive*) = *impersonal* ⇔ dt_3([(A1)≡ReflPron, A2, Ø]) ↓↑ [X1, (A1), (A2)]

Since the valence of *a-se-uita* is 2, the resulted lists are reduced from 3 to 2 elements, the final value of *sd* being:

sd(*se-uita*, ReflPron_*se*, reflexive, 2) = {[A1, A2], [A1, A2≡A1], [X1, (A1)]}

Due to different semantic diatheses, clause types with distinct readings are potentially parsed (in analysis task) or produced (in generation task). The following examples show the non-uniqueness for the *sd* function values at the lexical semantics level.

(1)(R) **Se uită** *la fratele lui*. (*sem. diathesis = active*)
(E) *He looks at his brother.*

(2)(R) **Se uită** *în faţa televizorului ore în şir*.
(*sem. diath. = reflexive*)
(E) *He forgets himself in front of the TV.*

(3)(R)**Se uită** *deseori semnificaţia zilei de 24 ianuarie*.
(*sem. diath. = impersonal*)
(E) *The significance of 24 January is often forgotten.*

For a complete treatment of the verb *a-uita*, we describe hereafter the non-reflexive counterpart of its lexicon entry. The *sd* and *dt* functions may have, for instance, (some of) the following values for the (non-reflexive) *a-uita* (*to–forget*) entry:

sd(*uita*, Acc_Clitic, active, 2) = {active}

sd(*uita*, ∅, passive, 2) = {passive}.

The feature of argument optionality is transferred from larger to smaller number of arguments. These *sd* and *dt* computed values can be lexicalized in clause constructions like:

(4)(R) *Ion* **a uitat-o** *pe Maria*. (*sem. diath.* = active)
(E) *John has forgotten Mary.*

(5)(R) *Geanta* **a fost uitată** *de Ion*. (*sem. diath.* = passive)
(E) *The bag was forgotten by John.*

The mechanisms of computing syntactic and semantic diatheses on grammatical structures (from clause to VGK and its lexical semantic head – and backwards) viewed as FX-bar (direct or inverse) projections, and involving as essential incorporated element the *predicational* feature they bear or inherit, substantiate our attempt of taking apart the machinery and anatomy of linguistic *predication*.

The predication was handed down from the classical, syntactic level to the lexical, thus lexicon level, using mechanisms developed within FX-bar theory. The next Section 3 takes advantage of the lexical-level predication and FX-bar projections to propose a unified treatment of the (Romanian) predicate, either verbal or nominal, and to establish a consistent relationship between *predication* and *predicate* within the framework of *intensional / extensional logic*. Local and global sentence / discourse parsing, machine translation, and FramNet thematic roles assigning [27] are natural applications of the present approach.

3 Syntactic Substructures of the Romanian Predicate

3.1 VSG*s* of the Verbal Predicate

A. The Tense Auxiliary SubGroup

The most frequent and natural VSG is the Tense Auxiliary SubGroup (TASG): *voi fi, aș fi, am fi, sunt*. TASG is a non-saturated VSG that needs as semantic head a noun (N), adjective (Adj), or non-finite verb (V) form. For V finite forms, TASG is considered to be enclosed, by default, within the synthetic inflection of the verb. TASG may receive the usual VG ingredients: *special adverbs*, *negation*. In its *basic* (*bare*) *form*, TASG cannot receive pronominal clitics (one can have "*i l-aş fi*" only in the presence of the 3-valued valence verbal form "*dat*"). TASG is non-predicational since its inner semantic head (in this priority order of occurrence) is either a copulative verb, passive auxiliary, or tense auxiliary. We shall use here TASG with the meaning of an (individual) assignment $x := y$, corresponding to the copulative relation between the terms x and y (as *intensive* or *extensive* variables or constants), in order to describe the intensional / extensional representations of the verbal and nominal predicate.

TASG is a natural *verbal subgroup* (VSG) of the Passive Tense Auxiliary SG (PTASG). (P)TASGs may have the same meaning of copular (assignment) relation, do receive special adverbs and negations, but they do not bear pronominal clitics (in their *basic form*). TASG and PTASG are both non-saturated, *i.e.* they need to receive a semantic head category, which is a *non-finite verb*, *an adjective* or *a noun*. Utterances such as "*Am fost.*" or "*N-am putut.*" (for modals) are verbal anaphora or anaphoric predicates.

PTASG may also contain variants of passive auxiliaries, conditional, passive conditional, etc. VSG types of TASG*s*.

B. The Modal Verb Subgroup

Another VG substructure refers to the Modal VSG (ModVSG). ModVSG derives normally from TASG, (not PTASG since one can not have "*s-ar fi fost trebuit* [*putut*]"), whose semantic head is *a-putea*, *a-trebui*. One may have "*[eu] pot; ar fi putut; s-ar fi putut; n-am fi trebuit*", with possible insertions of *special adverbs* and *negations*, but not pronominal clitics (in their bare forms). The modals (*a-putea*, *a-trebui*) are predicational polymorphic verbs (*i.e.* whose predication orders or valences may be distinct for different senses). Thus, they may have as semantic arguments either predications of first or second order, saturated (clauses) or non-saturated (VG*s*) categories, or extensional categories.

Examples.3.1.1. **(a)** *Am fi putut alerga.* **(b)** *Se poate că lumina* *l-a speriat.* **(c)** *Îi trebuie apă [ca] să crească.* **(d)** *N-ar trebui să putem cheltui toți banii.* **(e)** *Ar fi trebuit să nu mai poată trece granița.*

One may have various types of arguments for the modal verb head of the ModVSG, including (modal) recursion on its syntactic development. Once again, these VSGs receive the usual lexical insertions.

C. Special cases (whose analysis deserves a more detailed discussion, postponed here): **(a)** *Îi este ușor.* **(b)** *Îi voi fi coleg lui Ion.* **(c)** *Maria este colegă de clasă cu Ion.* **(d)** *Maria i-ar fi putut fi mamă Ioanei*. Hierarchical relations (*e.g. mother_of*, *colleague_of*) may be triggered by relational (but still non-predicational) nouns. Notice once again that, in their basic form, (P)TASG*s* and ModSVGs are non-saturated, polymorphic, and do not receive object (pronominal) clitics.

D. However, **the outcomes** of applying the basic VG substructures (P)TASG and ModVSG to their semantic heads may receive pronominal clitics according to the corresponding head valences. Two remarks:
(D1) When the head is a non-finite VSG, the potential clitics corresponding to the head valence are attached to the corresponding ModVSG.
(D2) When VSG has a finite head, the latter embodies its own clitics. From these observations, an important question is derived: utterances such as

(a) Aș fi putut eu să i-o împrumut.

(b) Nu trebuia [ca] Maria să-l fi citit.

are *biclausal* (as supported in [16]) or *monoclausal* constructions (as defended in [25])? A detailed analysis to decide on this question should be necessary. It is not essential whether the "modal clause" is applied to a finite VG or to another clause, but to decide if utterances such as **(c)** "?*Aș fi putut.*" or **(d)** "?*Nu trebuia.*" are truly finite clauses, while **(e)** "*Nu-i trebuia.*" is definitely finite. Utterances (c) and (d) in the previous sentence are *second-order non-saturated* predications, *i.e.* receive as their argument a finite clause. The problem is: can this type of predications be assimilated to a finite clause?

Formally, the functional representation is clear: one has ModVSG(*Finite_Clause*) or ModVSG(*Non_Finite_VSG*). The linguistic interpretation as monoclause or biclause is controversial. Furthermore, we can have *multimodal utterances* such as: (f) *Trebuia să poată să învețe.* (g) *Trebuia să poată învăța.* (h) *Se poate că Ion nu trebuia să vină aici*. We bet here on the monoclausal approach.

E. We definitely agreed on the necessity of completing the novel shape of the FX-bar scheme in Fig. 2 by representing the weak pronouns (clitics) or their *traces* (when covert) corresponding to the valence-based (direct) arguments of the VG predicational (semantic) head. Each VG semantic head should receive, either in overt or covert forms, adequate morphologic-syntactic devices to realize (local) anaphoric agreement with its valence-based arguments. For Romanian (and other syntactically similar languages), the classical inflection of the head verb and its (diathesis-free) agreement with the grammatical subject, as well as the (lexical or virtual) presence of the clitics semantically attached to the same VG semantic head, express exactly this linguistic reality. These clitics may naturally be viewed as multiple "inflections", valence-commanded, of the same VG semantic head. When covert, these valence-driven extended inflections of the VG semantic head (*viz.* the proper inflection of the head verb and the VG clitics) behave as veritable "linking" devices [28], including the local anaphoric binding, case marking etc. When covert (the head verb inflection is always covert), the clitics should receive the same bundle of linguistic features as they bear when overt.

Another problem to be solved (for Romanian, at least) is the distribution of the VG *linking indices* (or VG inside clitics, see also Section 2), either they are overt or covert). More precisely, the problem is to establish under which Verbal SubGroups (VSG*s*) of the VG the clitics are distributed (among which we include, once again, the inflection corresponding to the VG semantic head, accorded with the grammatical subject of the same clause) and, equally important, under what syntactic-semantic constraints. Interesting examples concerning this problem on the syntax-phonology interface are given in [25 :Chap.5, 244, Ex. (426)a.b.c.].

3.2 An Intensional / Extensional Modelling of the Verbal and Nominal Predicate

Let us consider the following *series* of predicates (we do not specify whether verbal or nominal ones).

Example 3.2.A. *a fost predată*

This VG is a *verbal predicate* in *passive diathesis* and *past tense.* "*predată*", the head to which is applied the TASG, is a (non-finite) *intensional predicate* of valence 3. *E.g.*, the intensional representation of "*Lucrarea a fost predată.*" could be *lucrarea*$(Y) :=_{past}$ *predată*$_{passive}(x,\ Y,\ z)$, where Y is an extensive variable, while x and z are extensional predicates. Here we take the extensional (context-depending) meaning of *lucrarea*, but it may also have an intensional (predicational) sense: *Lucrarea cu migală a pereților exteriori de către meșterii populari...*

Example 3.2.B. *a fost plecată*

This VG is a *nominal predicate* in the classical grammar. However, it may also be seen as a *verbal predicate* whose semantic head is a predication represented by a *non-transitive* (valence = 1) non-finite verb. Such a category has the representation *plecată*$(x(X))$, where x is the extensional predicate, and X is the extensional variable.

Example 3.2.C. *a fost frumoasă*

This is a clear *nominal predicate*, whose semantic head *frumoasă* is no more a predicational (intensional) category. Since any adjective, predicational or not, requires (at least one) *nominal* argument, written as the *extensional* predicate $x(X)$, the correct representation is *frumoasă*$(x(X))$, with x an extensional predicate and X an extensional variable.

Example 3.2.D. *a fost elevă*

This is a (classical) nominal predicate; the semantic head is representing the extensional predicate *elevă*(X).

Example 3.2.E. *va fi trădarea*

This is also a *nominal predicate*, consisting of a TASG whose semantic head *predarea* is a *predicational noun* [8] (thus non-finite) category. The intensional representation is $P :=_{future-pres}$*trădarea*$(x,\ y)$, where

P is an *intensional variable* corresponding to the intensional predicate *trădarea*, and x and y are *extensional predicates* corresponding to the 2-valence predicational (albeit) nominal category *trădarea*. For instance, P could represent the demonstrative pronoun (and *intensional anaphora*, as it follows) *Aceasta*, in the variant example: *Aceasta a fost predarea*.

Recapitulating this series of examples, one may see the structure of the *predicate* as a TASG applied to a verbal or nominal phrase whose *non-finite* heads vary as follows:

- *predată* = predicational (intensional) V, valence-3, non-saturated; (Example 3.2.A)
- *plecată* = predicational (intensional) V, valence-1 (non-transitive), non-saturated; (Example 3.2.B)
- *frumoasă* = non-predicational (extensional) A, non-saturated, requiring an (extensional predicate) nominal head; (Example 3.2.C)
- *elevă* = non-predicational (extensional) N, saturated; (Example 3.2.D)
- *trădarea* = predicational (intensional) N, 2-valence, non-saturated; (Example 3.2.E)

3.3 A Smooth Transition from Nominal to Verbal Predicate

Examples 3.3. a. *Lucrarea a fost predată.* is represented as $lucrarea(Y) :=_{past} predată_{passive}(x, Y, z)$, where Y is an extensive variable, while x and z are intensive variables (Example 3.2.A).
b. *Ioana a fost plecată.* is represented as $A :=_{past;\ act\ diat} plecată(x(A))$, where A is an extensive constant (*Ioana*) and x is an extensional predicate.
c. *Ioana a fost frumoasă.* is represented as $A :=_{past;\ act\ diat} frumoasă(x(A))$, where x is an extensional predicate as nominal head, and A is an extensive constant (*Ioana*).

d. *Eleva a fost frumoasă.* is represented as *eleva(X)* $:=_{past;\ act\ diat}$ *frumoasă*$(x(X))$, where *eleva* and *frumoasă* are extensional predicates and X is an extensional variable.
e. *Eleva frumoasă este studentă.* is represented as *frumoasă*(*eleva*(X)) $:=_{pres}$ *studentă*(X).

The ***transition point*** from *the verbal predicate* to *the nominal predicate* is located at Examples 3.2.B and 3.2.C (or 3.3.b and 3.3.c). As one can easily see, these predicates, although called verbal and nominal predicates, provide *the same intensional / extensional representations*, from different reasons: *plecată* is a predicational-intensional category but with a *single extensional* argument (being non-transitive), while *frumoasă*, is a non-predicational thus extensional category, being non-saturated, and requires an extensional predicate as its nominal head. These predicates do not provide, from natural causes, passive diathesis, which is an exclusive (possible) attribute of predicational categories with valence greater or equal than 2.

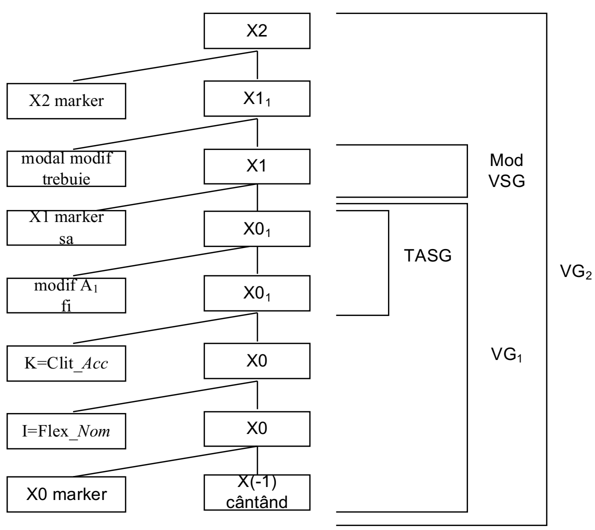
As in the case of FX-bar inverse projection of VG, from VGK towards (one of) its semantic heads [9], this function can not be specified without computing the VG semantic diathesis [12], relying basically on valence-arity and type-sort information of the semantic head (thus more than the simple presence of the predicational feature [8]). The same observation, as proved here, is true for distinguishing between *verbal* and *nominal* predicates, having the same lexical semantics based on intensional / extensional representations.

Furthermore, our approach provides an unitary taxonomy of the verbal and nominal predicate, based on intensional logic. Both constructions rely on (basic/applied) verbal subgroups (VSGs) that a VG is decomposed in, with tense auxiliary, copulative, modal, semi-auxiliary, restructuring head verbs. VSG substructures are (recursively) composing one another, using the predicational feature (including valence / sort of arguments, if necessary) and polymorphism of their semantic heads, to obtain complex FX-bar projections representing the VG.

Although there is still a lot of work to be done for complete FX-bar scheme characterizations of various classes of (Romanian) verbs, we designed here and in [9] detailed solutions that constitute a detailed solutions to VG analysis. The keypoint for the local, clause-level syntactic structures relies on the predicational feature and the newly defined *lexical predications* attached to the VG semantic head (see subsections 1.1, 1.2, and section 2), within the framework of FX-bar theory and lexical semantics – intensional logic formalism.

3.4 Examples of FX-bar Schemes Applied to VG*s*

In this subsection we expose several (linearized) FX-bar schemes (Figure 4), derived from the general FX-bar scheme (see Figure 2 above and [10], [11]), that mimics the decomposition model of the involved VSGs of the VG, described in previous subsections.



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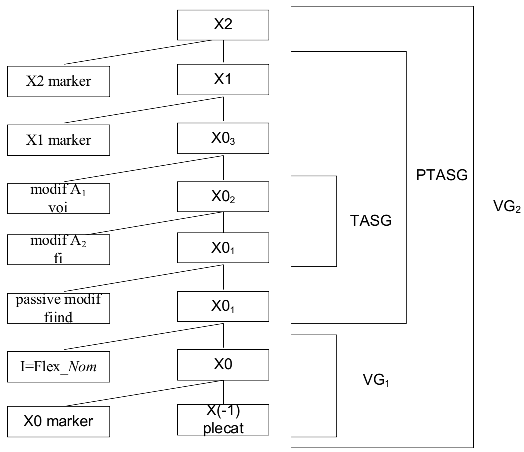
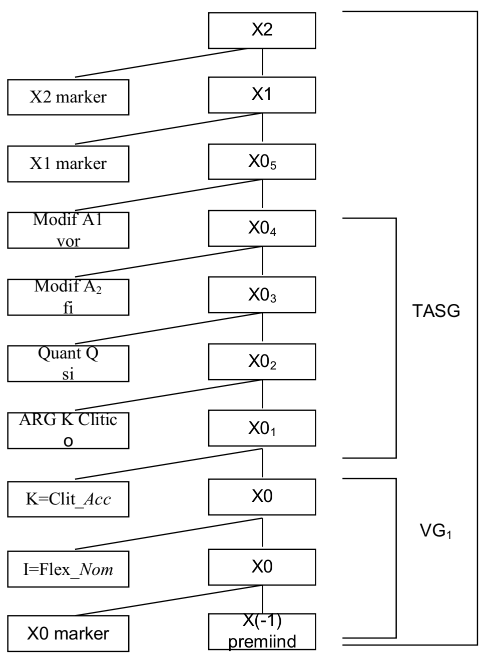


Voi fi fiind plecat



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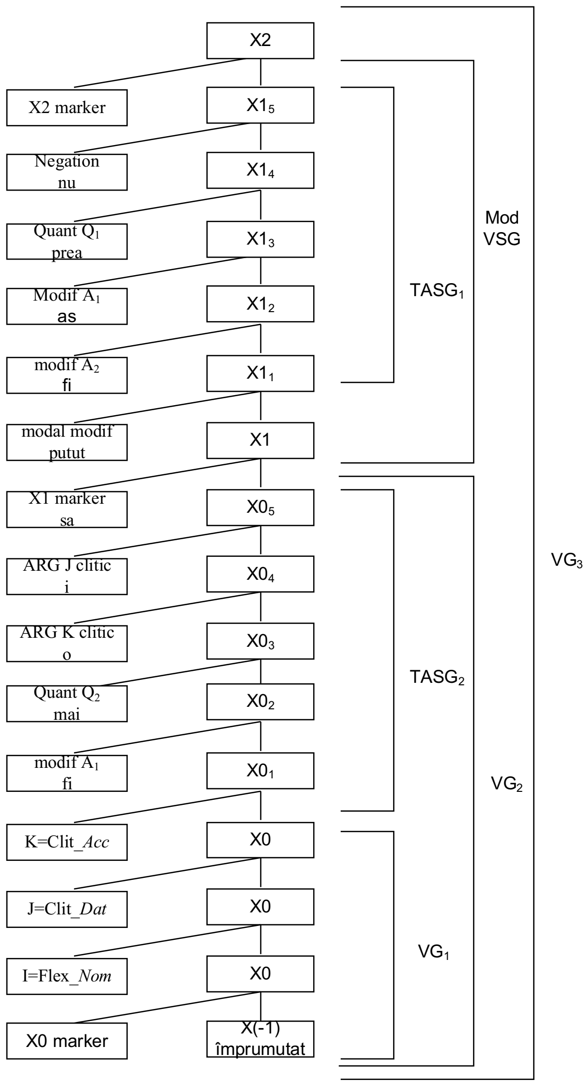

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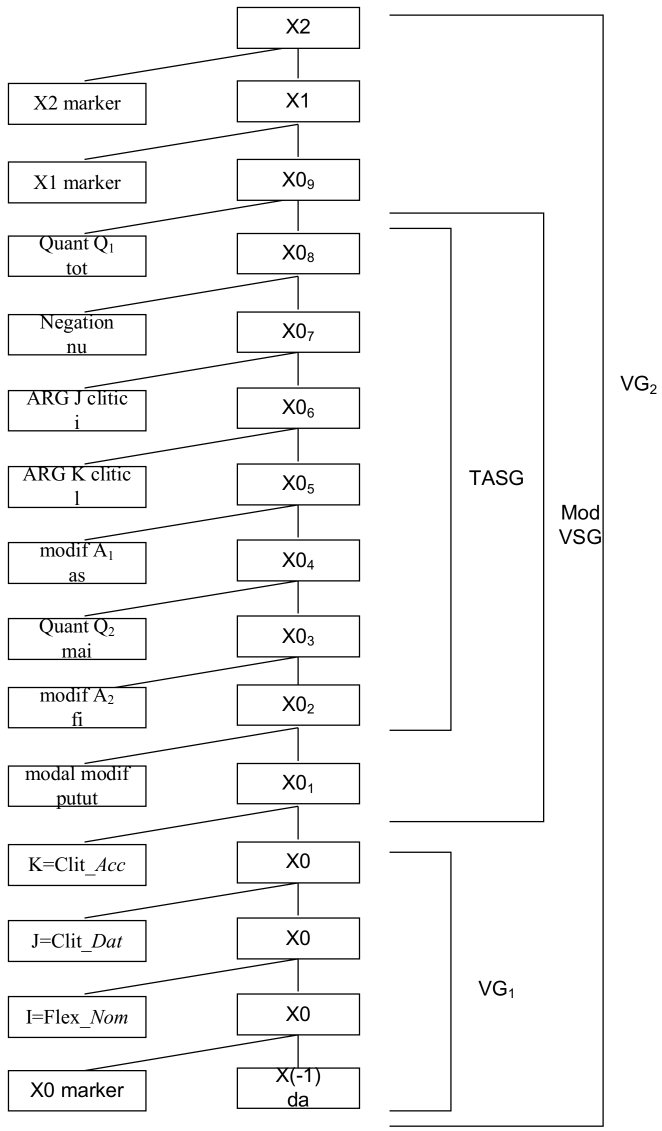

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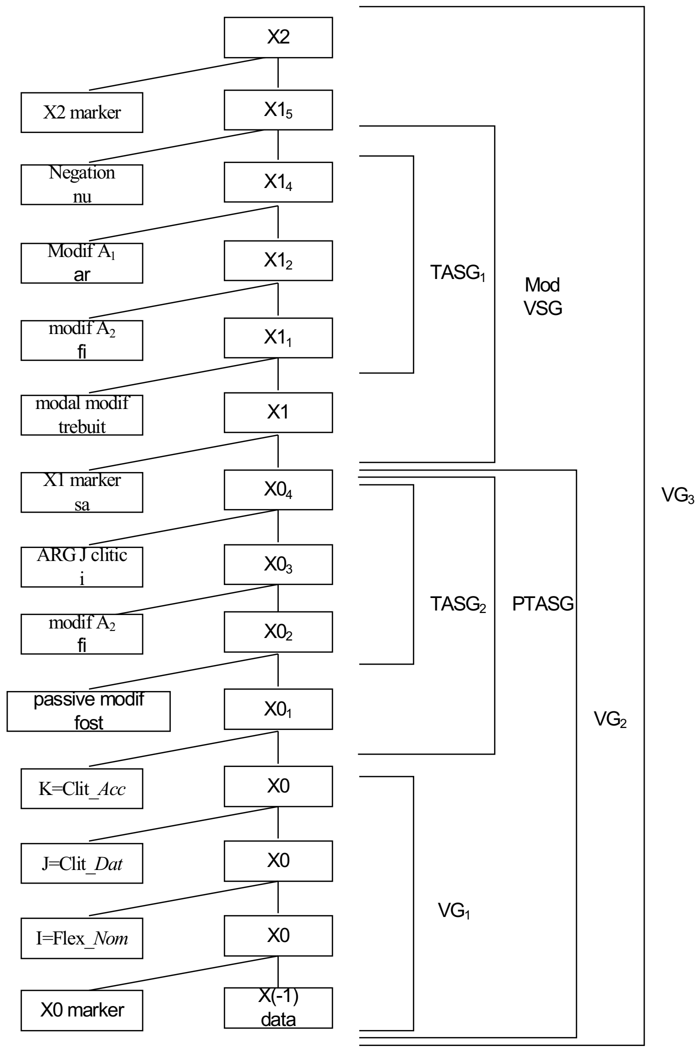

Nu ar fi trebuit să-i fi fost dată

Figure 4. Examples of linearized FX-bar schemes for VG*s*

4 Conclusions

There is still a large quantity of linguistic data, some of them with subtle variations, to be analyzed as interesting for VG substructures, *i.e.* VSG*s*. In terms of FX-bar projections (Section 2), our aim is to reveal and classify as (unitary) VG*s* the categories and sorts of *verbal and nominal predicates*, looking for consistent VSG*s* (when they exist) and all the FX-bar projections as intermediate syntactic-semantic layers situated between the finite clause, its VG predicate (which includes the lexical or virtual clitics as VG *linking* indices), and the VG semantic (predicational) head. The significance of such an analysis should be remarkable: clearing up the *regime of predication*, the status of *verbal* and *nominal predicate* (as VG*s*), the structure and role of VSG*s* as verbal operators successively composing to re-construct the VG, thus the configuration of *local* (clause-level) and *global* (discourse segment) text structures. As current and future research topics, we consider that the present results on classical syntax of VG can provide the development basis for Topic-Focus Articulation (TFA) [15] and linking algorithms [28] at the clause / sentence level, to reveal the *information structure* (IS) syntax at the global (inter-clausal and discursive) level and the configuration of the syntax-prosody interface for Romanian [14], [15].

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SONARES - A decision support system in ultrasound investigations

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In order really to know things, we have
to know them in detail; and since detail is almost
infinite, our understanding is always superficial
and imperfect.

(La Rochefoucauld, Maxims, nr. 106)

Abstract

The article represents synthesis of results obtained in the process of development of SonaRes – the decision support system for ultrasonographic diagnosis. The system structure, its main components are described, the series of problems with which the developers of Clinical Decision Support Systems confront are examined.

1 Introduction

Decision Support Systems (DSS) for medical assistance are considered to be truly the first DSS in the history of artificial intelligence [1]. Being initially conceived just as systems for medical diagnosis, in the sequel they extended the area of their functionality, covering the aspects of administration, management, treatment control, and as a matter of fact the assistance in diagnosis as well. Below we will concentrate on the last of the enumerated functions. In general aspect we will treat the decision support systems in compliance with following definitions:

- Decision support systems are a class of informatics systems with anthropocentric characteristics, adaptive and evolutional, which integrate a set of informatics technologies and communications of general use and specific communications and interact with other parts of global informatics system of an organization [2].

- DSS are the computerized assistants which help the manager with information transformation to actions which are effective for a system [3].

From the multitude of definitions for Clinical Decision Support Systems (CDSS) we will follow the one by Dr. Robert Hayward (taken from www.openclinical.org): ,,Clinical Decision Support systems link health observations with health knowledge to influence health choices by clinicians for improved health care."

Just as in any DSS the human-computer interaction in CDSS manifests itself in the following way:

- DSS cooperates with the decision maker in all considerable operations of the decision process besides the computational ones.

- The decision-making evolves in conditions of partial lack of information and at the enhanced level of uncertainty.

- In DSS the decision maker is the one who initiates and controls the process of decision-making in correlation with his personal objectives, the one who interprets the results and determines the solution choosing.

- Every decision maker is guided by his own specific rules of reasoning and makes the decisions having his own view on the problem.

The decision support in the process of ultrasonographic examinations constitutes our domain of interests. This process has the following characteristics:

Advantages:

- Paraclinic noninvasive investigations,

- Efficiency,
- Easy execution by *qualified* specialist,
- Reduced cost of equipment (comparatively with another imagistic equipment).

Disadvantages:

- Dependence on operator (in images obtaining and interpreting),
- Obtaining of false-negative or false-positive images,
- Reduced quality of images (comparatively with those radiographic),
- Lack of highly qualified personnel.

Especially we will emphasize that in reality the sequence of information exactness losses is inherent to the process of ultrasonographic investigation: analog signal emitted by probe is transformed in the digital one, which in its turn, serves as a source for image construction. This image is accepted (subjectively) by operator, obtaining as a result a written interpretation, which is more or less adequate to this image, depending on the operator's experience and professional skill. Our purpose when projecting the system SonaRes consists in decreasing of these information losses.

The system plays a consultative role and offers to users its variants of diagnosis. The primary use of the system might be as a 'second opinion' in difficult cases and in emergency; it does not replace physician who interprets echograms. Thus, SonaRes is destined to improve health care by providing a highly efficient diagnostics tool. In [4] one can find a comparison with existing systems according to the following functional capabilities: use of both the images and their descriptions, an interactive interface for knowledge acquisition, an intelligent interface, expertise reporting, explanation of the decision, possibility of adding to knowledge base on the basis of precedents, examination of the organs interaction, image processing, the standardized descriptions and decisions, possibility to use the system in automated learning, treating of patient's state in dynamics.

2 The system structure

Coming out of the experience of other systems exploitation we have taken and developed their advantageous aspects, having supplemented them with new qualities, namely [4]: to develop an approach which includes interaction between organs and uses current and precedent similar images in decision making process. Special attention is paid to ergonomic user interface, which is generated dynamically by system according to the DB content and is adaptable to preferences and objectives (of investigation type) of the physician-echographist.

We will offer to specialist, even without wide experience, an access to a resource where the process of ultrasound examination is detailed and formalized and includes an enormous amount of useful information on anatomy, ultrasonic semeiology, differential diagnostic as well as condensed presentation of the main nosologic entities that should appear in the physician's mind at the moment of examination of each organ.

The system SonaRes helps the specialist in ultrasonic analysis to draw the conclusion more correctly, especially, in emergency cases or in unspecific clinic/paraclinic cases, which do not seem to be included in any classical presentation; in cases where the obtained ultrasonic semeiology can provide a correct diagnosis without complicated and, often difficult of access, medical investigations.

SonaRes offers to a user a second opinion with necessary explanations and images that are similar to the examined case. Images can be processed and problem zone, if it is necessary for the user-physicist, can be marked out.

The main components of the system are the following:

- Knowledge acquisition
- Examination support
- Unified database (knowledge, images, annotations etc.)

- Image processing algorithms
- Reports generator

In order to develop these components we are elaborating and adapting:

- formalized descriptions of the abdominal organs, pathologies, anomalies;
- formalized descriptions of the ultrasound investigations methodology;
- unified, standardized disease descriptions;
- knowledge acquisition methods based on ultrasound investigations characteristics;
- a diagnostics validation tool;
- a database model for the medical images, their annotations and fuzzy information storage;
- images clusterization and quick database searching algorithms;
- an ergonomic, dynamically generated and user friendly interface;
- reports' prototypes and their generator.

At the first stage we deal with abdominal zone investigation. The investigation process of this zone is especially difficult (more organs with additional interactions, higher level of confusion, etc.). We have approved our technique on gall bladder and extend it on other organs.

3 Knowledge Structure Modeling in Ultrasound Investigation Domain

Ultrasound investigation domain, just as all medicine as a whole, is a weakly formalized subject domain. Therefore creation of the computer aided informational systems (for diagnostics, for learning, etc.) in this area needs a preliminary research of used knowledge structure, its acquisition and formalization.

Traditionally during knowledge acquisition process two persons are involved. The first one is the expert, the knowledge of which it is necessary to use. He should explain how he makes the decision basing on the initial information. The other person is "knowledge engineer". He does not possess knowledge of the expert, but understands how to present this knowledge in a format accessible for further use in computer systems. Also "knowledge engineer" defines the method of knowledge storage and representation, so he defines the structure of the future knowledge base, where the formalized knowledge received from the expert will be collected.

Inconveniences of "knowledge engineer" usage during the knowledge acquisition process are obvious. Time spent for interaction between the expert and the engineer influences terms of knowledge base creation. The information received from the expert can be apprehended incorrectly by the engineer that will cause mistakes in the knowledge base. So the time-consuming procedures of the additional control are necessary.

The alternative method is creation of an expert environment – accessible to the expert knowledge base generator with intuitively clear process of its filling. In this case the expert himself can supervise knowledge base filling process from the beginning up to the end. So the "knowledge engineer" only defines the method of knowledge storage and representation.

We had realized both methods [5,6]. This enabled us to estimate all advantages and lacks of both variants and to choose the best for ultrasound investigation domain. Considering, that absence of mistakes in the knowledge base is more important, than the time factor, the decision was to accept the first variant. Nevertheless, realization of the second variant enabled us to estimate correctly knowledge volume of our problem area and helped to distribute necessary resources in the future.

As models of knowledge representation in the medicine domain a model based on rules or a semantic network usually are chosen. In both cases the problem is reduced to:

- determination of objects, concepts and their attributes which are used in the given problem area;
- definition of links between concepts;
- determination of metaconcepts and detailed elaboration of concepts;
- construction of the knowledge pyramid, being scale of metaconcepts ranks, rising on which means the deepening in understanding and increasing the level of metaconcepts generalization [7].

Common work of the “knowledge engineer” and experts has shown that in the ultrasound investigation domain a reasoning with metaconcepts (facts) and knowledge representation as a pyramid completely corresponds to experts mentality and reasoning. However the division of metaconcepts up to the level of objects, concepts and their attributes, and construction of further reasonings on their base is not always clear to the experts, especially, if we demand this procedure at the initial stage of knowledge acquisition.

Basing on our experience we can conclude, that in ultrasound investigation area the approach of knowledge structure modeling is effective, when the knowledge received during direct dialogue of “knowledge engineer” with experts is represented as a pyramid of metaconcepts.

The described approach has been approved on an example of ultrasonic investigation of separately taken organ – gall-bladder [8]. As a result of 23 work sessions of the “knowledge engineer” with experts the pyramid of knowledge (consisting from 9 root nodes, 399 facts, 13 levels deep and 60 rules) has been received.

The further division of metaconcepts up to the level of objects, concepts and attributes, and construction of reasonings on their base can be done easily. The necessity of this depends on concrete program applications which will use the obtained knowledge.

4 Knowledge validation

As it was mentioned above, the knowledge of medical experts has been stored in the knowledge base (KB) and represented in the form of a tree with hierarchical structure. Every node of this tree represents an attribute which corresponds to an aspect of the organ description (e.g. organ's form, tonicity, dimension etc). In its turn, each attribute has a set of children. A child can be of two types - a value or a hierarchical characteristic of a more deep level.

Basing on the arborescent structure of the data and using knowledge about organ's pathologies and anomalies, the set of trees for decision rules is constructed. These trees contain all the factors which can help when formulating the conclusion.

The purpose of validation is to state the degree of knowledge base correctness and completeness. It is necessary for that to carry out testing of the obtained rules. Since the testing has been carried out by medical experts, it was necessary to develop the knowledge validation tool, which will be easy in use, will permit the simulation of investigation and evaluation procedure for the obtained conclusions.

Interface for knowledge validation is divided into two parts: in the left part we have a form, which represents the organ description and in the right part – the list of rules obtained as a result of values selection from form.

The form has an arborescent structure, where the children of a node can have one of the following types: "exclusive" and "description". The "exclusive" nodes are the possible values of the attribute, which is the parent-node for these nodes in the tree. The nodes of type "description" are the descriptions of the attribute. The nodes representation in the interface depends on their type. If they are the child-nodes of type "exclusive", they are represented in the interface in the form of „SELECT"; if they are the child-nodes of type "description", they are represented in the form of a list (Fig.1).

The validation process is being implemented in the following way: the attributes values are being selected and after that the conclusion is being deduced, which is formed on the basis of the rules from KB. For validation process perfection the precedent session is memorized, where the selected values for each attribute are kept.

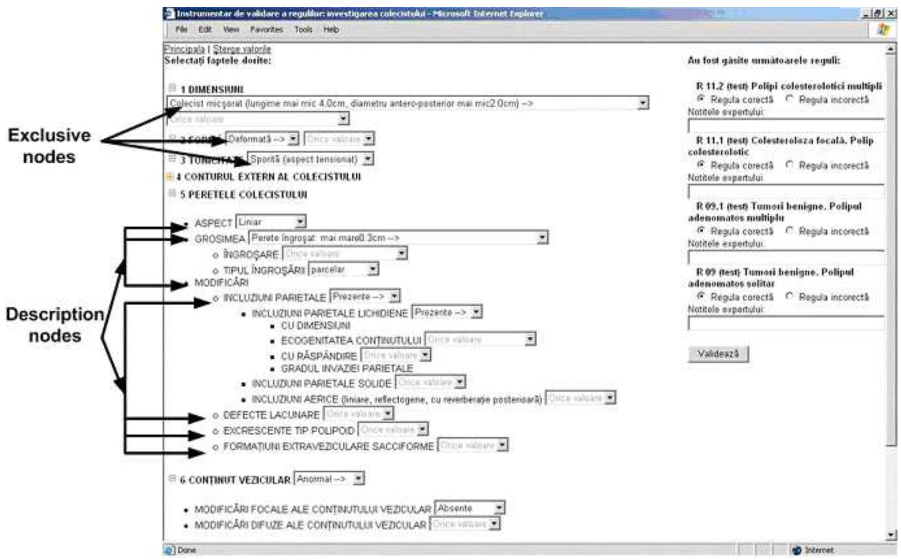

Figure 1. Knowledge validation tool

Hence for the simulation of new investigation, which differs from the precedent only by some values of some attributes, it suffices to modify only values of necessary attributes. For example, the rules "Acute lithiasic cholecystitis complicated gangrenous" and "Acute alithiasic cholecystitis complicated gangrenous" differ from each other only by different values of the attribute "Focal modifications of gall bladder content": in the first case this attribute gets the value "present", in the second – "absent". Also it is easy to verify in which decision rules every combination attribute-value is met.

It is necessary to mention that there are cases which are often met, when the values of some attributes may have not been selected, because they are considered not to be necessary, but which can take part in the rules description, on the basis of which the conclusion is deduced. For this reason in order to obtain a conclusion, all the rules are selected from the KB at the first iteration. Next there are excluded the rules which are described by the attributes, the values of which differ from the values of selected attributes.

During the validation process the expert can make some notes for the deduced rules and to indicate if the rule is described incorrectly. In order to view these notes, made during the validation process, every validation process can be saved as a session. The sessions have been saved in the data base and can be restored by request of the expert or knowledge engineer to be viewed (Fig.2). Each session contains the attributes selected by expert in the validation moment and the obtained rules. Each incorrect rule is followed by: a) some notes of the expert, in which an explanation of given decision is indicated; b) a field for knowledge engineer, in which his notes concerning this rule are indicated (e.g. the rule was modified in KB).

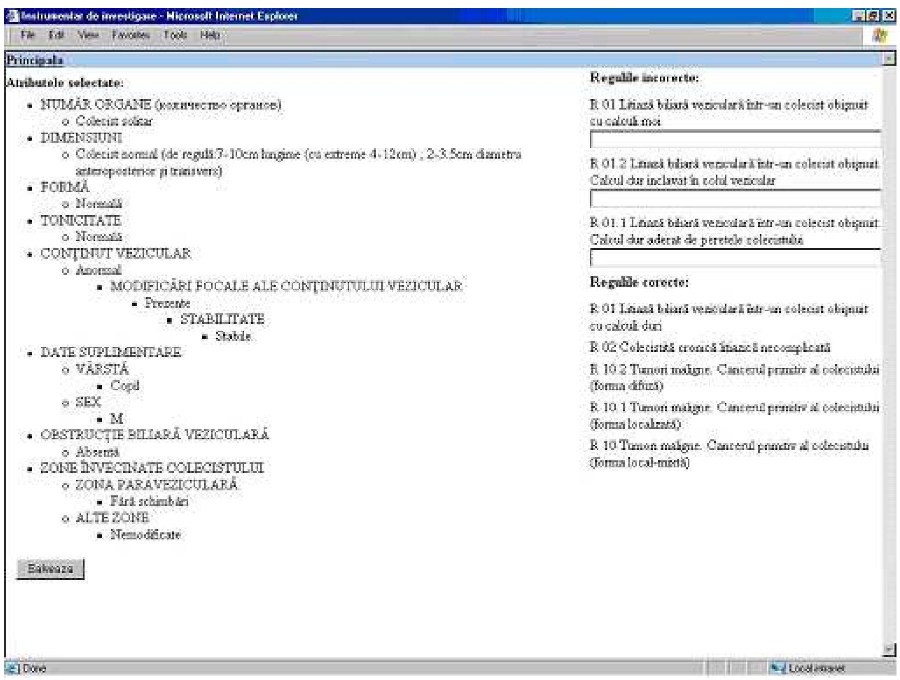

Figure 2. Tool for sessions viewing

At present there was validated the knowledge about one organ – gall-bladder, which serves for determination of the technology for KB formation. After validation the following modifications were made:

- new hierarchical characteristics of the tree were added;
- the values of a set of attributes in the trees for decision rules were modified;
- the set of trees for decision rules was modified;
- new decision rules were added.

The process of validation of knowledge about gall-bladder permitted to state the complete knowledge set for this organ diagnosis.

5 Image processing

Besides its advantages the ultrasound method has a serious drawback – ultrasound images are often affected by noise, possess poor contrast, and suffer from variations in illumination or from self shadow problems that result in masking the regions of interest [9]. So, for a novice in ultrasound diagnostics or even for an inexperienced physician it is complicated to identify what organ is referred to in the image on the basis of just one organ image. Moreover, the ability of getting the "correct" organ image itself strongly depends on the physician's experience.

Developing the system for both an experienced ecographist and inexperienced one, we put as the main scope quick and relevant image retrieval. Therefore, our system will achieve (and hence will propose to the physician) two kinds of images in database – the original image and the processed one. This processed image can be obtained as a result of the application of image processing operations (e.g. noise reduction or contrast adjustment algorithms). If it is necessary, image processing can be applied only to the region of interest, which needs to be marked out by the physician.

5.1 Image clusterisation

At first, all images from database are classified (clusterisation I) depending on the organ diagnosis – there may be some pathology or a description of the normal state of the organ. Organ diagnosis is based on qualitative and quantitative descriptors – organ characteristics, which are determined by a physician-ecographist. For example, in gallbladder investigation the location, shape, tonicity, contour, wall structure, ecogeneity and contents are qualitative descriptors. Dimensions and volume are quantitative descriptors. Such a classification helps one to extract images from image database, which have the same descriptors as the current (investigated) image. So, in the simplest case images from database can serve as "well done" illustrations for some fixed organ diagnosis.

One of the important tasks is the image query (where query is itself an image) with the purpose of retrieving those images which are 'close' to the query image. In this case another clusterisation (clusterisation II) will help us in classification of images depending on image statistics. It is necessary to specify the region of interest as well as to compute the distance between the query image and the images in the database. Consequently, some statistical descriptors (e.g. histogram, average and standard deviation of the image intensity, average of the standard deviation of the region intensities) are computed for every image. The advantage of these statistical descriptors in comparison with those mentioned above is that they are direct image related and independent of the specific physician's experience. An efficient iterative clustering method of ascendant hierarchical classification, which can be applied in the case of quantitative descriptors, is described in [10]. Once the hierarchical index structure for the images database is constructed, it can be used to extract the images most similar to a query image rapidly.

5.2 Image processing methods and results

The creation of our software tool for ultrasound image processing is aimed to accomplish the following principle tasks: noise reduction; contrast adjustment; borders and organ contours determination; structure and texture analysis.

First two tasks are directed to improve general image aspect or the region of the interest. Automatic image segmentation with borders detection helps to avoid manual time-consuming and tedious work, which requires expert knowledge; while structure and texture analysis is useful in detecting pathology (e.g. tumors and cysts).

There are a number of image processing methods, many of them being problem-specific or organ-specific oriented. Currently there is no one single segmentation method, sufficiently good for all ultrasound images. We suppose that an "ideal" segmentation algorithm must incorporate many families of the image models. So, we press towards implementation of different segmentation methods, and their combination will provide the acceptable results for every specific organ.

Image Statistics.

This submenu gives the useful statistical representation of the loaded ultrasound image, e.g. histogram of frequency – number of times that a pixel with a particular gray-level occurs within the image (Fig. 3).

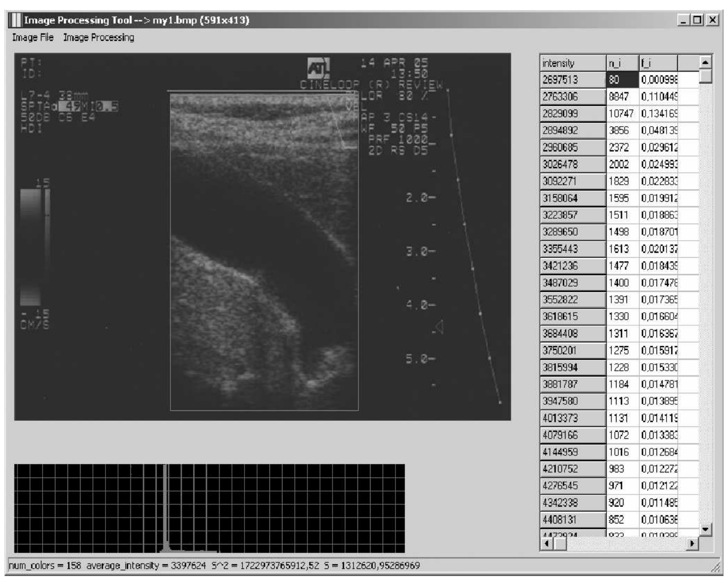

Figure 3. Image Statistics submenu (with specified region of interest

In the case of complex images which may consist of up to 256 gray levels, the resulting histograms will consist of many peaks. The distribution of these peaks together with the magnitude can reveal some significant information about the information content of the image. Average and standard deviation of the image intensity, average of the standard deviation of the region intensities can be computed. So, this submenu helps us in obtaining all necessary statistical descriptors.

Noise Reduction.

No edge detection algorithm can be expected to work well on raw unprocessed image data. Speckling presented in ultrasound images make accurate segmentation difficult, therefore noise reduction step is performed usually in the beginning. Gaussian and median filters were used with success in [9] for fetal ultrasound image smoothing. Currently we have realized this task by using Neighborhood Averaging Algorithm, which replaces each pixel with an average of its neighborhoods, and Median Filter, when each pixel of the filtered image is defined as the median brightness value of its neighborhoods in the original image (Fig. 4-5).

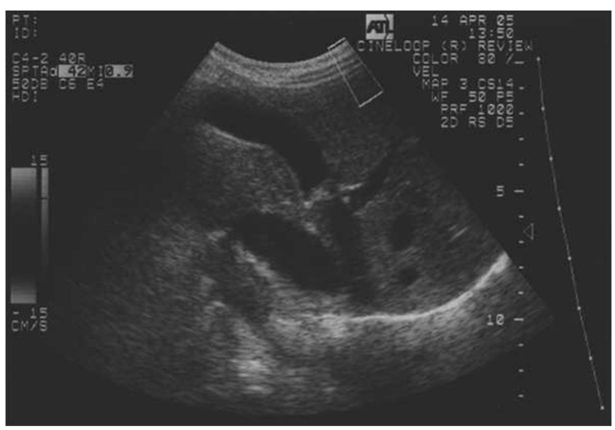

Figure 4. Original ultrasound image of the normal gall-bladder

For ultrasound images the averaging filter gives sometimes not better, and often quite worse image, than the original one.

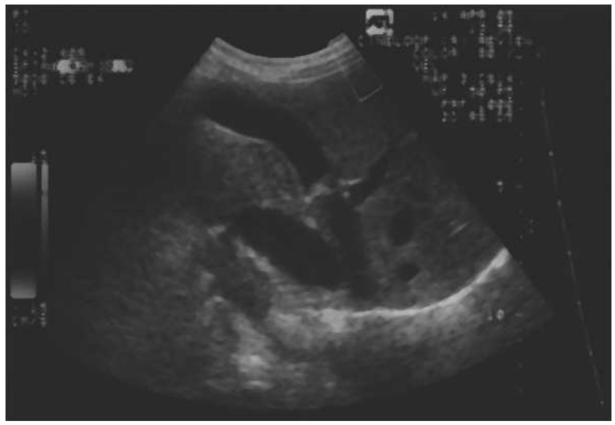

Figure 5. Image processed by applying median filter (filter window 3*3)

Contrast Adjustment. This approach renders the image more acceptable for the eye. We have implemented two methods to perform this task.

Thresholding of Intensity, which generally enhances the contrast in the image, is often used as an initial step in a sequence of the image processing operations. This is the technique of setting certain gray levels to zero relative to other one (threshold value separates the desired classes). The effectiveness of the method depends on the histogram of the gray level distribution on the original image exhibiting at least two identifiable peaks, so that at least one or other of the levels contributing to the peaks can be set to zero (Fig. 6-7). The major disadvantage of this method is that thresholding typically does not take into account the spatial characteristics of an image; this causes it to be sensitive to noise. This technique combined with the texture statistics was successfully used to segment ovarian cysts [11].

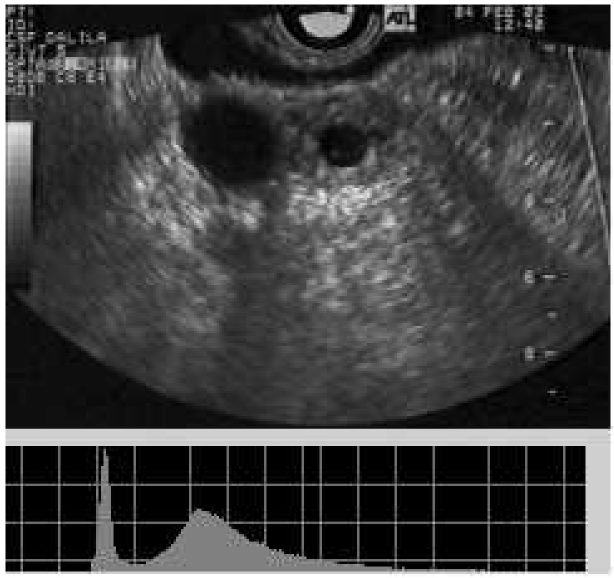

Figure 6. Original ultrasound image and its histogram

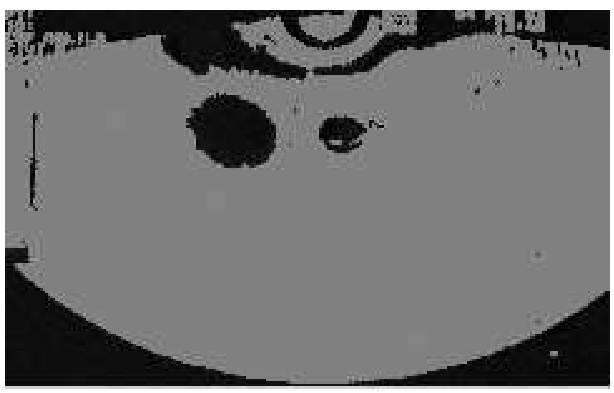

Figure 7. Images with thresholding of intensity, threshold value=1315860 (homogeneous light region intensity values were greater than threshold value)

Another method of contrast enhancement is the Histogram Equalization. This process increases the dynamic range (the ration between the minimum and the maximum of intensities) of intensities. Utilization of the transformation function equal to the cumulative distribution of the gray level intensities in the image enables us to generate another image with a gray level distribution having near uniform density (Fig. 8).

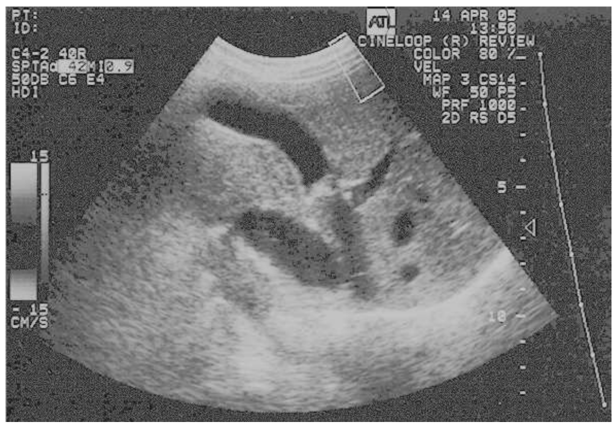

Figure 8. Image processed by applying histogram equalization (original 173 colors were transformed in 54 colors)

Borders and Organ Contours Determination.

This task is quite difficult one for ultrasound images. Usually, knowledge obtained from experts is directly coded in segmentation algorithms. Unfortunately, automatic image processing didn't give very good results. Therefore, automated segmentation is used with possibility of the initial learning [12] or in combination with genetic algorithms. Another interactive approach is more frequent, when physician-ecographist has possibility to determine the region of the interest. Thus, we have implemented some different algorithms.

Region Growing is the technique for extracting a connected region of the image. It may be used for delineation of small and simple structures as tumors and lesions. Usually it is not used alone, but within a set of image processing operations. The major disadvantages of this algorithm are that it requires the initial point to be manually selected and it is sensitive to noise. Split and Merge Algorithm is related to region growing, but does not require the initial point, so it can be used for "ideal" automated functioning. For the gall-bladder images these techniques give the promising results (after initial noise reducing), the future work is to test them on the ultrasound images of the other organs.

Deformable models can be applied for boundary detection using closed parametric curves [11]. It is an interactive technique too, because close curve (circle) must first be placed near the desired boundary (Fig. 9). The advantage of this algorithm is that it is robust to noise. Deformable models, which have good success in the segmentation of prostate boundaries [13], were used to determine boundary of the fetus and the fetus head respectively [14]. The results for gall-bladder ultrasound images are not stable – the fact, which needs to be studied more deeply.

Figure 9. Image processed by the deformable models technique (close curve must first be placed near the desired boundary)

6 Examination Support

The proposed method of acquisition (by means of expert shell) and storage of expert knowledge in Unified DB permits to effectuate a quick search of necessary information in two directions or modes [4]. The first direction is from the concrete case description to determination of pathology and/or anomaly; and the second one – from formulation of a hypothesis to its confirming or denying (Fig. 10).

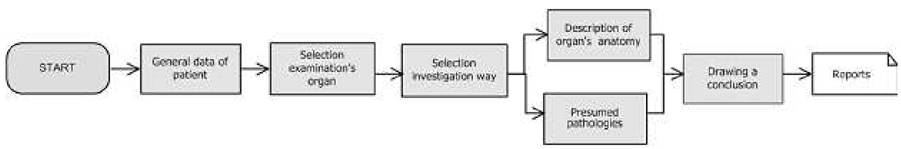

Figure 10. The structure of the interface for investigation

Following the first direction the user gives the necessary information describing a concrete case, and the system tries to determine if it is a pathology and/or an anomaly. To exclude at the early stage the input of inconsistent, erroneous or excessive information, this direction is followed step-by-step (Fig. 11). If at any step the system can determine, on the basis of the entered information, pathology and/or anomaly, it informs the user.

Following the second direction, the user forms a hypothesis about presence in the concrete case of pathology and/or an anomaly. Then the system by means of additional questions tries to confirm or to deny this hypothesis.

Realization of both modes within the framework of unified support system of ultrasonic investigation process corresponds to the daily work of physicians. The first operating direction satisfies the requirements of the detailed patient examination; and the second direction corresponds to a simplified one, when it is necessary to confirm or to deny any diagnosis.

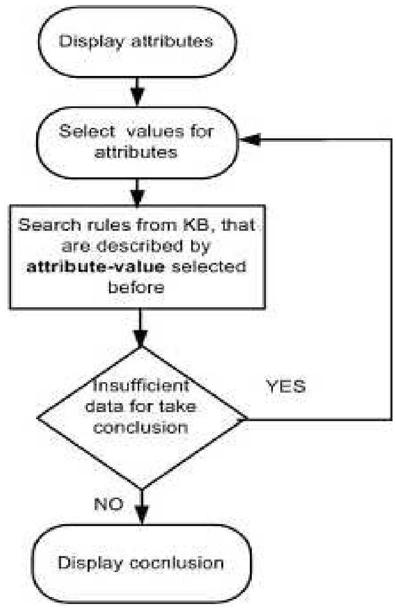

Figure 11. The scheme for the investigation process "step by step"

A convenient dialog with user-physician (due to dynamic intelligent interface which includes a standardized explanation of the decision proposed by system) involving images in decision making process (based on visualization and comparison of ultrasound examined image with similar images from Image DB) permits to create a comfortable environment for physician and helps him to prepare a standardized report, containing the examination results and, if necessary, the recommendations for additional investigation.

7 Reporting

The resulting report is the obviously unique result of ultrasound investigation that can be presented for view or saved for further reviewing. But traditionally the medical image report consists of both the well formalized part (patient and image data, digital measurement data) and the arbitrary formed description. Initially the description was a free-text that a physician prepare by his own way. The free-text form causes the ambiguity and is not suitable for quantitative analysis. Since the possibility of computer performance arose the researchers have being made attempts to structure the free-text description. The free-text description structuring is implemented by several methods. They can be grouped in two main approaches: extraction of meaning data from existing reports and generation of the reports by fixed rules. The first one is based on the analysis of existing radiology reports and uses the powerful AI techniques: natural language processing and data mining to extract regular data. The second way uses predefined elements for report construction. It takes some results of the first one to build the dictionaries of corresponding lexicon. Starting with proposing the standard phrases set by the second way has driven to definition of Structured Reporting.

Structured Reporting is both the image term and researching domain that covers the construction and processing of formalized and structured clinical reports. At the DICOM Structured Reporting Workshop (March 29 -30, 2000, Donald E. Van Syckle) Structured Report was defined as a “Databaseable Document” which: uses standardized or private lexicons; provides unambiguous “semantic” documentation of diagnosis; allows links to multimedia context. It means that the report context is the set of objects which have standard and recognizable attributes and can be easy packed in underlying clinical database.

But the choice of standards for structured reports remain difficult. There is the full set of different standards related to equipment, transition protocols and clinic documentation. The physicians keep trying to resolve unification problem, but even at 2006 at the conference IHE (Integrating the Healthcare Enterprise) Workshop there were mentioned several standards which are used in radiology reporting: DICOM SR, IHE "Report Integration Profile" that specifies a template for diagnostic reporting, HL7 (Health Level 7), CDA (Clinical Document Architecture), SNOMED (Systemized Nomenclature of Medicine, Unified

Medical Language System), HIPAA (Health Insurance Portability and Accountability Act), ACR (American College of Radiology) Standard for Communication. IHE is an industrial initiative to bring information resources in healthcare. IHE does not develop standards but annually issues the recommendations which have a high probability of a quick uptake in the medical market because of quantity of IHE participants. Between 1999 and 2005 more than 160 companies, including most of the market leaders in domains of RIS (Radiology Information System), and PACS (Picture Archiving and Communication System), have developed IHE-compliant systems. So the methods of structuring represent the essence of researching in this domain.

The most frequently used method of report structuring is the generation of reports by templates. This method provides the control of report design but also causes some problems because the user's choice between similar templates can be ambiguous.

The template controls both layout and content of the report. In terms of report layout the template marks some "widgets" and image multimedia which are the images and video clips. The report content templates usually belong to one of the two types. The form part of report is created by the template of the first type. In this part the patient and image data are set. The templates of the second type are essential for the results of investigation. As it was mentioned above these results contain both digital data and text descriptions. The templates for text description depend on structuring method. The template can propose the set of "brick"-phrases with predefined image meaning. Another method consists in the representation of the report by tree structure. This type of structure corresponds to the process of radiology investigation and can be easily stored and processed using XML paradigm.

Taking in consideration that our system is targeted at diagnostics we intend to use in reporting the data already collected during diagnostic session. This session is implemented by "down-tree-walking" methods and so the data are well structured. Only to add the data which can not be received from diagnostic session another interface will be proposed. The changeable template of report will be represented by external XML-file.

In [15] the complete solution for development of application implementing structured reporting is proposed. Some conceptual solutions announced here can be used to achieve the implementation of discussed features of structured report. The most important features for our future implementation are: generating of the report by assembling from components which are intelligent and verified; collecting of such components in knowledge base; tools for components generation and editing. The process of proposed application activity includes both the generation of reports and obtaining new components through analysis of newcoming reports.

8 Conclusion

The proposed system does not intend to replace completely the physician; it just offers him a second opinion. In all cases user can receive all rules and judgments on the basis of which the decision was made. If the user doesn't agree with the decision, proposed by the system, his opinion will be sent to expert group for examination.

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Affordability and Paradigms in Agent-Based Systems

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At each level of complexity entirely new properties appear.

Psychology is not applied biology, nor is biology applied chemistry.

PHILIP W. ANDERSON

Abstract

The paper aims at substantiating that in universities with scarce resources, applied Information Technologies (IT) research is affordable, even in most advanced and dynamic sub-domains. This target is split into four specific objectives: a) to set up a framework for IT research affordability in universities representative for current East-European circumstances; b) to outline a workable approach based on synergistic leverage and to assess the paradigms prevalent in modern artificial intelligence through this "affordability filter"; c) to describe the evolution and the current stages of two undertakings exploiting paradigms founded on *emergence* (the sub-domains are *stigmergic coordination* and *agent self-awareness*); d) to summarise for both sub domains the mechanisms and the architectonics (the focus is on computer science aspects; implementation details will be given in future papers). The results in both directions appear as promising and reveal significant potential for transdisciplinarity. From this perspective, the paper is a call to improved cooperation.

Key-words. Open, heterogeneous, dynamic and uncertain environments (OHDUE); Emergence; Synergy; Stigmergy; Agent self-awareness; Agent-oriented software engineering (AOSE).

1 Introduction

As regards advanced IT, it is generally accepted that academic research in East-European countries is still limited not by scientific potential but rather by financial or logistic boundaries. Considering the case of the "Lucian Blaga" University of Sibiu, the paper tries to show that – without aiming at immediate spectacular results – such research can be afforded even in demanding fields like agent-based systems (ABS). The key seems to be updated context awareness and a short delay in exploiting it. This context is delineated by:

Environment. Present-day IT environments, except for some irrelevant applications, are *open* and *heterogeneous* (the resources involved are unalike and their availability is not warranted), *dynamic* (the pace of exogenous and endogenous changes is high) and *uncertain* (both information and its processing rules are revisable, fuzzy, uncertain and intrinsically non-deterministic – as every stimuli generator) [47]. All four features are there in any modern IT system, albeit with different weights. (Over)simplifying, it could be considered that the first two features are universal (i.e., any significant activity environment in the post-industrial age enjoys them), whereas the last two are their – more or less avoidable – consequences. However, in IT this general role – still essential – is surmounted by an even weightier one: in the Internet era of "computing as interaction" [1], dynamic and uncertain environments are inherent, since deterministic applications are practically vanishing. In short, nowadays, relevant applications are grounded in open, heterogeneous, dynamic, and uncertain environments (OHDUE).

Affordability. For the current Romanian (technological, social, and economic) context, this is the key feature focused on because applications should be not just inexpensive, but also convenient as tools for ordinary interactants in the emerging "information (or broad-band) society".

Anthropocentrism. Here it means focusing on the human being as user, beneficiary, and, ultimately, raison d'être of any application. Anthropocentrism becomes common in IT because it is crucial for user acceptance (the main macro-architectural features looked for are *flex-*

ibility and *user-friendliness*). Only powerful IT companies can impose technocentric solutions. Hence, affordability requires rather "user-pulled" than "technology-pushed" research. (Anthropocentric interface design is commented in [10].)

Technological Trends. Prigogine's idea that the most interesting scientific activities seem to occur at domain interfaces [28] is a confirmed – and, because of financial reasons, often (first of all, now, in Romanian universities) the *only affordable* – path for applied research [21] [20]. Again, only powerful IT companies can afford to exploit effectively mature technologies. Academic research is confined to find "Prigogine niches"; they can be found mainly through innovative, emerging technologies.

Considering the context described above, the target is split into four specific objectives: a) to set up a framework for IT research affordability in universities representative for current East-European circumstances (the University of Sibiu is taken as instance); b) to outline a workable approach based on synergistic leverage and to assess the paradigms prevalent in modern artificial intelligence (AI) through the "affordability filter"; c) to describe the evolution and the current stages of two undertakings in challenging and innovative areas, exploiting (related but distinct) paradigms founded on *emergence* (after filtering, the sub-domains selected are *stigmergic coordination* and *agent self-awareness*); d) to summarise for both sub-domains the mechanisms applied and the architectonics of the current experimental models (considering the journal profile, the focus is on computer science aspects regarding the sub-domains; implementation details as well as aspects related to complexity science, will be given in future papers).

Accordingly, the rest of the paper is organised as follows: the *affordable synergy*-based *approach* is outlined in Section 2 and used for the *paradigm filtering* (*and blending*) in Section 3. The next two sections describe abridged the emergence-based core undertakings stemming from: a) *simulated emergence* (in Section 4 stigmergic coordination (SC) simulates self-organization in ant colonies); b) *emulated emergence* (in Section 5 Gödelian self-reference tries to emulate self-awareness of interface agents). The paper concludes (Section 6) that results in both directions appear as promising and reveal significant potential for transdisciplinarity as well as for teamwork. From this perspective, the paper is a call to improved cooperation in developing innovative and still affordable ABS. (Why *Agent-Based* Systems? Because of two nuances – both related to affordability: a) Although many such systems are *Multi-Agent Systems* (MAS) – or, at least labelled as such – it is not necessary to exclude applications with a few agents. b) Agent-*based*, not agent-*oriented*, to cover also very simple agents in unpretentious applications.)

2 An Affordable Approach: Synergy as Leverage

To draw a workable approach, the previous assertions about the context are restated as premises and commented upon, focusing on their consequences as regards the very approach:

- *Affordability Is Sine Qua Non.* Moreover, it is vital for both research aspects: a) *Effort.* A university research undertaking is considered affordable if it proves workable as a project ending with a few experimental models validated "in vitro" (for instance, within the narrow scope of a PhD thesis [43]). b) *Applicability.* Applications embodying the research results should be intrinsic *usable* (to represent solutions first to toy problems but soon to real-world problems – albeit small-scale one – so as to be at least roughly conclusive) and easy *extendable* for further research. Thus, the undertaking must ensure affordability for future end users with quite scarce resources, i.e. the applications must be not just inexpensive, but also convenient as tools for ordinary interactants in the emerging "information (or broad-band) society" (for instance, a research project regarding inductive [33] [53] [54] non-algorithmic [51] e-Learning [47], should be tested also by individual students on usual configurations).

- *Anthropocentric Design Is Crucial For User Acceptance.* The goal of anthropocentrism entails a kind of "anisotropic" flexibility: at the outer surface (that means at the interface level), the application has to match only user expectations, i.e. to *adapt itself* to the user (the users are not forced to adapt themselves). Nevertheless, as this requirement does not hold also for the internal application layers, in order to improve efficiency – above all, under time criticality – the application and the controlled process itself can (and should) *be adapted* and *adapt* mutually. However, how can we reach such a comprehensive flexibility, expressed through both its exogenous facet (*adaptability*), and its endogenous one (*adaptivity*)? While *adaptability* (adapting system behaviour to user *explicit* requests) can be attained rather easily through generic, parameterised functions, *adaptivity* (learning to shape, refine, and update several actions so as to meet *implicit* user expectations) involves, first of all, *intentionality* and *ability to learn* [26] [6] [7]. That means genuine distributed and multifaceted AI.

- *Technological Trends in Artificial Intelligence Means Agent Technologies.* The trend is well-established, steady, obvious, and uncontested. However, general consensus stops here. The palette of divergent opinions is impressive and involves almost all facets of agent-orientation (AO). Some of the most controversial issues are [9]: complexity (many simple agents or a few complex ones?), degree of parallelism (coarse-grain or fine-grain, genuine or simulated?), degree of autonomy (strict human control but low agent effectiveness or high autonomy but uncertain – even potentially dangerous – agent behaviour?), design mechanisms (are object-oriented tools suitable for implementing agent architectures or are needed new tools?), etc. The very nature of agent logic is disagreed upon [17]: should be reasoning based on symbolic or on sub-symbolic inferences? Thus, comparing and selecting paradigms is a hot issue in any context.

Such very restricting premises require an approach with a high "performance/resource ratio". In turn, that entails a kind of "resource amplifier". The ancient, best known, verified, versatile and affordable universal amplifier is *synergy* [29]. Thus, *in nuce*, the approach could be defined: "in search of synergy, from Aristotle to Haken", i.e., "synergy whenever and wherever it emerges" (reminding the slogan about information, the idea sounds familiar). Where does synergy come from? Considered pragmatically, in its comprising Aristotelian (or Daoist) meaning, synergy has three sources (adapted and extended after [21] [9]):

A) *Homogeneous Amassing of Many Simple Entities.* For instance, although ants behave rather as robots than as agents, the system they belong to is not a "multi-*robot*" system, but a "multi-*agent*" one. This wonder is due to the synergistic effect of their interaction: beyond the individuals (ants or ant-like entities), the team (colony, society, system) comes out. That is the preterminological meaning of "synergy" due to Aristotle: the whole is stronger than the sum of its parts. This kind of synergy (referred to as "*classical synergy*") is intrinsically linked to *multiplicity* and *parallelism.* Obviously, if it would be only "one part", the "whole" could not be stronger than itself. However, multiplicity implies *parallelism*, not just because the ,,parts" creating the swarm *coexist* but because their incessant *interaction* (imposed by the real-world dynamics).

   Since synergetics is a well established science, Haken's principles [32] [37] should be considered too (in parentheses are comments on their role in this paper): a) "Subsystems slaved by the system" (rather irrelevant when the system – for instance, an ant colony – remains unexplained). b) "Cooperating subsystems" (does not apply directly since ants do not communicate). c) The "threshold" principle (of unquestionable importance in both nature and IT: a few ants are surely unable to run a colony and, as well, a few artificial ones are unable to solve research problems, no matter how long they try). d) The "self-organization" principle (the conceptual crux of emergence).

B) *Heterogeneous Interacting of Few Complex Entities.* Dissimilar entities create "added value" rather by *complementarity* (e.g., in symbiosis) than by *crowds*. Physical entities can be substituted by areas of expertise, sub-fields, or paradigms. However, despite the simple idea of combining paradigms to reach synergy, in IT as a whole and in AI in particular, paradigms are still poorly connected. In principle, any paradigms can be mixed up but, since engineering requires *symbols*, integrating the symbolic paradigm with subsymbolic ones (mainly based on biological models) is the target at hand. This kind of synergy will be called here "*inter-paradigmatic*" (see next section).

C) *Trans-Disciplinarity*. The third source matches Prigogine's idea mentioned in Section 1, about domain interfaces. It is a confirmed path for research (because of affordability, it becomes the only one). The prefix *trans* (instead of the usual *inter* or *multi*) highlights the trend towards osmotic-like confluences.

Since not all connotations of those three kinds of synergy are suggested by the term "*emergent synthesis*" (more frequently used in modern IT contexts), here the term "*synergy*" is preferred.

More common approach facets (e.g., micro-continuity, rapid and/or successive prototyping, generic architecture) have been described in [6] [7] [8] [11] [20] [13] [16] and do not need further comments.

3 Filtering and Blending Paradigms

(Instead of) Methodology. First *synergy* itself was deeper investigated, in its relationship to both *complexity* and symbols [9] [19] [21]. The results highlighted the criteria for selecting and the directions for combining paradigms able to boost SC (details in Section 4). Here they are updated, extended to all emergence-based paradigms as well as to transdisciplinarity [29] [9] [17] [13] [16] [15], and adapted to the paper target:

- a) As regards *complexity*, older results were reinforced: Synergy implies *multiplicity*; multiplicity entails *parallel interaction*; this implies two kinds of complexity: *structural* (regarding the system) and *cognitive* (regarding the way the system is perceived by its users). From another outlook, complexity may lie at two levels: *entity* or *system*. In this respect classical synergy is exclusive: entities should be simple, and complexity should emerge at system level, through the huge number of interacting components. Thus, the threshold principle becomes crucial also from an engineering standpoint: "where from start a huge number?" Indeed, albeit almost any biologically inspired model (even when considerably modified) has proved to be helpful to AI, the number of entities should stay affordable. However, artificial neural networks are founded on massive, fine-grain parallelism (as a premise for connectionism); likewise, evolutionary algorithms yield relevant results only with numerous populations; but massive parallelism is hardly affordable with scarce resources, even when intense simulation is involved. (Fortunately, there are fewer ants in a colony than neurons in a neural network or chromosomes in an evolutionary algorithm.)

- b) As regards *symbols*, it seems that not even nature can afford to deal with very many complex entities: the strength of synergy seems to be proportional not only to the scale of parallelism itself (number of entities involved) but also to the extent of sub-symbolic depiction; in other words, self-organization emerges easier in sub-symbolic contexts. According to Heylighen [34], there are at least seven characteristics of self-organising systems; here are relevant four of them: global order from local interactions; distributed control; robustness and resilience; non-linearity and feedback. Therefore, sub-symbolic paradigms, with their vast intrinsic synergistic potential, are a good choice for exploiting the first synergy source. Combining this result with those mentioned above, the best choice is the biologically inspired paradigm involving the smallest number of entities, i.e., *stigmergic coordination*. Though, the symbolic approach (Newell-Simon hypothesis) is unavoidable for at least four reasons: b1). Primarily when complexity (of all kinds) is high, software effectiveness becomes uncertain and direct human intervention is rather welcomed. Since modern IT systems are anthropocentric, the users (no matter whether system engineer, application developer, manager, and so on) should be allowed to monitor the system and to communicate with, using familiar semantics – i.e., symbol-based languages, humans are accustomed to. b2). The same reason holds for any human-agent interaction (vital for interface agents). b3). To prevent unintended – and not reasonably predictable – conduct in OHDUE, agent actions having potential ethical implications should be more rigorously controlled. Consequently, without obstructing agent autonomy, their "ethical architectonics" should be based on symbolic processing [14] [44]. b4). From a software engineering perspective, symbolic processing is not a (best) *choice*, but a *must* because any engineering undertaking involves symbols: design means to *project*, and any relation to the future implies symbols.

- c) To get synergy also from the second source, components based on different paradigms could be mixed in the same model, provided that both extreme irreconcilable dogmata (the Newell-Simon hypothesis versus the physical-grounding (ethological) paradigm applied in Brooks' automata challenging the need for symbol-based explicit representation) are deprived of their *necessity* conditions, i.e., are considered only as *sufficiency* conditions. Moreover, as corollary of the assertions above, some paradigm blend involving the symbolic paradigm is not just possible but highly desirable: humans – seen as the apex of symbolic reasoning – act as counterparts of sub-symbolic entities, in getting inter-paradigmatic synergy. Hence, any blend should include both symbols AND sub-symbols (indeed, here the "AND" should be read almost as the similar Boolean operator). After all, the way humans make inferences proves that nature created in our brains the amazing blend of (a kind of) "von Neumann"-like algorithmic procedures (in the left hemisphere) with non-algorithmic (creative, heuristic, emerging) procedures (in the right hemisphere). As a rule, in agent strategic decision making, the layer of mental (symbolic) context should prevail over the layer of situational (sub-symbolic) context. (For the time being, it is safer to set up ABS founded also on *reason* not just on *instincts*! Nevertheless, in the long run, it will depend on the future "Zeitgeist-stance".)

- d) The third synergy source, being grounded on transdisciplinarity, seemed to be, until recently, outside the scope of software engineering but the promising *memetic* approach [25] could help, since most paradigms in modern AI have an obvious memetic character ([15] [16] and future papers).

4 Simulated Emergence

The problem is shaped by affordability restrictions and by the question (unanswered in Section 3) "where from start a huge number?" Unfortunately, all biologically inspired paradigms model massively parallel societies/systems. Thus, all are affordable only through simulation. (Even the less demanding SC involves usually at least tens of entities.)

On the other hand, albeit AO is already a well-established course in AI – and even in IT as a whole – at the engineering stage its effectiveness is rather unsuitable for affordable ABS, no matter what paradigms are applied, because – despite the increasing number of biologically inspired models – the newer paradigms they are founded on are in a yet syncretic stage, embodying a promising (but too little exploited) niche in itself – for both applied research and effective implementation. Thus, paradoxically, despite the increasing shift from predominant algorithmic reasoning towards subsymbolic reasoning paradigms (seen rather as complement, than as alternative) and although the fidelity towards the biological model is sometimes quite low, letting place for components sticking to older paradigms – mainly the symbolic one – inter-paradigmatic synergy is rather not manifest enough.

To exploit the niche, as graft paradigm there was chosen the symbolic one (for obvious conceptual and engineering reasons; moreover, albeit not always asserted explicitly, symbolic processing is already present in some successful algorithms based on SC – e.g., Dorigo's *Elitist Ant System*). On this groundwork there was set the engineering construction [45] [21] [20] [46] [23] [48] [31]: a) designing specific mechanisms to graft symbolic components onto the sub-symbolic foundation (the filtered biological model); b) tailoring the mechanisms to sub-fields (primarily, manufacturing control); c) building an experimental model as a test-bench for this sub-field but, considering also future extensions. Even if in SC emergence is impressive, the trouble to understand what is in fact going on at system level, is less upsetting than in the case of more familiar sub-symbolic paradigms (as artificial neural networks or evolutionary algorithms) since ant behaviour is easier to follow due to its simplicity: the ant travels from the ant hill to the food source and back guided *only* by pheromones.

Specifically, some (less quantifiable) synergy was achieved deviating from the biological model applied in the Elitist Ant Systems by adding symbolic processing components (firstly adapting the environment and secondly instituting limited central coordination). Focusing on affordability and keeping a definite engineering perspective, the immediate purpose of [20] was to save computer resources in applying stigmergic control to industrial problems by exploring the relationship between the number of digital ants and problem complexity. The long-range target is to follow the analogy to superconductivity: moving the threshold in order to improve performance and/or save computing resources. Since the ideal threshold is expressed by Heaviside step-functions, as asymptotes to sigmoid functions, every discrete function expressing a solution instance will be represented by a fitting sigmoid:

$$Sq = Obj/(1 + exp(Td - s)) \tag{1}$$

where: s("swarm") is the number of ants; Td ("threshold") is the value of $s$where self-organization [5] becomes manifest (the number of ants closest to the inflexion point of the sigmoid); Obj ("objective") is the optimal solution (the minimal number of iterations for reaching the optimal route given by the benchmark program); Sq ("solution quality") is the instance result, reflecting the degree of self-organization expressed through the ratio between the number of iterations for the best simulation run and the numbers of iterations for the current run (both for reaching 95% from the optimal solution). The term “swarm” was chosen for its ambiguity: it has the connotation of both “crowd” (discrete variable) and “multitude” (indefinite). Thus, it allows simplifying the language without affecting mathematical rigor (requiring a continuous domain for a sigmoid); of course, during simulations, only integer values where assigned to s, considered as cardinal of the swarm set. Td is obtained from (1):

$$Td = ln(Obj/Sq - 1) + s$$

The corresponding sigmoid for $Td = 4$ is represented in Figure 1.

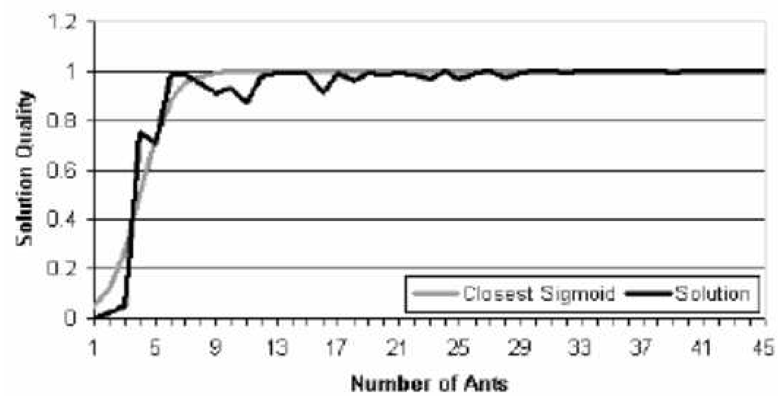

Figure 1. A very low threshold of self-organization in stigmergic coordination (taken from [20]).

As regards early validation attempts in industrial environment, synergy achieved through SC (called in [20] “Stigsynergy”) will be tested as component integrated in a more comprehensive software toolkit for virtual enterprises [27]. Tools for catalysing emergence in such projects will be described in more implementation-oriented papers.

5 Emulated Emergence

Albeit both governed by emergence, the two kinds of undertaking are quite different: whereas when *simulating* common ant behaviour, emergence is expectable also from artificial ants and – despite obvious non-linearity – their performances can be improved "incrementally" (as shown in Section 4), when *emulating* emergence the basic argument about "holism versus reductionism" transcends theory and becomes crucial for applications. Indeed, here are hidden not only the internal processes of self-organization (unanswered "Why?"), but also any "stigmas" (unanswered "How?").

Research regarding self-awareness in ABS is founded on Hofstadter's ideas [35] and was presented in: [13] (to illustrate the broadband technology potential from an anthropocentric and transdisciplinary perspective); [15] (in a larger interdisciplinary framework); [16] (focusing on computer science aspects, and keeping a definite engineering perspective); [47] (offering an alternative approach to e-Learning, where "*Learning*" is action-oriented and highly personalised, while "*e*−" is carried out through a software entity acting as self-referencing coach and interacting with the user as interface agent). The outline below follows [16]. Since the target is a generic architecture – based on Gödelian self-reference (GSR) – for applications meant for present-day environments (i.e., OHDUE), the key question is one of viability: is it suitable to consider self-awareness as relevant agent feature when many other strong agency characteristics are missing, even in current large-scale ABS? Yes, because: system complexity makes it desirable [24] [2] [4] [22] [40] [41] [42], agent technology makes it possible [1] [30] [36], and approaching it by GSR (the agent clones itself – usually spawning better architecture) makes it affordable. Albeit the "Self-*" memeplex invaded modern IT and despite memetic likeness, the "duplicate me" [38] instructions in the genotype and the "I clone myself" message in Figure 2 are fundamentally different. Agent self-cloning means spawning an agent identical to its parent. An example at implementation level (for systems with Windows-like application programming interface): the parent-agent main thread calls a "*CreateThread*" system function [12] passing itself as parameter. It is expectable that such self-reference could be a matrix for "strange loops", which in turn could lead to a stepwise emergence of (a primitive kind of) self-awareness, hoping that "Isomorphisms Induce Meaning" [35]. If this expectation should be too great, at least GSR should provide a workable mechanism for improving agent architecture (as "Plan B" for real-world applications, as used in [47]). Self-cloning is conservative: the agent clones itself, preserving self-representation (its "I"), but not necessarily its old world model too. Instead, the model is regenerated through "phenotypical expansion", in short through elementary learning: as the agent learns, it fills out the ontology (the black part of its rucksack), and, when assessing a significant improvement, it transfers the latest assimilated knowledge into the executable program representing statically the agent (i.e. into its "genotype") by cloning itself. Here lies the weakest link of the generic architecture, since filling out ontologies for real world problems is resource demanding (because it takes much time, it is the only key application component still in the stage of suiting only toy problems). This drawback is somewhat balanced by attractive features, as assigning semantic value to the iconic space (e.g., in the context of computer-aided semiosis in trans-cultural interfaces [18]).

From the pragmatic perspective of an application, the process is seen rather as spawning "smarter progeny" (as shown for e-Learning in [47]). Evolution is assessed through a performance metrics suited to action-oriented "Simon-type machine learning" [52] [3] (i.e., the diminishing duration of task completion).

Hence, in emulating emergence there are two key problems: a) *Feasibility*. Is the hypothesis valid? For instance, in nature (humans included) is self-awareness emerging from strange loops? b) *Effectiveness*. How can be the expected feature modelled? For instance, can agent self-awareness stem from GSR? Corollary: a "Plan B" is mandatory to save the undertaking as applied research when the basic target is too far. As a result, the e-Learning application [47] is designed to be useful

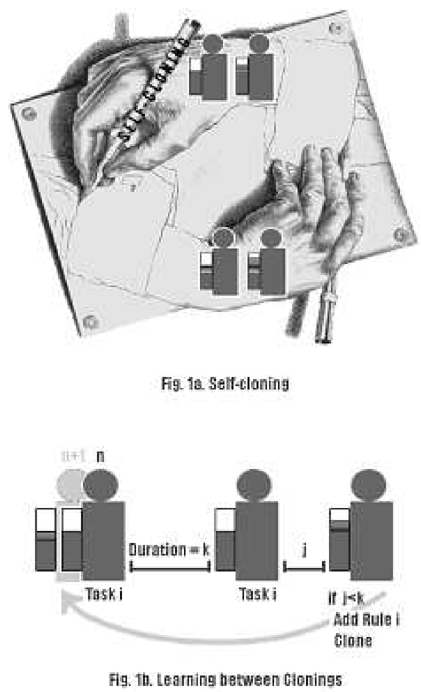

Figure 2. The Self-Cloning Loop: Doing, Learning, Knowing, Cloning (taken from [16]).

even if agent self-awareness is not yet achieved: learning is considered – in both humans and agents – as a process where most effectiveness is reached through a blend of symbolic ("left-hemisphere"-like) and subsymbolic ("right-hemisphere"-like) modi operandi. Hence, neither "apprenticeship learning", nor "by rote learning". However, the two extremes, albeit equally dangerous, are not similarly hard to fight: at least in Romania, nowadays, the average approach to learning is much closer to "by rote". Thus, the balance is redressed, favouring right hemisphere tactic, i.e., "non-algorithmic" course of action. Fortunately, that does *not* imply necessarily "sub-symbolic", because: a) Symbolic processing is unavoidable in any learning process (fact rejected only by radical cognitive theories denying knowledge decomposition and decontextualization [3]). b) Anthropocentric interfaces require symbolic human-computer communication. c) As asserted in Section 3, massive parallelism is hardly affordable.

6 Conclusions and Future Work

The results in both directions appear as promising and reveal significant potential for transdisciplinarity as well as for teamwork. Since it is an ongoing research, the conclusions are grouped in three time ranges: A) *short* (relevant results obtained with current experimental models), B) *medium* (directions for future work likely to be successful), and C) *long* (engineering and scientific openings):

A1. As regards *simulated emergence*, the experimental model attested that the threshold *exists* and depends on problem *type* and *complexity*; the same solution quality can be obtained with fewer ants than used in common benchmarks. Moreover, combining *stigmergic control* with *symbolic processing* components has significant synergistic potential (the most useful mechanism proved to be "*User-Driven Heuristics*").

A2. As regards *emulated emergence*, the current agent endorses the model, and, mainly, the usefulness of self-cloning. Its generic architecture proved to be affordable for toy problems (inductive non-algorithmic e-Learning) and the model was not difficult to implement (the only exception: filling out dynamic ontologies, even for primitive toy problems is hard work and risky outside an authentic transdisciplinary effort). In short, "Plan B" is viable.

B1. For *stigsynergy*, despite insufficient statistical relevance, it seems that: a) The sigmoid pattern seems credible because it is similar to – or, at least, consistent with – trustworthy results regarding exponential convergence [49]. This similarity is significant because both the target (*performance* vs. *affordability*) and the approach (systems achieving *global ends based on local behaviour* vs. the *principles of synergetics*) were different. b) From an engineering perspective, in operational research, comparable solution quality could be obtained with a significantly less number of ants than used in common benchmarks, saving thus at least one order of magnitude of processing time. c) The results remind the von Neumann theorem for the complexity threshold (e.g., a map with only 14 towns proved to be too simple to allow self-organization).

B2. For emulating *agent self-awareness*, the main hindrance imposed by affordability restrictions is the purely software, bodiless, agent nature: the agent will lack the awareness of its own body, crucial for the somatoception-based self-representation achievable by robots. Hence, the expected emergence of a primitive "I" should be catalysed through a powerful temporal dimension and an emphasised non-algorithmic behaviour: the main feature to be added to usual interface agent architecture and preserved through self-cloning is its primal sense of time (besides its intrinsic architectonic value, it could be helpful in future "pseudosomatoception" as surrogate for the lacking sense of space and haptic proprioception).

C1. a) From an engineering perspective it is worthwhile to try to exploit the analogy between self-organization in *stigmergic coordination* and in *electromagnetism*, based on the correspondences:

problem solving vs. superconductivity; number of digital ants vs. absolute temperature; solution quality vs. conductivity. The target would be to lower the threshold of self-organization for operational research problems modifying the macro-parameter M (M stays for *Model* in SC and for *Material* in electromagnetism). b) From a scientific perspective it seems attractive to find out whether in the real world, natural and digital beings live in, there are relevant problem classes (or, more general, processes) where "many starts from four" (as the results for 45 towns in Figure 1 may suggest).

C2. From a computer science perspective it is much too soon to claim that agents could achieve self-awareness through Gödelian self-reference *per se*. (Nevertheless, first indices mentioned in A2 and B2 are rather encouraging.) improve agent architecture, first of all its dynamic ontology, sense of time and reactivity (it should be much more event-driven).

C3. Complexity as macro-parameter must be better investigated: a) For *stigmergic coordination* besides the number of ants and the number of towns, probably other factors (e.g., map topology, anisotropic graph edges) can play a major role. b) For self-referencing agents a much improved architecture – first of all their dynamic and visual ontology, sense of time and reactivity (they should be much more event-driven) – could help emulating the autocatalytic process of self-awareness.

C4. Since synergy is essential fundamental in both proposed approaches, and transdisciplinarity is a primary source, a second-degree synergy (a kind of "synergy of synergies" expressed as second derivative) may appear, creating relationships closer to the ideas of Aristotle and Lao Zi, than to those of Haken.

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An edge colouring of multigraphs

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Abstract

We consider a strict *k-colouring* of a multigraph $\boldsymbol{G}$ as a surjection f from the vertex set of $\boldsymbol{G}$ into a set of colours $\{1,2,\ldots,k\}$ such that, for every non-pendant vertex x of $\boldsymbol{G}$, there exist at least two edges incident to x and coloured by the same colour. The maximum number of colours in a strict edge colouring of $\boldsymbol{G}$ is called the *upper chromatic index* of $\boldsymbol{G}$ and is denoted by $\overline{\chi}(\boldsymbol{G})$. In this paper we prove some results about it.

1 Introduction

Let $\boldsymbol{G}$=(X,$\mathbf{E}$) be an arbitrary multigraph. A *strict edge k-colouring* of $\boldsymbol{G}$ is a surjection f from the edge set $\mathbf{E}$ into a set of colours $\{1,2,\ldots,k\}$ such that, for every non-pendant vertex x of $\boldsymbol{G}$, there exist at least two edges incident to x and coloured by f with the same colour.

Following the definition, the minimum number of colours in a strict edge colouring of a multigraph is one. This is a complementary fashion of the fact that, in the classical edge colouring, the maximum number of colours is trivially equal to the number of edges of the multigraph.

The maximum number k for which there exists a strict edge k-colouring of a multigraph $\boldsymbol{G}$ is called the *upper chromatic index* of $\boldsymbol{G}$ and is denoted by $\overline{\chi}(\boldsymbol{G})$. An edge colouring of $\boldsymbol{G}$ which uses exactly $\overline{\chi}(\boldsymbol{G})$ colours is called a *maximal edge colouring.*

2 Main results

Theorem 2.1 - *Let $\boldsymbol{G}_1$,$\boldsymbol{G}_2$ be two disjointed multigraphs, x a vertex of $\boldsymbol{G}_1$ such that $d(x)\geq 2$, y a vertex of $\boldsymbol{G}_2$ such that $d(y)\geq 2$, σ a simple path from x* to *y with no edge in common with $\boldsymbol{G}_1$ and $\boldsymbol{G}_2$, $\boldsymbol{G}=\boldsymbol{G}_1\cup\boldsymbol{G}_2\cup\sigma$. Then $\overline{\chi}(\boldsymbol{G})=\overline{\chi}(\boldsymbol{G}_1)+\overline{\chi}(\boldsymbol{G}_2)+1$.*

Proof. Let be $h=\overline{\chi}(\boldsymbol{G}_1)$, $k=\overline{\chi}(\boldsymbol{G}_2)$ and let f be a strict edge h-colouring of $\boldsymbol{G}_1$, g a strict edge k-colouring of $\boldsymbol{G}_2$ with no colour in common. Since we can obtain a strict edge $h+k+1$-colouring of $\boldsymbol{G}$ simply by giving to all the edges of the path jointing x and y a colour distinct from all the colours of f and g, then $\overline{\chi}(\boldsymbol{G})\geq h+k+1$.

Suppose that $\overline{\chi}(\boldsymbol{G})\geq h+k+2$. Then there exists an edge p-colouring f of $\boldsymbol{G}$, with $p\geq h+k+2$. Since the edges of σ must be coloured with the same colour, the number of colours of f in the multigraph $\boldsymbol{G}_1$ is not less than $h+1$ or the number of colours of f in the multigraph $\boldsymbol{G}_2$ is not less than $k+1$, that's false. So $\overline{\chi}(\boldsymbol{G})=h+k+1$. □

Theorem 2.2 - *If $\boldsymbol{G}$ is an eulerian multigraph and P is an edge partition of $\boldsymbol{G}$ in cycles, then $\overline{\chi}(\boldsymbol{G})\geq|P|$.*

Proof. For an eulerian connected multigraph, there exists, as it is well known, a partition as P. Observe that it is possible to give the same colour to all the edges of every cycle of P and colours pairwise distinct to every cycles of P. □

Remarks

1) Considering theorem 2.2, there exist cases in which $\overline{\chi}(\boldsymbol{G})>|P|$. It suffice to examine a simple graph $\boldsymbol{G}$ with 6 vertices formed by two cycles of length 4 having two vertices and no edge in common: since every vertex has even degree, this graph is eulerian and $\overline{\chi}(\boldsymbol{G})=3$.

2) Observe that, if every cycle of the partition P has exactly one vertex in common with exactly one other cycle of P, then the graph is simple and $\overline{\chi}(\boldsymbol{G})=|P|$.

M. Gionfriddo, L. Milazzo, V. Voloshin proved [4] the following theorems:

Theorem 2.3 - *Let* $\boldsymbol{G}$=(X,**E**) *be an arbitrary multigraph*, *c the maximum number of disjoint cycles*, *p the number of pendant vertices of* $\boldsymbol{G}$. *Then*

$$\overline{\chi}(\boldsymbol{G}) = c + |\mathbf{E}| - |\mathrm{X}| + p$$

Corollary 2.4 - *For a graph* $\mathbf{K}_n$ *with* $n \geq 3$, *we have*:

$$\begin{cases} \overline{\chi}(\mathbf{K}_n) = \frac{9k^2-7k}{3} & \text{if} \quad n = 3k \\ \overline{\chi}(\mathbf{K}_n) = \frac{9k^2+k-2}{2} & \text{if} \quad n = 3k+1 \\ \overline{\chi}(\mathbf{K}_n) = \frac{9k^2+5k-2}{2} & \text{if} \quad n = 3k+2 \end{cases}$$

Now we can prove the following

Corollary 2.5 - *For a graph* $\mathbf{K}_{m,n}$ *with* $1<m \leq n$, *we have*:

$$\begin{cases} \overline{\chi}(\mathbf{K}_{m,n}) = \frac{2mn-2n-m}{2} & \text{if } m \text{ is even} \\ \overline{\chi}(\mathbf{K}_{m,n}) = \frac{2mn-2n-m-1}{2} & \text{if } m \text{ is odd} \end{cases}$$

Proof. Observe that the maximum number of disjoint cycles of $\mathbf{K}_{m,n}$ is $\frac{m}{2}$ if m is even and $\frac{m-1}{2}$ if m is odd. Since $\mathbf{K}_{m,n}$ has $m+n$ non pendant vertices and mn edges, the statement follows by simple calculating from theorem 2.3. □

In the case $m=n$, we have:

$$\begin{cases} \overline{\chi}(\mathbf{K}_{n,n}) = \frac{2n^2-3n}{2} & \text{if } n \text{ is even} \\ \overline{\chi}(\mathbf{K}_{n,n}) = \frac{2n^2-3n-1}{2} & \text{if } n \text{ is odd} \end{cases}$$

Theorem 2.6 - *For every tree* $\boldsymbol{A}$=(X,**E**), *we have*

$$\overline{\chi}(\boldsymbol{A}) = \sum_{x \in X} (d(x) \div 2) + 1$$

where, for every m,$n \in \mathbf{N}$, $m \div n = m - n$ *if* $m \geq n$ *and zero otherwise.*

Proof. Let r be a root of the tree. Observe that every maximal edge-colouring f of $\boldsymbol{A}$ has the property that, for every vertex x of $\boldsymbol{A}$ with $x \neq r$ and $d(x) > 2$, there exist exactly $d(x)$-2 edges incident to x coloured by f with colours pairwise distinct. Since for every pendant vertex y of $\boldsymbol{A}$, $d(y) \div 2 = 0$, the statement of theorem follows. □

Before introducing theorem 2.7, we will call *p-tree of height h* a tree defined by induction in the following way:

1) A vertex is a p-tree of height 0;

2) A p-star is a p-tree of height 1;

3) For $h \geq 2$, we call a p-tree of height h a tree obtained from a p-tree $\boldsymbol{A}$ of height h-1 by connecting every pendant vertex of $\boldsymbol{A}$ with p other vertices.

Theorem 2.7 - *For a p-tree* $\boldsymbol{A}$ *of height h with* $p \geq 2$, *we have* $\overline{\chi}(\boldsymbol{A}) = p^h$-1.

Proof. By induction. If h=1, the statement is trivially true. Let be $h > 1$ and suppose the statement true for every p-tree of height h-1. From a p-tree $\boldsymbol{A}'$ of height h-1 and from a maximal edge colouring f of $\boldsymbol{A}'$ we can obtain a p-tree $\boldsymbol{A}$ of height h and a maximal edge colouring g of $\boldsymbol{A}$ by adding p^h vertices and p^h edges, from which at most $(p\text{-}1)p^{h-1}$ can be coloured by colours pairwise distinct from the colours used by f. Therefore $\overline{\chi}(\boldsymbol{A}) = \overline{\chi}(\boldsymbol{A}') + (p\text{-}1)p^{h-1} = p^{h-1}\text{-}1 + (p\text{-}1)p^{h-1} = p^h\text{-}1$, and so the assertion follows. □

Remarks

1) It is possible to prove theorem 2.7 starting from theorem 2.6. In fact, in a p-tree of height h with $p \geq 2$, there are 1 vertex with degree p, $\frac{p^h-1}{p-1}$-1 vertices with degree p+1 and p^h pendant vertices, so that:

$$\overline{\chi}(\boldsymbol{A}) = \sum_{x \in A}(d(x) \div 2) + 1 = (\frac{p^h - 1}{p - 1} - 1)(p - 1) + p - 2 + 1 = p^h - 1$$

2) If we apply theorem 2.3, we obtain simply the statement of the-

orem 2.7 by observing that a tree is acyclic and the number of pendant vertices of a p-tree of height h is p^h.

Corollary 2.8 - *For a p-tree* $\boldsymbol{A}$ *with* $p \geq 2$ *and* n *vertices, we have* $\overline{\chi}(\boldsymbol{A})=(n\text{-}1)(1\text{-}\frac{1}{p})$.

Proof. Let h be the height of $\boldsymbol{A}$. Since $n=\frac{p^{h+1}-1}{p-1}$, we obtain $n=\frac{p(\overline{\chi}(\boldsymbol{A})+1)-1}{p-1}$, from which, by a simple calculation, the statement follows. $\square$

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Generalized Priority Models for QoS and CoS Network Technologies *

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Abstract

The variety of priority queueing systems with random switchover times is suggested in this paper. Such systems represent generalized models for a wide class of phenomena which involve queueing and prioritization and are considered in QoS and CoS network problems. The classification of such systems is given and methods of their analysis are discussed. Specialists in QoS and CoS technologies may find such models adequate and appropriate for the network traffic analysis.

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Quality of Service (QoS) and *Class of Service* (CoS) technologies play nowadays a crucial role in the analysis of a network traffic, which is highly diverse and may be characterized in terms of *bandwidth*, *delay*, *loss*, and *availability*. Some more specific characteristics can also be considered.

Most of the network traffic is IP-based today. On the one hand it is beneficial, as it provides a single transport protocol and it simplifies maintaining of the hardware and software products. However, IP-based technologies have some drawbacks. First of all, under the IP protocol network packets are delivered through the network without taking any specific path. This results in the unpredictability of the quality of service in such networks.

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However, today, networks deal with so many types of traffic, that these may interact in a very unfavorable manner while being transmitted through the network. QoS and CoS technologies serve to ensure that diverse applications can be properly supported in an IP-network, i.e. see [21]. This is achieved by distinguishing between different types of data and by managing them using the mechanisms of data prioritization.

We consider in this paper a diverse class of priority queueing systems involving switching to describe, model and analyze phenomena which involve prioritized queueing and may take place in the studied or designed network. We suggest that some performance characteristics of such priority queueing systems can be used for estimating and providing a respective Quality of Service.

In the following section we discuss briefly the QoS and CoS methodologies and their applications in analyzing and modeling networks.

We further discuss the priority queueing disciplines in details, then introduce the most important characteristics of such systems and indicate on the methods of their analytical and numerical study. We also give a brief description of the imitation modeling of such priority systems.

In the last section we consider an example of usage of such systems, and, in particular, we discuss the benefits of using them for obtaining QoS in WLANs.

1 QoS and CoS methodology in network traffic analysis

1.1 Quality of Service and Class of Service

Quality of Service is a general concept referring to the capability of a network to provide better service to selected network traffic over various technologies, including *Frame Relay*, *Asynchronous Transfer Mode* (ATM), *Ethernet* and *802.1 networks*, *SONET*, and IP-routed networks that may use any or all of these underlying technologies (e.g. [7]).

Define by a *flow* in a broad sense a combination of packets passing through a network. Basically, QoS enables to provide in a network a better service to certain flows by assigning the higher priority of a flow or limiting the priority of another. This can be done in different ways: mostly by designing corresponding queue management mechanisms.

One can represent the basic QoS architecture by the following three components and steps [7]:

- QoS marking techniques for coordinating QoS from end-to-end between network elements

- QoS within a single network element (e.g. queueing, scheduling, traffic-shaping tools)

- QoS policy, management and accounting functions to control and administer end-to-end traffic across a network

We refer in this paper mostly to a QoS of a single network element (i.e. to a second step of the QoS providing architecture scheme given above).

QoS within a single network element, or node, can be specified by a *congestion management*, *queue management*, *link efficiency*, and shaping/policing tools.

The Class of Service concept is a concept of the flow network traffic division into different classes. This concept provides class-dependent service to each packet in a flow, depending on which priority class it does belong to (see [24]). CoS provides end-to-end prioritization for frame relay and ATM traffic over IP networks. In a framework of CoS traffic is prioritized by setting the *Differentiated Services* code in the header of an IP data packet.

1.2 Prioritization in Information Systems

As we saw, the prioritization plays the crucial role in QoS and CoS technologies.

In information networks it is desirable to provide shorter waiting times for control packets (packets that contain information about network status), voice connection packets, and packets associated with messages which should be delivered urgently.

There are many ways to attribute preferences. However, on a conceptual level, there are not so many ways to provide preferential service in a queueing system or queueing network. In Section 2 we describe a wide range of service disciplines in priority queueing systems involving switching between flows.

For examples and more account on prioritization and its forms the reader is referred to [2]. Description of some queueing disciplines implemented at nodes of an ad hoc network can be found in [16]. QoS in ad hoc networks and mechanisms of data prioritization in such networks is discussed in [1], [25] and references therein.

1.3 Priority Queueing Systems in QoS and CoS analysis, modeling and design of networks

The mathematical models of queueing systems play an important role in analysis, modeling and design of various networks, including Wireless Local Area Networks (WLAN). The IEEE 802.11 standards, widely used in WLAN, are playing a more and more important role in building of the concepts of the Next Generation of Mobile Networks. Some specific queueing models are still proposed for network management and performance analysis based on mentioned technologies (see, e.g., [20]).

It appears that one of the important problems on the way to next generations of Mobile Networks will be a problem of providing enhanced mechanisms for the delivery of QoS and CoS facilities. The QoS is very relevant in WLAN, due to the growing demand, even in the case of mobile users, for multimedia applications, such as streaming video and teleconferencing. Recently pursued standardization efforts in IEEE 802.11e attempt to provide a level of service differentiation by statically associating different QoS parameters for pre-defined traffic classes, while CoS enables more predictable traffic delivery by assigning different delivery status for each application. For example, a first priority label can be assigned to data application which requires faster turnaround, such as mission-critical data transaction, video or voice transmission, etc. A lower priority label is assigned to less time sensitive traffic, such as e-mail or web-surfing.

To summarize, there are two ways of achieving a certain level of quality of service in networks: (i) by increasing bandwidth (which is not always possible), and (ii) by adding complicated QoS and CoS traffic management mechanisms.

What do we offer? We offer the modeling of the processes which take place at the nodes of a network (or any other phenomena involving prioritized queueing) by generalized priority queueing systems with random switchover times, where appropriate. QoS parameters defined to measure service quality include traditional parameters such as *latency* (delay and delay jitter), *packet loss-rate*, and *throughput* (allocated bandwidth). There are also parameters that are more related to wireless networks, as *varying channel conditions*. We believe, that these parameters can be estimated more appropriately by representing all the processes involving queueing and waiting phenomena and taking place in a network (network nodes' processes, switching). Analysis of the performance characteristics of such queueing systems can significantly help in understanding of the network design, analysis and modeling in order to provide higher QoS level.

Thus, we do not point any attention on the traffic management mechanisms. Assuming that a certain mechanism is chosen to be considered we only provide a way of representing any prioritized queueing process and suggest that performance characteristics of the service process in such queueing system may be used in estimation of the end QoS at the level of a network by estimating QoS's within network nodes.

2 Priority queueing systems with switchover times

2.1 Introduction

Priority queueing systems form a large class of queueing systems where the incoming requests are to be distinguished by their importance. Such systems represent adequate models of many aspects of everyday life, when a preferential service is to be granted to certain kinds of requests (demands or customers). Priority queueing systems have also found important applications in the modeling and analysis of computer and communication systems: packets transfer and routing in computer networks, distributed operations and calculations (multiprocessor OS's, etc), telephone switching systems and mobile phone networks. Some civil services (surgeries, ambulances, fires, etc.) can also be modeled using the concept of priority queueing systems.

The general rule of service in priority queueing systems is as follows: the requests which are in the system and have a higher priority should be served before those that have lower priorities. However, the mode of the device's behavior in such systems may essentially diversify them. In addition, there are systems where device needs some time to switch itself from the servicing of one kind of requests to another. All this gives a great variety of the considered systems. Accordingly to these phenomena the description and classification of the priority queueing systems is given below in the great generality.

2.2 Notations, systems description and classification

The classification given here takes its origin from the works of Klimov and Mishkoy [17], and Bejan and Mishkoy [4].

Consider a queueing system with a single device and r classes of incoming requests, denoted by *class 1*, *class 2*, ..., *class* r, each having its own flow of arrival and waiting line. Requests of a particular class are served on one of the two following bases within their own line:

- a first-in-first-out basis (FIFO);

- a last-in-first-out basis (LIFO).

Suppose that the time periods between two consecutive arrivals of the requests of the class i are distributed identically and have a cumulative distribution function (cdf) $A_i(t)$, $i = 1, \ldots, r$. Similarly, suppose that the service time of a customer of the class i is a random variable (rv) B_i with a cdf $B_i(t)$, i.e.

$$\mathbb{P}(B_i \leq t) = B_i(t),\ i = 1, \ldots, r.$$

For conciseness let us call the requests of the class i by *i-requests*. We say that i-requests have a higher priority than j-requests if $1 \leq i < j \leq r$. Thus, 1-requests are the requests of the highest priority, whereas r-requests are of the lowest one. Device gives a preference in service to the requests of the highest priority among those presented in the system.

However, some time is needed for the device to proceed with a switching from one line of requests to another. This time is considered to be a random variable and we say that C_{ij} is the time to switch from the service of i-requests to the service of j-requests, $1 \leq i \leq r$, $1 \leq j \leq r$, $i \neq j$. Refer further to C_{ij} as *ij-switchover time* with a cdf $C_{ij}(t)$.

Sometimes it is plausible to view the temporal structure of the switchover time C_{ij} as a sum of two independent periods:

$$C_{ij} = T_i + S_j,\ i \neq j, \tag{2.1}$$

where T_i is a (random) time of **t**ermination of all service procedures referring to the class i, and S_j is a (random) time of the arrangements the device may need to **s**tart servicing the j-requests. Technically, this phenomenon may be imagined as device's passing through a special *neutral* or *null state* – while proceeding with the ij-switching the device needs the time T_i to get to the neutral state from class i, and it needs the time S_j to get further to the class j from the neutral state. We shall call such switching policy by *neutral state switching*. Under this policy the cdf's of rv's $\{T_i\}_{i=1}^r$ and $\{S_i\}_{i=1}^r$ will be some known families of functions $\{T_i(t)\}_{i=1}^r$ and $\{S_i(t)\}_{i=1}^r$.

2.2.1 Disciplines of service

Consider two disciplines of service — both traditional in the theory of priority queues: *preemptive service discipline* and *non-preemptive service discipline*. It is assumed under the former discipline that any request of the priority higher than the one that is being served interrupts the service process and requires device's switching to its class immediately. Under the latter discipline, the request of a lower priority level will receive a complete service after which the device will proceed with the switching, if needed. In both cases, on completion of service of the requests of some class, the device will be ready to move to the non-empty queue corresponding to the class of the highest priority level presented in the system at that moment.

Preemptive service discipline. Consider different scenarios in regard to the request whose service was interrupted:

1. *preemptive resume policy* — the interrupted request will be served the residuary period of time after device's return, i.e. the time which this request would have been served, if its service was not interrupted, from the moment of the interruption.

2. *repeat again* policies:

    - *preemptive identical repeat policy* — the interrupted request will be served again after device's return. The service time will coincide with the complete time this request would have been served if its service was not interrupted.
    - *preemptive non-identical repeat policy* — exactly as in the previous policy, but the repeat service time is new, though distributed in accordance with corresponding service law, i.e. having cdf $B_i(t)$ if the request to be served again is from class i.

3. *preemptive loss policy* — the interrupted requests will be lost and removed from the system.

Non-preemptive service discipline. There will be no immediate interruptions of requests' services under this discipline. Yet, on completion of service of each request (of several requests within a line), the device is ready to move to the non-empty queue with the highest priority level requests, if any are presented in the system and are waiting to be served. Instead of the term *non-preemptive service discipline* one can, following Gaver [9], use another name for this discipline — *postponable priority service discipline.*

The postponable priority service discipline can be of different kinds, as how the switching to higher priority requests is postponed:

1. *request postponable priority service discipline* — on completion of service of any request, the device is ready to switch to the non-empty queue of the higher priority requests.

2.
   - *exhaustive postponable priority service discipline* — the device will be ready to switch to the non-empty queue of the higher priority requests only and only when the queueing line of requests, which are being served at the moment, becomes empty.
   - *gated postponable priority service discipline* — exactly as in the *exhaustive postponable* discipline with the difference that the device will only serve those requests which came in the system before the interrupting ones.

2.2.2 Switching

One should take into account that some of the incoming demands may find the device switching to the requests of lower priority. Therefore, by analogy with the service process disciplines, distinguish between the following switching process disciplines: *preemptive switching discipline*, *preemptive neutral state switching discipline*, *non-preemptive switching discipline*, *non-preemptive neutral state switching discipline.*

Preemptive switching. Under the *preemptive switching* and *preemptive neutral state switching* disciplines any ij-switching will be immediately interrupted by k-requests, if and only if $k < j$, i.e., if some higher priority requests enter the system. After interruption a new switching to these requests is initiated. The two switching disciplines differ only in the absence/presence of the special null state — an intermediate device's state while switching (see definition of a neutral state on p. 223).

Sometimes it is plausible to consider the preemptive type of switching involving neutral state, formally as in (2.1), where the termination works T_i are never interrupted. Call such type of switching *pseudo-preemptive switching.*

Non-preemptive switching. Under the *non-preemptive switching* and *non-preemptive neutral state switching* disciplines no switching can be interrupted by higher priority demands. The latter discipline differs from the former one in the existence of an intermediate switching state — neutral state, as introduced above.

Consider the *non-preemptive neutral state switching discipline* and recall that the structure of the switching consists in this case of two paths, as given by (2.1). Suppose that the device was found by a k-request switching to the j-requests, where $k < j$, i.e. realizing some ij-switching of the length C_{ij}. This moment could fall either on one of the following two periods: switching to the null state (of the length T_i) or switching from the null state (of the length S_j). Therefore consider the following two subdisciplines:

- *normal switching* — the switching to the k-requests will be made either after switching to the null state from i-requests (and then its duration will be S_k) or after the switching from the null state to the j-requests (and then its duration will be C_{jk}).
- *postponable switching* — the switching to the interrupting k-requests is possible only after the ij-switching is completed (and lasts then the time C_{jk}).

2.2.3 Behavior of the device in the idle state

We move now to the specifications of the device's regimes in the idle state. First, regardless the regime, let us assume that the device needs some *warming time* to proceed with the switching or servicing when the first customer comes in the empty system, i.e. after a *period of* *idleness*. This warming time is a random variable W with a cdf $W(t)$. If the warming time is equal to zero (the device requires no warming), then $W(t) \equiv H(t)$, where $H(t)$ is the Heaviside function.

Following the tradition which takes its origin from the work of Gaver [10] differ within the following modes of behavior of the device when the system becomes empty:

- *set to zero* — upon the completion of service of the last request in the system the device switches immediately to the *neutral state*. If the first request which enters the empty system is a request of the priority i, then the device proceeds with the switching of the duration S_i. Obviously, this regime is well defined in the systems with the neutral state switching disciplines. However, one can define the *set to zero* regime for the systems with the "neutral state free" switching processes. For this, consider a neutral state as a special state of device's relaxation while being idle. Additional random times $\{C_i\}_{i=1}^{r}$ of post-warming switching will be required to be specified then.

- *look ahead* — the device switches itself to the 1-requests' line at the moment the system becomes empty.

- *wait and see* — the device remains switched to the queueing line of the last served request.

- *wait for the most probable* — the device switches to the flow of the most likely to appear customers. To clarify, this can be understood as follows. Let $a_i(t) = A_i'(t)$ be the density of the i-requests' inter-arrival times, $i = 1, \ldots, r$. Then, by the flow of the most likely to appear customers understand the p-requests' flow, where $p = \arg\max\limits_i a_i(t_0+)$, where

$$t_0 = \min_{i=1,\ldots,r} \sup_{a_i(t)=0} t.$$

  If p is not determined uniquely, then some additional considerations may be taken into account — for instance, p may be taken as follows:

$$p = \min\{\arg\max_i a_i(t_0+)\}. \qquad (2.2)$$

A large class of priority queueing systems is described. Essentially, it comprises the systems defined by the following information and identifiers:

- arrival flows — distributions of inter-arrival times (for each flow);
- service times — distributions of service times (for each flow);
- switching times — specification of the switching type (neutral state or not) and distributions of switching times;
- warming time — distribution of waiting times;
- order of service within a line (FIFO, LIFO);
- service discipline;
- switching discipline;
- behavior of the device in the idle state.

Adopt the generalization of the standard Kendall notation $A_r|B_r|1$ for such systems with writing of an additional information on the identifiers listed above, which specify the system.

Example 1. *The queueing systems with the Poissonian incoming flows are of great importance in the theory and practice. In this case the inter-arrival times are exponentially distributed, i.e.* $A_i(t) = 1 - e^{-\lambda_i t}$, $i = 1, \ldots, r$, *where* $\lambda_1, \lambda_2, \ldots, \lambda_r$ *are some non-negative real numbers with the physical meaning of the flow arrival rates. A typical system with the Poissonian incoming flows may be specified then as follows:* ***FIFO*** $M_r|G_r|1$ ***"neutral state"-"request postponable service discipline"-"preemptive switching" priority queueing system with the "wait for the most probable" device's regime.***

Here, the most probable requests are the p-requests, where p is determined from (2.2), i.e. $p = \min\{\arg\max_{i=1,\dots,r} \lambda_i\}$*, and it has a clear physical meaning — p is the highest priority level of the requests among those which have the greatest arrival rate.*

2.3 Characteristics of system performance

One can specify many stochastic processes taking place in the described queueing systems. Some of the characteristics of these stochastic processes are of special interest and may well serve as system performance characteristics.

Begin with the notions of *busy period* and *idle period* (or *vacation period*). Call by the *busy period* the period of time during which the device is occupied either with servicing of the requests or with the switching. The notion of busy period is intuitively absolutely clear. We shall call the periods of time which alternate busy periods by *idle periods*. It is clear that a busy period follows some idle period and vice versa.

Let $\mathit{\Pi} = \{\Pi_1, \Pi_2, \dots\}$ be consecutive busy periods of the system. Note that in $M_r|G_r|1$ models $\mathit{\Pi}$ is a sequence of independent and identically distributed (iid) random variables with some cdf $\Pi(t)$, unless it is the model with the *"wait and see"* mode of behavior of the device in the idle state. Therefore, denote the random variable which has a cdf $\Pi(t)$ by Π and refer to it as a busy period. Note that its distribution $\Pi(t)$ does not depend on the order of requests' service (FIFO, LIFO). We conjecture that all this is also true for the scheme *"wait and see"*.

Describe by vector $\mathbf{m}(t) = \{m_1(t), m_2(t), \dots, m_r(t)\} \in \mathbb{N}^{*r}$ the state of the system at time t, where $m_i(t)$ is the number of i-requests in the system at time t. Here $\mathbb{N}^* \stackrel{\partial ef}{=} \mathbb{N} \cup \{0\}$. Denote by $m(t)$ the number of all requests in the system at time t. Thus,

$$m(t) = \sum_{i=1}^{r} m_i(t).$$

Introduce also the following notations for cdf's of $\mathbf{m}$ and m:

$$P_{\mathbf{m}}(t) \stackrel{\partial ef}{=} \mathbb{P} \text{ (there are } m_i \ i\text{-requests in the system at time } t),$$

where $\mathbf{m} = (m_1, \ldots, m_r)$; and

$$P_m(t) \stackrel{\partial ef}{=} \mathbb{P} \text{ (there are } m \text{ requests in the system at time } t).$$

The following rather abstract notions of *virtual waiting time* and *virtual sojourn time* are very important in the theory of queueing systems and its applications. Consider i-requests and ask the question: what time should wait an i-request to get start served if it arrived in the system at time t? This time period can obviously be considered as a random variable. Denote it by $W_t^{(i)}$ and call *the virtual waiting time of i-requests*. Denote the cdf of $W_t^{(i)}$ by $W^{(i)}(t,\tau)$, i.e.

$$W^{(i)}(t,\tau) = \mathbb{P}(W_t^i \leq \tau).$$

Analogously, the time that an i-request would spend in the system if it entered the system at time t is a random variable denoted by V_i with cdf $V_i(t,\tau)$, i.e.

$$V^{(i)}(t,\tau) = \mathbb{P}(V_t^i \leq \tau).$$

Note that the virtual waiting and sojourn times essentially depend on the requests' service order (FIFO, LIFO).

Introduce also the notion of a *loss probability.* Let

$$P_{loss}^{(i)} \stackrel{\partial ef}{=} \mathbb{P} \text{ (an } i\text{-request will be lost)}$$

for the scheme "with losses".

Stationarity. The notion of stationarity is very important in the study of time-evolving stochastic systems. Usually the system is considered to be stationary if its behavior becomes stable and, in some sense, settled down. Many system characteristics have stationary analogues then and often these are very convenient for describing the settled system behavior after some, may be quite long, period of time.

More formal means for the study of the stationarity in the family of the systems considered here are provided by the theory of regeneration processes and embedded Markov processes. General methodology here is to discern some underlying, embedded process, say a (continuous) Markov chain, in the main stochastic process, described, for example, by vector $\mathbf{m}(t)$, and then to impose some restrictions on the system parameters to obtain the condition of stationarity. Often such condition is just sufficient and usually it can be formulated in terms of some quantity ρ which is then to be called a *system workload*, or *traffic coefficient*. We shall call it a *node traffic coefficient*. Standard form of expressing the stationarity of the system is an inequality of the following form:

$$\rho < 1. \tag{2.3}$$

In the following section we will again point out the importance of this characteristic for the network traffic analysis.

3 Performance characteristics of priority systems with switchover times

3.1 Busy period

The definition of the busy period in priority queueing models involving switching is given in §2.3.

3.1.1 Motivation

The notion of the busy period is a very important notion. It is really important to know how busy periods are distributed in order to evaluate the system performance and the load of the device.

It may also be useful and necessary to evaluate the busy periods when we want to find some other characteristics of a queueing system, such as queue length or server's state, for instance.

Let $P_{\mathbf{m}}(t)$ be the probability of the event "there are $\mathbf{m} = (m_1, \ldots, m_r)$ requests in the system at time t." Define $P(z,t) \stackrel{\partial ef}{=}$

$\sum_{\mathbf{m}\geq 0} P_{\mathbf{m}}(t) z^{\mathbf{m}}$, where $z^{\mathbf{m}} = z_1^{m_1} \ldots z_r^{m_r}$, $z_i \in [0,1]$. Then, the Laplace-Stieltjes transform

$$p(z,s) = \int_0^\infty e^{-st} dP(z,t)$$

of this generating function may be determined with a help of the following

Theorem 2. *([19]) The Laplace-Stieltjes transform $p(z,s)$ of $P(z,t)$ in $M_r|G_r|1$ can be found as follows:*

$$p(z,s) = \frac{1+\sigma\pi(z,s)}{s+\sigma-\sigma\pi(s)},$$

where $\sigma\pi(z,s) = \sigma_r\pi_r(z,s)$ may be determined from the following recurrent equation

$$\begin{aligned} \sigma_k\pi_k(z,s) &= \sigma_{k-1}\pi_{k-1}(z,s) + \gamma_{k-1}(s,z)\nu_k(z,s) \qquad (3.1)\\ &+ \frac{h_k(z,s)}{z_k - h_k(s+[\sigma-\lambda z]_k)}[\gamma_{k-1}(s,z)\nu_k(s+[\sigma-\lambda z]_k)\\ &+ \sigma_{k-1}\pi_{k-1}(s+\lambda_k) - \sigma_k\pi_k(s)], \text{ where}\\ \gamma_{k-1}(s,z) &= \sigma_{k-1}[\pi_{k-1}(s+[\sigma-\lambda z]_k) - \pi_{k-1}(s+\lambda_k)] + \lambda_k z_k, \qquad (3.2) \end{aligned}$$

and $[\sigma-\lambda z]_k := \sum_{i\leq k} \lambda_k(1-z_k)$; h_k and ν_k should be specified for a certain discipline (e.g., see Theorem 3). Here $\sigma_k := \sum_{i=1}^{k} \lambda_i$.

In this theorem h_k is a LST of a *k-service period* H_k — the time which starts when a k-request enters the server and finishes when the server is ready to serve the next k-request queueing in a respective waiting line; ν_k is a LST of *k-switching period* N_k — the period of time starting from the switching to k-requests' waiting line and ending when the server is ready to serve k-requests.

To summarize: to know how the busy periods are distributed is to be able to evaluate many other system performance characteristics.

3.1.2 Traffic coefficient and the generalized Kendall equation

We give here more details on node traffic coefficient and its connection with busy period in systems $M_r|G_r|1$. We assume, that $C_{ij} \equiv C_j$, independently on i.

The following result is due to Mishkoy [19].

Theorem 3. *For the system $M_r|G_r|1$ under preemptive discipline and scheme "with losses" the following equations hold*

$$\pi_k(s) = \frac{\sigma_{k-1}}{\sigma_k}[\pi_{k-1}(s+\lambda_k) + \delta_{k-1}(s)\nu_k(s+\lambda_k[1-\bar{\pi}_k(s)])] + \frac{\lambda_k}{\sigma_k}\pi_{kk}(s), \tag{3.3}$$

$$\pi_{kk}(s) = \nu_k(s+\lambda_k[1-\bar{\pi}_k(s)])\bar{\pi}_k(s), \tag{3.4}$$

$$\bar{\pi}_k(s) = h_k(s+\lambda_k[1-\bar{\pi}_k(s)]), \tag{3.5}$$

$$\nu_k(s) = \frac{c_k(s+\sigma_{k-1})}{1-\frac{\sigma_{k-1}}{s+\sigma_{k-1}}[1-c_k(s+\sigma_{k-1})]\pi_{k-1}(s)}, \tag{3.6}$$

$$h_k(s) = \beta_k(s+\sigma_{k-1}) + \frac{\sigma_{k-1}}{s+\sigma_{k-1}}[1-\beta_k(s+\sigma_{k-1})]\pi_{k-1}(s)\nu_k(s),\ k=1,\ldots,r, \tag{3.7}$$

$$\pi_0(s) = 0. \tag{3.8}$$

The condition of stationarity is

$$\rho_r = \sum_{k=1}^{r} \lambda_k b_k < 1, \tag{3.9}$$

where $b_1 = \frac{\beta_{11}+c_{11}}{1+\lambda_1 c_{11}}$, *and*

$$b_i = \Phi_1 \ldots \Phi_{i-1}\frac{1}{\sigma_{i-1}c_i(\sigma_{i-1})}[\frac{1}{\beta_i(\sigma_{i-1})}-1], \tag{3.10}$$

$$\Phi_1 = 1, \tag{3.11}$$

$$\Phi_i = 1 + \frac{\sigma_i - \sigma_i\pi_{i-1}(\lambda_i)}{\sigma_{i-1}}[\frac{1}{c_i(\sigma_{i-1})}-1]. \tag{3.12}$$

Here ρ_r is nothing but the node traffic coefficient ρ.

The condition (3.9) means that $\Pi(t)$ is a proper cdf, i.e. busy periods are almost surely of finite length. This is an important condition for the QoS traffic analysis, as it is useful for nodes' overloading control.

Note, that the moments of both cycles and busy period may be easily obtained by differentiating their Laplace-Stieltjes transforms at zero. Note also, that the equations (3.3) and (3.5) can be viewed as generalizations of the classical Kendall equation for the LST of busy period in $M_r|G_r|1$. It is really necessary to solve the system (3.3)-(3.8) for the values of $\pi_i(\lambda_i)$ as these are required for the evaluation of the traffic coefficient. Moreover, if one has to get more complete information about distribution of busy periods, then one should be able to solve the mentioned system at any non-negative point s and to invert (numerically) the Laplace-Stieltjes transform.

3.1.3 Examples and numerical methods

Consider the systems of described above type with "degenerated" (i.e. null, zero) orientation time. The following typical result is known from [11] (we give it in a short form, more suitable for our needs now).

Theorem 4. *In $M_r\,|G_r|\,1$(scheme "with losses") the following system of functional equations*

$$\begin{cases} h_k(s) = \beta_k(s+\sigma_{k-1}) + \frac{\sigma_{k-1}}{s+\sigma_{k-1}}[1-\beta_k(s+\sigma_{k-1})]\pi_{k-1}(s), \\ \pi_{kk}(s) = h_k(s+\lambda_k-\lambda_k\pi_{kk}(s)), \\ \pi_{ki}(s) = \pi_{k-1,i}(s+\lambda_k-\lambda_k\pi_{kk}(s)),\ i=1,\dots,k-1 \\ \sigma_k\pi_k(s) = \sum\limits_{j=1}^{k}\lambda_j\pi_{kj}(s) \end{cases}$$

determines unique functions $h_k(s), \pi_{ki}(s), \pi_k(s)$ $(i,k=1,\dots,r)$, which are analytical in the half-plane $\Re s>0$, where $|h_k(s)|<1$, $|\pi_{ki}(s)|<1$, $|\pi_k(s)|<1$. Moreover, if $\rho := \lambda_1\beta_{11} + \sum\limits_{j=1}^{k-1}\frac{\lambda_{j+1}}{\sigma_j}[\frac{1}{\beta_{j+1}(\sigma_j)}-1] \le 1$ then $h_{k+1}(0)=\pi_{ki}(0)=\pi_k(0)=1$, and no one equality holds otherwise. Here $\beta_{11} := \int\limits_0^\infty t dB_1(t)$ and $\pi_0(s)\equiv 0$.

Functions $\pi_k(s), \pi_{ki}(s)$ included in the expressions above are LST's of cdf's of some supplementary time intervals. Specifically, $\pi_r(s)$ is nothing but a $\mathcal{LS}[\Pi(t)]$, i.e. the Laplace-Stieltjes transform of the cdf $\Pi(t)$. Note, that this theorem can be easily derived from the more general result provided by Theorem 3.

These examples of relatively simple priority queueing models show that it is necessary to develop numerical methods of their analytical description.

For some of the described schemes such numerical algorithms have already been developed and applied in [3]. The work is in progress to provide the numerical algorithms for all the schemes from the classification given in Section 2.

4 The problem of the input flow type and imitation modeling of priority queueing systems

In the previous section we have proposed a wide range of priority queueing models to describe processes taking place in communication and information networks. As it has been already pointed out, in order to design better communication network and to provide higher level of quality of service, it is really important to be able to evaluate network performance parameters. We concentrated ourselves on node traffic characteristics and we described complex priority queueing models with switching.

One of the crucial cornerstones of queueing theory traditionally was the assumption that queues and incoming requests can be modeled as continuous-time Markov chains. Alternatively, one can distinguish an embedded Markov chain and still perform the analysis of a system. This allowed to make extensive use of the exponential distributions and memoryless properties in the study of such systems.

However, it has been recently discovered that, in practice, flows of incoming requests in queueing systems may exhibit some additional statistical properties that cannot be ignored in the theory. For instance, it has been found that traffic in communication networks can exhibit such phenomena like *self-similarity*, *long-range dependence* and *burstiness*. In such cases development of traffic models is more sophisticated and analytical methods became less powerful. Zwart [28] notes that a careful statistical analysis in [18] showed that Ethernet LAN traffic at Bellcore exhibits these properties. It also behaves extremely bursty on a wide range of time scales. Among other sources that confirm that discussed phenomena take place in today traffic we mention [5], [22], [23], [26], [27].

Yet, one of the alternative ways of study of such systems is the method of *imitation modeling*. One can choose different tools and methodologies to use this method in the context of telecommunication technologies, and, particularly, in the context of wireless systems: [8], [13] (using OPNET), [14] (using stochastic Petri nets), etc.

We only concentrate ourselves here on the priority systems described in Section 2. As it has already been pointed out, the assumption about non-Poissonian nature of arrival flows makes analytical methods to be less efficient in providing information on the system performance characteristics.

Let us assume that instead of $M_r|G_r|1$ priority queueing system with switchover times a $G_r|G_r|1$ system is studied and it is the system of interest in providing a corresponding node QoS. The simulation package of classes $PQSST$ by Botezatu and Bejan [6] can be efficiently used for these purposes. It was designed to provide simulation tools of the performance analysis of systems $G_r|G_r|1$, supporting all the disciplines described in the previous section. In this package the interarrival and service times for each flow can be chosen to be of one of the following probabilistic laws: *Arcsine*, *Beta*, *Chi Square*, *Constant*, *Erlang*, *F-Ratio*, *Gamma*, *Logarithmic*, *Lognormal*, *Parabolic*, *Pareto*, *Power*, *Rayleigh*, *Triangular*, *Uniform*, *Weibull*. The package is implemented as Java applet which is accessible online at the following address: `http://vantrix.net/queues/applet.htm`

Original data and system representation algorithms were used in the package $PQSST$ which are based mostly on an object-oriented approach in modeling of such systems (e.g., see [12]).

The package $PQSST$ allows to obtain full chronology of the system under study. Additionally, it provides summary on busy periods statistics, idle periods statistics, mean waiting times of requests, loss probabilities (see § 2.3).

It is believed that the package *PQSST* will be of real interest for those interested in performance analysis of priority queueing systems with switchover times, and particularly, in the context of QoS provision in communication traffic systems.

5 Example of network modeling with priority queueing systems

We continue with an example of usage of the described systems. This example is based on a Cisco Priority Queueing technology which is described in [15].

Priority queueing is useful for making sure that mission-critical traffic traversing various WAN links gets priority treatment. For example, Cisco uses priority queueing to ensure that important Oracle-based sales reporting data gets to its destination ahead of other, less-critical traffic. Priority queueing uses static configuration mechanism and does not automatically adapt to changing network requirements. In this example prioritization represents the process of placing data into four levels of queues: high, medium, normal and low. This is shown schematically in Figure 1.

It is easy to see that this process of prioritization can be modeled as $G_4|G_4|1$ priority queueing system with postponable priority service discipline and correspondingly chosen densities $a_i(t)$ and $b_i(t)$ of inter-arrival and service times, respectively (arrival process can be complex and exhibit such properties as self-similarity, long-range dependence, or burstiness, as discussed above). The discipline of switching can also be appropriately chosen.

However, one might prefer to consider a service discipline other than non-preemptive one (as *postponable service discipline* is, accordingly to the classification given in the previous section) in order to minimize mean waiting times of the packets, for instance. The package *PQSST*

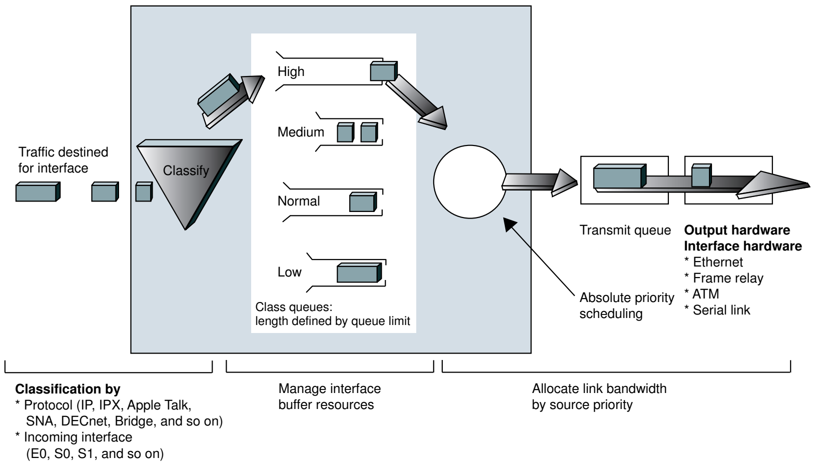

Figure 1. Priority Queueing Places Data into Four Levels of Queues: High, Medium, Normal, and Low (reproduced from CISCO documentation [15]).

may be useful for these purposes, unless the incoming flows are of Poissonian type (analytical methods can be applied then).

6 Concluding remarks

We described in this paper a large class of priority queueing systems involving switching as a class of adequate models of the phenomena which take place in a network. The performance analysis of such systems may essentially influence the ways of estimating and providing a respective level of QoS in networks via estimating nodes QoS's.

One of the most important characteristics of the priority queueing systems is the node traffic coefficient ρ. This quantity plays the crucial role in estimation of the node QoS. The role of the stationarity condition of the form (2.3) (or, for instance, of the condition (3.9) for the system $M_r|G_r|1$ under preemptive discipline and scheme "with losses" with zero switchover times) has been discussed. This is an important condition on a way of providing network QoS. Note, that if at least one of the node traffic coefficients of a network is equal or greater than zero, than the corresponding nodes becomes overloaded (busy periods are of infinite length with probability one).

It has been pointed out that special numerical algorithms and schemes should be elaborated in order to estimate node traffic coefficients in the systems of general type. As it may be easily seen from the results of Theorem 3 and Theorem 4 the problem of estimation of node traffic coefficients is closely related to the problem of the busy periods' estimation.

It will be shown in further research that the *blocking probability* (which is one of the main QoS characteristics) can also be expressed with the help of the system of functional equations of the form (3.3) - (3.5). It has been mentioned that the system (3.3) - (3.5) represents a generalization of the well-known Kendall equation. Similarly, the result of Theorem 2 can be viewed as a generalization of the classical Pollaczek-Khintchine formula.

Yet, an alternative method of study of the considered system is the method of imitational modeling, which was applied to the described systems: the package $PQSST$ has been designed to imitate such systems and estimate empirically their most important performance characteristics.

In this paper we suggested to relate network QoS characteristics to node QoS characteristics on a qualitative level. It is a matter of future work to propose such a connection on a quantitative level.

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Balkan Olympiad in Informatics for school students

In the period of 07.07-13.07.2007 the XV-th edition of Balkan Olympiad in Informatics (http://boi2007.edu.md) was held in the capital of Moldova – Chisinau. 36 school students from 8 countries (Bosnia, Bulgaria, Cyprus, Greece, Moldova, Romania, Serbia, Turkey) took part in that forum. The results of this contest are in Table 1.

The places, which countries-participants took according to the number of students' Gold, Silver and Bronze medals, see in the Table 2.

Table 1:

#	Medal	Name	Country
1	Gold	Rostislav Rumenov	Bulgaria
2	Gold	Ionescu Bogdan-Gabriel	Romania
3	Gold	Airinei Adrian	Romania
4	Silver	Mikloš Homolja	Serbia
5	Silver	Mantoulidis Christos Ap.	Greece
6	Silver	Ivan Labath	Serbia
7	Silver	Svilen Marchev	Bulgaria
8	Silver	Iskren Chernev	Bulgaria
9	Silver	Tataroiu Bogdan-Cristian	Romania
10	Bronze	Kaan Soral	Turkey
11	Bronze	Miroslav Bogdanovič	Serbia
12	Bronze	Boreico Iurie	Moldova
13	Bronze	Ibrahim Numanagič	Bosnia & Herzegovina
14	Bronze	Iacob Alexandru	Moldova
15	Bronze	Dragus Marius-Ioan	Romania
16	Bronze	Emil Ibrishimov	Bulgaria
17	Bronze	Ahmet Ridvan Duran	Turkey

Table 2:

Place	Country	Gold	Silver	Bronze
1	Bulgaria	1	2	1
2	Romania	2	1	1
3	Serbia		2	1
4	Greece		1	
5	Turkey			2
6	Moldova			2
7	Bosnia and Herzegovina			1
		3	6	8

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