REX Paradigm for Robotic Expert Systems

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***Abstract*—How to make robots more intelligent is the main challenge of our time. We present one such solution - REX (Robotic EXpert systems paradigm). It is an organic approach which is used in cognitive computing such as IBM Watson. We prove its viability by applying it to the very difficult and novel area of LAWbots (legal robotic systems). The paradigm entails: gestalt – a deeper model of the expert knowledge and reasoning process; multiplicity – simultaneous use and cooperation of different and conflicting approaches; layering – use of a hierarchy of independent layers of control and processing, through which the input and intermediate results are propagated. The independence of each layer enables implementation of different approaches at different layers. The hierarchical layering of control and abstraction of lower by upper layers enables the cooperation and solution of contradictions arising from the use of a variety of different approaches. In very broad, plain terms, at each layer there is a small expert system controlling, generalizing and inducing the cooperation of different approaches in a larger expert system of the next layer. The paradigm was very successfully use to create real life applications.**

***Index Terms*—Cognitive computing, Expert Systems, Robotics, Watson.**

I. Introduction

The main obstacle in robotics is the intelligence part. Lately non-algorithmic approaches have been proposed such as cognitive computing implemented in IBM Watson. The crucial difficulty is the lack of comprehensive methodological paradigm for such organic methods. We present here such an organic paradigm - the REX (Robotic Expert) paradigm. It is described using the implementation of a LAWbot (legal robot) as a Legal Expert (LEX).

Expert systems (ES) were historically the flagship of applicative artificial intelligence (AI). Then came the realization that out of many thousands of ES only a negligible part made it out of the laboratory and into the real world. This had a dual effect: engaging in more theoretical research (such as deep models and ontologies), and developing other types of intelligent systems, usually less pretentious (such as decision support systems).

After more than two decades of an immensely diversified research, we are facing a barrage of vastly different, but nonetheless promising results. We feel that the area is once more ready for crystallizing a new paradigm for a very powerful intelligent system, incorporating and consolidating the vast volume of research. Though we propose to christen such a system after its grandmother: "expert system", there should be not an ounce of confusion between the two.

An endeavor of this magnitude will need much concentrated effort of many researchers and will stretch over a considerable period of time. We initiate such a debate by proposing quite a detailed account of one possible paradigm, analyze an expert system built using its principles, and propose guidelines and framework for further research.

This paper presents results of both theoretical research into AI, Computer Science and Robotics, and developing novel engineering technologies and know-how. Some of the research of many years has resulted in successful robotic projects in the unique Organic Knowledge (OK) Robotics Lab.

Our paper has several parts, arranged from the more theoretical to more engineer-oriented implementation description. We start by outlying the general ideas of such a new organic paradigm and introduce the idea of organic knowledge (OK) system. Next we describe the REX version of the OK paradigm. Then we study the paradigm in a more detailed fashion while applying it to a very difficult area of legal expertise. We present a legal expert system we have proposed – LEX (determining the quantum of damages in personal injury cases). In conclusion we outline possible framework and guidelines for further research.

II. Organic Knowledge (OK) Systems

A. Organic Knowledge

An Organic Robotic Environment is an Organic Knowledge System (OKS). Organic Knowledge (OK) systems are the newest generation of Knowledge-Based Systems (KBS), one of the major branches of AI.

Organic Knowledge (OK) is a Knowledge System paradigm that simulates and enhances through mutual learning the knowledge of both the IT and Robotics expert and the knowledge of the domain expert.

In a nutshell the organic approach is treating the problem and the solution process as evolution of different and frequently conflicting units of knowledge, algorithms and solutions. It is modeled after the growth and evolution of a living organism (or ecology of organisms if more appropriate) where different units of knowledge, algorithms and solutions are the organs [1].

The organic solution is like a child – in the beginning having no knowledge (except some basic mechanisms needed for evolution), and by process of feedback and Darwinian natural selection the solution gradually evolves, becomes better and better using its growing body of

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knowledge [2].

The most basic aspects of the paradigm are the especially massive body of organic knowledge and the organic life-cycle. Organic life cycle is somewhat reminiscent of the prototype cycle but it is much more sophisticated. It simulates the growth of human intelligence, creating solutions more and more plausible using mechanisms of feedback and learning [3].

B. *OK Systems Implementation*

Organic Knowledge (OK) systems are ICT systems incorporating human expertise. One would be tempted to describe them as Expert Systems (ES) "on steroids" transforming them into Knowledge Systems (KS). They are an ecological system of many different and sometimes contradictory experts called organs. OK system are Turing's "child programs" [4] and Minsky's learning, evolving and non-algorithmic Society of Mind [5].

OK system is:

- intelligent
- evolving
- learning
- organized
- distributed
- dialectical
- having very big knowledge base

Each organ is simulating an independent expert, and includes:

- knowledge base (data, meta-data and procedures)
- feedback apparatus:
    - knowledge acquisition mechanism (interfaces and communication)
    - learning mechanism (inference of new knowledge and processing)
    - evolution mechanism (creating and changing organs in view of the new knowledge)
- interfaces:
    - environment (local)
        - subjective (user)
        - objective
    - communication (network)
        - with other organs (o2o)
        - with remote servers
        - with remote users (p2p)
        - with remote resources
- execution (proactive).

The OK paradigm was successfully used in OK systems in various areas of application such as:

- Business management and administration [1]
- Computer science [2] [10]
- Software engineering [6]
- Children education [3]
- Adult education [7] [8]
- Gamification [9]
- Web search [11]
- Intellectual property [12]

III. REX (ROBOTIC EXPERT) PARADIGM

A. *General outline of the paradigm*

The Gestalt-Multiplex-Layering (GML) paradigm entails: gestalt – a deeper model of the expert knowledge and reasoning process; multiplicity – simultaneous use and cooperation of different and conflicting approaches; layering – use of a hierarchy of independent layers of control and processing, through which the input and intermediate results are propagated.

The independence of each layer enables implementation of different approaches at different layers. The hierarchical layering of control and abstraction of lower by upper layers enables the cooperation and solution of contradictions arising from the use of a variety of different approaches.

In very broad, plain terms, at each layer there is a small expert system controlling, generalizing and inducing the cooperation of different approaches in a larger expert system of the next layer.

B. *Gestalt*

Gestalt is the skeleton, the deeper model, the concept, the meta-model of the lower layer, abstracting, generalizing, controlling and interfacing it, and mediating between the lower layer, the upper layers and the user.

ES are frequently built around ontology, schema, meta-model controlling and coordinating: ontologies and semantic schema coordinating a multi-agent ES [13]; tentative designs, templates [14]; scenario generation [15]; knowledge acquisition filtered by models [16]; story model [17]-[19]; fuzzy model [20]; active behavioral database of goals and rules coordinating the knowledge database [21]; declarative and executable object-oriented model [22]; data structure at object level [23]; frame templates [24]; interaction manager [25]; knowledge model used by agents to manage the others [17].

Gestalt has at least three facets: *the declarative:* the data and knowledge, the static aspect of knowledge; *the procedural:* the reasoning models, the data processing techniques, the inference engines, the dynamic aspect of knowledge; *organizational:* the interaction control of the multiplicity at the lower level, conflict resolution, user interface control, user involvement, feedback, the integration manager.

In general, the gestalt will involve a different approach than the lower level, and include more than one component. Architecturally it is a quite complex structure. It can be viewed as a small expert system at the heart of and controlling the larger one. In a multi-agent society, it's the ruler, the governing ideology and body.

C. *Multiplicity*

The basic commonplace of folklore: "two heads are better than one" is validated by such hard science approaches as dialectics, to become a central component in our basic approach. The cognitive science teaches us that the integration of a variety of different techniques in a soft approach has immense advantages.

Many modern ES integrate more than one basic method: multi-agent society of different behavior patterns and different roles [13],[17]; integrating inductive decision trees and neural networks [26]; multiple input channels and methods [27]; CBR with RBR discrepancies solution [28];

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three independent models of knowledge representation and inference [20]; integrating CBR, neural networks and discrimenant analysis [29]; blackboard method of integrating multiple experts (sources of knowledge); integrating ES with DB approaches; integration of various rule paradigms into a single KBS; a hybrid neuro-fuzzy reasoning [31]; voting over multiple different learners; multi-expert systems combining such different approaches as extensional and intentional [21]; integration of conflicting schemas; integrating different analytical decision models [22]; integrating semantic expressions with examples [23]; combination of relational and object-oriented paradigms [24].

We can conclude, as a guideline, that the more different, even conflicting techniques we use, the wider and deeper view of the solution we will achieve. But this is too general and we need a more restrictive and precise method of integration.

First we prefer merging to compromise. While compromise loses some of the positive features of each ingredient, a price for one monolithic consistent approach, merging recruits all, as contradictory as they may be, and the larger the diversity, the softer and fuzzier the result.

This requires such components built into the system as conflict resolution, control manager of interaction, data flow and resource allocation, user transparency and involvement, priority indexing of approaches. These are among the components of our gestalt, deep model driven, structural, hierarchical, layered architecture paradigm, which transforms the chaotic multiplicity into a well behaved, disciplined one.

D. *Layered approach*

The layered approach proved itself very useful in such different areas as computer networks (the reigning seven layers model), operating systems (e.g. the UNIX kernel-shells model), compilers (the three layered: lexical, syntactical and semantic model), client-server, front-end back-end approach. Among the many advantages are: independence, structuring, error protection, abstraction, precise interaction model, modularity, transparency, portability.

In the ES domain it is now also widely used: structured libraries of behavior; client-server; hierarchical cases and domain specific indexing; two-level model with kernel and coordinating module [15]; three layers: semantic, syntactic and lexical for structured processing [14]; a hierarchical architecture modeling and inference [20]; an object-oriented organizational layering; intentional layer over extentional [21]; layering by generalization of schemas; hierarchical structuring of models [23]; dual hierarchy, by structure and logic of data [24]; three layers structured by human-computer interaction [25]; a layered agents society [17].

In the paradigm the layering permits structured abstraction, conflict solution by a higher level, different approaches at different layers, control and management, changeability and user involvement.

E. *REX methodology*

The essence of the approach is it's softness, a very popular feature in many ES and general AI: fuzzy rules and terms [32]; fuzzy logic in imprecise language systems [33]; fuzzy qualitative constrains; fuzzy analysis; fuzzy inference integrated with neural network [31]; fuzzy logic modeling [34].

It should be emphasized that though the layering concept has a linear structure connotation, the gestalt component certainly enables a much more complex architecture. The gestalt makes the structure dynamic rather than static, it actively, intelligently, intermediates at each layer and between layers and directs the intermediate results.

It's rather a network of many possible interconnections and interactions between the different components of the system. The gestalt chooses at each stage the next path to be taken. The choice defines the layering, i.e. the sequence of nodes in certain order, of data processing, along the chosen path.

Such a distributed approach is adopted in multi-agent societies; multi-agent systems [13,[14]; distributed multi-agent environments [35].

The paradigm could be seen as a model of multi-agent society with one, very clever, best connected agent, as the ruler. We have forged a symbiosis of two models: distributed and centralized.

Not every specific real life system has to include all the complexity and intricacies of the complete GML paradigm. A researcher will use the paradigm techniques most suited for the needs of the domain and the resources limitations, including the time and space complexity of the resulting system.

The main stages of the algorithm of GML application are:

1) Initial raw data and reasoning techniques acquisition.
2) Initial gestalt formation.
3) Gestalt processing of the raw data stream into knowledge and reasoning multiplicity.
4) Layering of multiplicity, layers formation through horizontal and vertical classification, structuring, matching, clustering and abstraction.
5) Global control manager formation (user, feedback, resources allocation).
6) Evolutionary interactive incremental feedback - driven improvement.

In this fashion the REX GML paradigm allows building expert systems in complex and not well defined domains, where the human experts are bewildered when required to give clear answers regarding the knowledge and reasoning process, such as law.

IV. LEX – LEGAL REX

A. *LEX gestalt*

Though there exists a constant temptation to view law as a logical system, the approach of modern jurisprudence is different. It's more existential, empirical. Law is more of an art and an instinct than pure logic. We need to analyze the empirical operation of law rather then its logical principles.

We have used semantic network model to build the kernel of legal principles and reasoning model in the specific domain of determining the quantum of damages that should be awarded to a victim of an accident for personal injury.

We have managed to extract a basic general algorithm which is activated when there are no specific rules or precedents. The kernel of six relevant input variables includes: age, income, invalidity, loss of income, expenses, hospitalization. All the knowledge bases will be built using frames, built using this kernel of six input variables, the result variable and the identification of the legal source.

B. *Multiplicity in LEX*

The main knowledge bases used are:

1) *patterns* - the basis scenarios, abstraction of real live situation;
2) *rules* - general legal rules governing the domain;
3) *cases* - the legal precedence, mainly court decisions;
4) *general* - fundamental law application algorithm.

The main reasoning models used are:

- inductive,
- deductive,
- statistical,
- fuzzy.

The inference engines used are:

- abstraction,
- deductive-logical,
- nearest neighbor,
- pattern matching,
- statistical,
- inductive feedback pattern extraction.

C. *LEX layering*

The LEX system is layered in many of it's operational and application aspects. We have an hierarchical structure in different knowledge bases, in inference engines, in data representation. The central layering system is that of input propagation.

The input is propagated through five layers. Each layer sends to the next the processed input and intermediate results. The layers are: input layer, abstraction layer, inference layer, gestalt layer and the feedback layer. Each layer is in it term structured into sub-layers. For instance, in LEX the inference layer includes four sub-layers through which the input is propagated in the following order: pattern matching, CBR, RBR, general law.

V. LEX Implementation

LEX is implemented modularly. The implementation language for the main module is Prolog, and for the inductive feedback using neural network C++. The basic data unit is a frame implemented as a Prolog predicate. It's very flexible possessing both declarative and procedural power, as it directly participates and drives the various inferences. The structured object-oriented nature of a frame also simplifies the inference models.

The knowledge representation is very concise. A case is saved in a full text format, and also in the gestalt driven predicate format. Example: a Supreme Court decision, civil case 122 for the year 1997, awarding the sum of 400,000, where victim's age was 30, his income - 20,000, invalidity - 60%, loss of earning capacity - 20%, monthly expenses 10,000, and he was hospitalized for 90 days.

LEX representation as a Prolog predicate:

decision(3,supreme:civil:122:97,30,20,60,20,10,90,400,des3).

A rule example: a victim under the age of 21 is presumed to have the average potential earning capacity in the future, is implemented as a prolog predicate thus:

rule(2,Age,_,_,_,_,_,_):-
Age<21,
eq(average_income,Average),
ch_abs(factual_income,Average).

The soft and shell features of the system enable fuzzying a parameter.

VI. Further Research

The paradigm is in its initial stages of consolidation. But of vital importance is its existence, even in this skeletal form. For the first time in many years we are in possession of a fundamental inclusive methodology, enabling the building of very powerful systems in very complex domains.

There is a major promise and great need for further research at three levels: the *theoretical* - formalization of the paradigm, defining its relations with other paradigms and approaches; the *applicative* – more in-depth analysis and synthesis of the various components and techniques, structures and architectures, creating the needed classification and terminology, validation and evaluation techniques; *empirical* - building real life systems based on the paradigm, field testing them and using the feedback at the two higher levels of research.

To achieve the optimum ROI (efforts vs. results) and complexity vs. results ratio, we need a more exact analysis, classification and evaluation of interaction of different approaches and of their different features. The crude classic dichotomies, such as induction-deduction, RBR-CBR, logic-statistics, will not suffice.

There is a need for more general methodologies, facilitating the precise analysis of the process of development and operation of REX from a structured, deep model integrative (GML) point of view.

Great real-life success of robotics in general and novel non-traditional algorithmic solutions such as IBMs Watson make the need for a sound theoretical and engineering foundation of the organic approach, such as was presented in this paper, crucial and urgent.

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