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COMPARATIVE OVERVIEW AND INTERACTIVE SYSTEMS FORMAL MODELS ANALYSIS

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Abstract:

The current stage of development of software is characterized by the prevalence of interactive systems which provide solution of various classes of problems on the basis of the optimum separation of functions between a user and a computational machine. The task of development of interactive systems is multiple-aspect and incorporates virtually all of the major problems in the field of programming. For its solution it is necessary to use theoretical apparatus and tools which are the technological basis for creation of modern effective interactive systems. A significant role among the main and mandatory phases of building such systems is given to selection and development of a formalized system model to streamline the system description, make it easier for its design and analysis, provide a conceptual framework to analyze its behavior and implementation. An interactive system model is a description of schemes of dialog processes and actions performed by the system.

In the paper we present a specific classification and review of formal and informal models of interactive systems, as well as the tools and techniques of their building. The analysis was conducted in order to identify the most strong points of presented formalism which, according to the authors, could be useful in formulating a common approach to description of interactive systems.

Keywords: interactive systems, interactive systems, system modeling

1. Introduction

The current stage of development of software is characterized by the prevalence of interactive (dialog) systems to provide solutions to various classes of tasks based on the optimal separation of functions between a user and a computational machine. Upon that, one should note that the task of development of dialog systems (DS) itself is multi-aspect and incorporates virtually all major problems in the field of programming; for its solution, it is necessary to have a

theoretical apparatus and tools which are the technological basis for creation of modern effective dialog systems. The difficulties encountered in the course o solution of this task, in particular, are:

- lack of a unified approach to description of dialog system (uniform abstract model of an interactive system), uncertainty of existing descriptions;
- lack of common terminology;
- a small number of integrating works on the methods and means of building dialog systems.

2. Models of Dialog Systems

A significant role among the main and mandatory stages in building dialog systems is given to selection and development of a formalized model of the system allowing the description of a dialog system to organize, to facilitate the task of design and analysis, provide the conceptual basis for the analysis of their behavior and implementation.

Model of a dialog system is a description of schemes of dialog processes and activities (functions) performed by the system; and it should meet the following requirements:

- Be simple and expressive;
- Have the ability to ignore the content of a dialog (separation of roles between a person and the dialog system);
- Be available for formal mathematical treatment;
- Provide the ability to transform into a software system.

For a software implementation of interactive systems, it is possible to identify well-known difficulties associated with absence of the most appropriate way of describing both the dialog system and its behavior that is caused by difficulties in formalizing a description of the actions of the dialog system user, as well as the difficulties in describing the representation of dialog domain knowledge. It is therefore necessary to give a certain systematization of the methods and means used in the description of interactive systems and their behavior. Currently used methods and tools for building models of interactive systems can be divided into informal (or partially formalized) and formal methods.

3. Informal Methods of Building Interactive Systems Models

Such models in the main do not use any specific formal notations for their determination. However, it is impossible in general to describe accurately and clearly the overall concept of the organization and functioning of the dialog system

through informal methods. Problems of building a dialog system for such models are similar to the problems of visual programming. The following methods and means of building informal models are used:

- block - schemes (schemes of a dialog);
- state diagrams;
- tabular forms of description;
- texts in high-level programming languages;
- texts in the language of a virtual machine;
- methods of structured programming;
- methods based on the approach "A man in the world of objects".

The following tasks should be specified in these models as promising areas of research and the practical implementation of interactive systems:

– review of state diagrams as a means of describing the dialog interaction in terms of impact and response;

– description of the dialog systems that uses state diagrams to tune the system to the specific application;

– problems of state diagrams description formalization and building a syntactic machine on their basis;

– description of a dialog system model as a set of subsystems model (problem - oriented and service); a subsystem model includes dialog chart and its interpretation.

Currently, the most promising with regard to the building models of interactive systems is the approach "A man in the world of objects" which provides such means of dialog that make available any data stored in the computer. The end user is as if in the world of objects, or data, where it is possible to move around using the direction keys what makes the decision-making process similar to the games. The very system ceases to serve as a "buffer" between a person and an object, turning from an intermediary with which it is necessary to conduct a dialog just in a tool for studying and changing "the world."

4. Formal Methods For Building Interactive System Models

Certain specialized formal notation are applied by using formal methods for building models of interactive (dialog) systems. Two main directions in such formalizations could be distinguished: a model for the description of organization

and / or operation and models as tools of analysis, evaluation and optimization of an interactive system, as well as the approach to the study of human - computer interaction expressed to certain types of tasks being solved, in the allocation of abstract means of their solution, as well as "given" analysis of various types of human - computer interaction.

It can be distinguished the following main tasks devoted to the study of formal models of interactive systems:

– formalization of means and methods of human-machine interaction;

– research and systematization of human - computer communication models in a natural language;

– experimental comparison of several formalisms for building interactive interfaces.

Building a formal model of a dialog system comprises the following steps:

1. Accurately and clearly describe the overall concept of the organization and functioning of the dialog system (bind and present in a united way structural, dynamical and informational aspects of the dialog interaction);

2. Use the model as a basis for the design and implementation of interactive system software;

3. Get the tools for analysis and evaluation of the interactive system;

4. Act as a methodological basis for creating automated dialog system development tools.

It should be noted that the development of appropriate formal models of interactive systems is closely linked to the issues of development of formal models of their domains.

It is now possible to distinguish the following formal models of interactive systems:

1. Graph (automaton) model;

2. Models using the network representation (Petri nets, Woods network, and generalized transition networks);

3. Models built on the basis of the formal grammars apparatus;

4. Model using the apparatus of the satisfiability modulo theory;

5. Probabilistic models;

6. Models using the process concept;

7. Models based on different methods of formal specification;

8. Relational and frame relational models;

9. Models built on the basis of operator schemes;

10. Models using the game theory principles;

11. Models based on the use of wireframe machinery of the model theory.

4.1. Graph models

Such models are currently the most common way to describe a dialog system. The functioning process in these models is represented by a transition graph of deterministic finite automaton. Transition graph can be represented as a hierarchical directed graph, connected graph, a graph with loops, loaded oriented graph. In this graph, each vertex describes the dialog states in which the dialog system waits for a message input from the user, and depending on input text it goes along arcs which reflect the possible actions, to another (or the same) state.

By way of description of the dialog interaction, at least two approaches can be distinguished in such models: either the whole process of human - computer interaction is described by an automaton of a class or every act of human-computer interaction is represented by an automaton itself.

Let's consider the advantages and disadvantages of graph models. Among the advantages there are natural account of the formal structure of a dialog as a messaging process, clarity, simplicity and ease to define a model. The disadvantages of these models are the need for a large number of states for a complete description of the complex dialog and the impossibility of explicit specifying a human behavior as a dialog partner. In general, since a graph is a structure of a very common form, the graph model allows only to fix (and not to justify) the result of designing an interactive system, since it describes rather the structural characteristics of the system than the dynamics of its operation.

At present, there is a need to systematize the works on theoretical issues of development and use of graph models, and to select studies on the use of automatic models of three types - with a "short-term" memory, with "long-term" memory, and automaton model of a redesignable dialog, and studies of models based on the representing of an interactive system in a form of a hierarchy or recursively related languages and interactive design machines.

The following may be considered as the basic model:

- two-component model to describe a process of parallel operation of the user and the system, and their asynchronous communication;
- model based on the use of the interconnected matrix and graph models;
- combination of graph and linguistic models;

- graf - linguistic model which main components are a set of allowed states (finite set X) of human-computer interaction, and a set of permissible transitions from state to state described by a binary relation;
- device that allows to describe sequential processes of a dialog interaction in the form of graphs and analysis mathematical models with logical-linguistic representation of situations; a means composition for formalized representation models is based on Yanov's schemes apparatus elements, generalized structural method elements and elements of formal generative grammar theory;
- Method of formal description of interactive systems based on the finite state automaton.

L-machine refinement could be considered as a model for the organization of multi-level interactive dialog system; the refinement is associated with the introduction of interrupt elements to it and the built-in dialog function.

Model of a dialog system which takes into account the peculiarities of interaction with its intelligent components can be represented using initialized Mealy automaton.

The researches and development of the dialog management methods based on the apparatus of formal languages and automata theory are also relevant. Of interest are works devoted to the use of nested or recursively related automata upon building dialog system models.

A model which uses system of nested automata interacting with each other is relevant to consider. A built abstract model must be analyzed by the following examples: in the dialog editor, in an interactive system for table information processing, in interactive computer graphics system, and in integrated human-machine system.

One group of dialog system models could be recursive, in particular a hierarchical model of dialog system which is represented as a hierarchical or recursively related idealized machines, as well as the languages in which these machines interact with a user. The model is the base for development of the meta-language intended for designing languages and machines the way of application of which determines the technology of building and method of documenting dialog systems.

It is possible to consider another group of interactive systems that are based on graph models or use them. The most important representative of this group are interactive systems which should be considered as instrumental complex of coarse-grain programming and are designed for creating interactive systems on definition of their graph domain models (DM). A domain model is described by routing graphs, or oriented loaded pseudographs a set of which vertices

corresponds to steps of computing tasks, and a set of arcs (routing and corrective) is determined by control and information chains between the steps.

Other representatives are instrumental complexes for developing interactive systems using a contextual dependency graph in the capacity of the domain model of dialog. The dialog subject is described in the form of loaded oriented graphs. Also, there can be used information and computing model converted into a graph model - scenario, logical steps of the algorithm are set as its nodes, and the logical connections as its arcs.

Operation of graphic interactive systems can be defined as a graph of dialog states. A state description includes: the type of status (active or internal), a message to the user, numbers of transition states and system reactions. The active states analyze user actions; internal states are intended to analyze some of the results of programs execution and histories of a dialog.

4.2. Models which use the network presentation

These models are more sophisticated formal apparatus which allows an equal display of dialog partners actions to give, as well as the conditions of implementation of these actions.

The most common are models using the apparatus of Petri nets. Any elementary fragment of dialog interaction in these models that consists of a description of certain conditions of a dialog (state) and action of the system in this state is represented by an elementary network consisting of a set of vertices - places ("Conditions") and their corresponding network transition ("Events"). Complex structures of a dialog can be represented as compositions of elementary structures. Attraction of the mathematical apparatus technique of Petri nets allows studying a structure of an interactive system without regard to the particular user language, dialog form, and its technical facilities. However, significant shortcomings were a sharp increase in model complexity while increasing the level of detail for modeling the dialog system and orientation of the apparatus to a fixed structure of the dialog.

Up-to-date trend is the empowerment of Petri nets apparatus, dynamic Petri nets, and their use to describe the model of a universal graphic dialog system, the use of the formal apparatus of the modified Petri nets in designing an invariant dialog system, analysis of the relationship between finite automata and Petri nets, as well as reducing a number of Petri network theory tasks to effectively solved automaton tasks. It is considered a model that combines the properties of functional networks and Petri nets. More powerful and expressive means of presenting dialog systems models are Woods

networks and augmented transition networks (ATN). A dialog system model is represented as a set of two automata: a dialog monitor and a network interpreter. There is a need in systematization of experience on organization of interactive interfaces based on Woods' networks and augmented transition networks. Among the other models, the dialog models feature that are implemented with the use of augmented transition networks with returns, formalisms combining recursive transition Woods networks and grammar Petri - Chomsky nets.

The set of tools nay be represented as instrumental that includes a system for designing interactive and linguistic processors based on the model of generalized augmented transition networks (GATN).

4.3. Models using the formal grammars apparatus

Grammars as the dialog process descriptors represent its linear, branched and cyclic forms, various options for nesting such processes and their recursive interaction. However, use of the formal grammars apparatus requires certain degree of skill which is hardly possessed by application programmers.

It is necessary to carry out the systematization of works devoted to this approach, and to examine how the apparatus of the formal grammars theory is used for logical presentation of interactive processes. Lines of research can be a syntactic method for definition of a dialog system and its interpretation by MP - automaton, and the possibility to use attribute grammars to describe the dialog system.

4.4. Probabilistic models

Such models are used when either a further dialog step is not defined, or its search is too complicated or user-dependent. The main mathematical tool used in these models includes the set theory, the graph theory, the predicate calculus, and the queuing theory. Study of a dialog system as a queuing system is carried out using both analytical and simulation methods. Simulation modeling is understood as experimentation with a mathematical model. The issue of discussion is a generalized dialog model built with the use of the theory of random processes and situational management. For example, an analytical model of an interactive system such as "system manages - the user is forced to choose". The model is constructed from the point of a number of mathematical models with time-sharing in terms of queuing and theory of regenerating processes. The problem of designing the "human - computer" interface is relevant to consider in the form of multicriteria problem. Attempts are being made to identify and formalize such criteria as minimizing the average response time, minimizing the probability of error, the flexibility and adaptability of the interface, and comfort in use.

4.5. Models which use the concept of process

This line is represented in the form of approach to the representation of a dialog system behavior as a hierarchy of special kind processes: exhaustive processes. Each exhaustive process and their relationship in the hierarchy are described in natural language. Another approach is based on the concept of a process model that takes into account the user's actions and describes the directive and challenge-response dialog.

4.6. Models based on various methods of formal specification

The approach to the representation of an interactive model of the system based on the methods of formal specification allows concisely describe the complex behavior of the system without going into its structure and implementation details and provides a possibility to have a solid mathematical basis which enables to make a conclusion on behavior of the dialog system using logical deduction. However, the problem for these models is that the complete specification of a dialog system should determine the functions implemented jointly by the program and the user.

Currently known is a number of lines on research the possibility to apply for the formalization of an interactive system model the program layout logics (PLL), constructive logics, predicative grammars formalism, imperative programming logics (algebra), Hoare logics, and SIGMA programming.

Application of logics of program layouts built on constructive logical calculi to organize the dialog uses for designing a language interface the predicate formalism of grammar and translation which is well-implemented in Prolog language, as well as the possibilities of a logical description of the dialog system using the apparatus of constructive logic and generalized calculi.

In practical terms, there can be used concepts and methods of compositional programming, in particular the apparatus of imperative programming logics (algebra) applied to building a dialog system model. The basis of the compositional programming are separation and subordination principles, i.e. using to build complex programs the simpler ones joined by a generalized structural method for evaluation of the "human-technology" systems on the basis of description of a process by an absorbing Markov chain (M - chain).

A hybrid model also can be used that is characterized by the combined application of various formal methods to describe separate parts of a dialog system (a part of the system is represented by a regressive model, and another part by the simulation). The use of stochastic networks is proposed in one of the areas for building probabilistic models. It is

proposed for the analysis of multi-terminal interactive systems to use stochastic network models which take into account the dialog structure (diversity of operations and order of their execution), in particular, the model of the process of solving a problem in a human-machine system that is represented as an exponential closed stochastic queuing network, and the programs should be considered as special (denominated) functions defined on denominated sets.

A separate area is represented by using the theory of interacting sequential processes in the capacity of a conceptual apparatus which provides formal means for specification and analyze of processes in the dialog system.

4.7. Relational and frame - relational models

These approaches in relation to the definition of an interactive system model are based on a single relational data representation and a typical set of data processing procedures which include, along with the operations of relational algebra, operations on calculating a number of functions and composed functions from attributes to the relationship. Instrumental complex for automated development of an interactive system can be built on the basis of a relational model built upon relational algebra and relational calculus. The description of an information processing system is frame-based approach. A frame is represented as a network of nodes and links between them. The upper levels of the frame are clearly defined as they reflect the situation identified in advance on the basis of an analysis of a priori knowledge in the problem domain.

4.8. Models which use game theory principles

Promising are approaches which use principles of game theory for simulation of a dialog in interactive systems. In this case, a dialog is considered as a two-person game with nonconflicting interests; the game theory methods are used to solve the real problem of choosing the best mode of dialog in the conditions of user's characteristic uncertainty.

4.9. Models based on the apparatus of skeletons from the theory of models

These models offer an approach to the design of interactive systems that allows representing an interactive system as a set of interactive systems aimed at addressing common problems or revealing certain aspects of the problem area under consideration. When setting a specific task the components required for its solution should be combined to form a single interactive system. The proposed approach is based on the concept of building a consistent domain model by combining multiple systems into a single interactive dialog system. Apparatus of skeletons from the theory of models is used to formalize this process.

5. Natural Language Model of a Dialog System

One of the curious and, of course, promising directions for the development of interaction systems are interactive systems models based on the achievements of computer linguistics in the field of work with natural languages. A key feature of this model is to draw up a dialog in natural language. In such a system, a user does not choose from a limited set of proposed actions, and enters a query or a response to a question of the system in a natural language in the form of text or, more preferably, using voice activated dialing. The system also analyzes the received request and transits to the desired state, and performs the desired action. This model combines the features of the approach "A man in the world of objects" and graph modeling. The advantage of the model is convenience and naturalness of the user interface, and flexibility of its implementation. Naturally, the success of implementation of such an approach depends on the linguistic direction for creation of a system. The most elaborated direction is the methodology of analysis of natural language queries that is used in search engines. Its techniques include machine learning, the use of neural networks, and other methods based on statistical analysis of language. Much less developed area is semantic analysis of a language. Key developments in this area are associated with interactive learning systems, such as electronic testing systems. Dialog in this case is constructed as a "question of the system - the answer of the tested person", and the action of the system is to assess the response and to transit to a next question. In this direction, the perspective for dialog systems is pragmatically oriented approach to the semantic analysis of natural language. This approach is based on the assumption that a question sets some response context, and limits its form and variations. This allows for avoidance the full and unlimited analysis of natural language text and simplify the task to an acceptable level for implementation.

6. Conclusion

The present paper provides certain systematization and an overview of formal models of interactive systems, as well as the tools and techniques of their building. Up to the moment, a problem to give a comprehensive overview of these methods and means have not been set, and the paper reflects the state of affairs in this area only in the last few years. In general, we can conclude that at present it has not yet allocated the means and methods for building formal models of interactive systems that allow for performing full display of the structural, functional and informational aspects of the dialog interaction from a unified point of view. The analysis was conducted in order to identify the most strong points of

the presented formalisms which, according to the authors, could be useful in formulating a common approach to the description of a dialog system. The strongest parts of some models described are the following:

- Due to a graphical notation, graph (automata) models give a clear idea about the organizational structure and functioning of the dialog system.
- Network models allow the most adequately to represent the simulation process of communication with computers on a limited subset of natural languages and simulation process for dialog system information flows.
- Despite some difficulties of understanding, logical models have, in author's opinion, two highest advantages: a logical conclusion and consistency with programming languages. These advantages make them indispensable for the simulation of calculation planning processes and actions in an interactive system and an adequate representing the model in the software system.
- Relational and frame-relational models allow most adequately represent a knowledge about a dialog (knowledge necessary a system for organizing the dialog process, and tools of their presentation).
- Probabilistic models and models which use the principles of game theory provide interactive system developers with tools of their analysis, evaluation and optimization. Means of these formalisms allow the use of the model apparatus as a tool to understand the fundamental properties and laws of conduct of the dialog system, to evaluate the set parameters and the resources needed to implement the system, to optimize the parameters that are essential for its development and operation.
- Natural language models provide natural, easy to use and flexible in implementing interface to interact with the system.

In general, the most optimal would be a combination of the strongest sides of the formalisms discussed into a common approach to the definition of a dialog system formal model. Creating an apparatus and conceptual framework to enable this is an urgent task. Currently, studies of conceptual foundations for the possibility of creating an apparatus for producing a class of interactive models by composition or the projections of the existing ones remain actual. Such separate area as the tensor modeling has been and remains a promising approach.

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References

1. D. Goldson.Abstract modelling of interactive systems // Human - Computer Interaction INTERACT ’97 pp 134 - 141, Springer US (1997).
2. Laurence Nigay, Jullien Bouchet, David Juras, Benoit Mansoux, Michael Ortega, Marcos Serrano, Jean - Yves Lionel Lawson. Software Engineering for Multimodal Interactive Systems// Multimodal User Interfaces From Signals to Interaction pp 201 - 218, Springer Berlin Heidelberg (2008).
3. Susan J. Boyce. Spoken Natural Language Dialogue Systems: User Interface Issues for the Future // Human Factors and Voice Interactive Systems pp 37 - 61, Springer US (1999).
4. Alistair Sutcliffe, David Benyon. Domain Modelling for Interactive Systems Design // Springer US (1998).
5. Stéphane Chatty, Programs = Data + Algorithms + Architecture: Consequences for Interactive Software Engineering // Engineering Interactive Systems, Volume 4940 of the series Lecture Notes in Computer Science pp 356 - 373, Springer Berlin Heidelberg (2008).
6. Ann Blandford, Thomas R. G. Green, Iain Connell. Formalising an Understanding of User - System Misfits // Engineering Human Computer Interaction and Interactive Systems, Volume 3425 of the series Lecture Notes in Computer Science pp 253 - 270, Springer Berlin Heidelberg (2005).
7. Camila Cordero Mansilla, ángel de Miguel Artal, Eladio Domínguez Murillo, Ma Antonia Zapata Abad. Modelling Interactive Systems: an architecture guided by communication objects // HCI related papers of Interacción 2004 pp 345 - 357, Springer Netherlands (2008).
8. Stefan Sauer, Kai Breiner, Heinrich Hussmann, Gerrit Meixner, Andreas Pleuss, Jan Van den Bergh. Combining Design and Engineering of Interactive Systems through Models and Tools (ComDeisMoto) // Human - Computer Interaction – INTERACT 2011, Springer Berlin Heidelberg (2011).