Methodology and tools for component interface design of next-generation intelligent computer systems

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***Abstract*—In the article, the methodology of designing interfaces for next-generation computer systems is considered. The stages of designing adaptive intelligent multimodal user interfaces and the usage of these stages in the context of the OSTIS Technology are described.**

***Keywords*—interface design methodology, adaptive intelligent multimodal user interface, OSTIS, ostis-system interface, next-generation intelligent computer systems**

I. Introduction

Interface design is one of the most important stages in the development of any system.

Design of the interface is often thought of as art rather than science and suffers from lack of formalisms, models, tools, and methodical design approaches. Slowly, the design process is becoming more structured, and more formal tools are becoming available [1].

The user interface is a set of software and hardware tools that ensures the interaction between the user and the system.

The user, when dealing with the interface, must imagine what information about the problem he has and in what state are the means by which they will solve this problem. The effectiveness of the user and their interest is ensured by a properly formulated methodology of development and design of the user interface.

Currently, the organization of user interaction with the computer system is the paradigm of a **competent user**, who knows how to manage the system and is fully responsible for the quality of interaction with it. The variety of forms and types of interfaces leads to the need for the user to adapt to each specific system, to learn the principles of interaction with it for solving the problems they need.

Friendliness of the user interface should consist in the adaptability of the system to the characteristics and qualifications of the user, the exclusion of any problems for the user in the dialog with the intelligent computer system, in a permanent care to improve the communication skills of the user. Consequently, it is necessary to move away from the usual user adaptation to the system (by learning to use it) in the direction of adapting the interface itself to the purposes, problems, and characteristics of a particular user in real time [2].

The interface of next-generation intelligent computer systems should provide interaction with the user on an equal basis, be able to adapt to its characteristics, as well as to perceive different types of information input. The terms of adaptive, intelligent, and multimodal interface are often used to organize such interaction.

The interfaces to be designed must comply with the following aspects:

- Uniformity is one of the main principles of user interface design. In the modern world, users are familiar with using different systems. Comparing systems with each other, it is possible to notice some similarities in their design (for example: search is located at the top of the page, navigation menu is located on the left, etc.). When using the system, the user develops a pattern of thinking.
  A pattern of thinking is knowledge about the system and how it works. When a user operates a system that is new to them, they apply this model to new situations. Accordingly, using a new system provides a lower cognitive load, i.e., users spend less time acquiring the interface. In this case, users can spend more energy to achieving their purposes.
  This suggests that when designing user interfaces, it is necessary to consider general interface design rules that build around existing patterns of thinking, without first having to learn the specifics of how the system works. Designing an interface that meets expectations allows users to apply their knowledge based on previous experience, and some similarity of the new system to the old system allows them to focus on the things that are important to them.
- Ease of usage – interaction with the interface and movement through it should be easy and simple for users, i.e. requiring minimal effort. The time

required for a user to move to and interact with an interactive interface element is a critical parameter. It is important to properly set the size and position of interactive interface elements so that they are easy to find and so that the clickable area for selecting the element meets the user expectations. Currently, there are various ways of selecting elements, such as mouse, finger, stylus, etc. Such elements have different accuracy, which consequently complicates the design of interfaces.
- Simplification. Simplifying an interface or process helps reduce the cognitive load on users and increases the possibility that they will complete their task and achieve their purpose. But it is also worth considering that simplification can affect the user experience negatively – when we simplify everything to the point of meaninglessness and it is no longer clear, what interface actions are available, what the next steps might be, and where to find the correct information.

By adhering to these aspects, it is possible to minimize the complexity of the interaction between users and systems.

At the moment, the following problems in the design of user interfaces are relevant:

- the lack of common methods and tools for designing user interfaces limits the reusage of already developed components and increases the time required to teach the user new user interfaces, which also increases the development time and cost of designing and maintaining user interfaces;
- the extensibility of the interface components is not supported;
- the ability to transfer user interfaces from one implementation platform to another is difficult;
- most systems do not allow modifying the user interface during operation;
- the tools of helping the user to interact with the system interface are usually designed separately from the design of the interface itself;
- interface design tools and the system for which it is intended, as a rule, differ significantly, making it difficult to integrate the interface into the system;
- most systems do not have an ability to flexibly adapt the user interface to the needs of a particular user.

To solve these problems, in the article, an approach to designing user interfaces based on a unified logical-semantic model is proposed.

The design of user interfaces includes a number of sequential stages. Within this article, the design stages of traditional user interfaces and the design stages of adaptive intelligent multimodal user interfaces will be considered.

II. State of art

Adaptive user interface is a set of software and hardware tools that allows the user to use the system most effectively by automatically adjusting the interface to the specific user with respect to their needs and context [3].

Configuration of functionality and interface parameters can be performed either manually by the user or automatically by the system based on the available information about the user. Thus, it is necessary to distinguish between adaptive and adaptable systems – these terms are not synonymous, although in the literature, it is often possible to find a substitution of these concepts [4].

In adaptable systems, any adaptation is predefined and can be changed by users before the system runs. In contrast, in adaptive systems, any adaptation is dynamic, that is, it occurs at the same time as the user interacts with the system, and depends on the user behavior. However, the system can also be adaptable and adaptive at the same time [5].

In the literature, it is also possible to find the term 'adapted interface'. Adapted user interfaces are user interfaces adapted to the end-user at designing time, with no adaptation changes occurring in running time [6].

An Intelligent User Interface (IUI) is a user interface that can assume further user actions and provide information based on that assumption [7].

Next, we consider the stages of designing adaptive intelligent multimodal user interfaces.

A. Design methodology for adaptive intelligent multimodal user interfaces

The author of [8] identifies 4 main stages of design.

The first step is the **Analysis of users, system, and environment**.

The analysis phase is probably the most important phase in any design process, but even more so in IUI design. In the design process of a normal non-intelligent interface it is necessary to analyze who is the average user, what problems the interface should support, and on what system they will be performed. With an IUI there often is no average user. Ideally, an IUI should be able to adapt to any user in any environment. Therefore, the used adaptation technique should be designed in such a way that it can support all types of users. In practice, this is hard to achieve so we simply focus on certain user types. David Benyon [9] has identified five interrelated analysis activities for designing adaptive systems:

- Functional analysis: what are the main functions of the system?
- Data analysis: what is the meaning and structure of data in the application?
- Problem knowledge analysis: which cognitive capabilities do the users need to have, for example, the assumed mental model, known search strategies,

level of cognitive loading, etc? This analysis does require some design to have been completed before it can be performed.
- User analysis: what types of users are there and what are their capabilities, intelligence, and cognitive abilities?
- Environment analysis: in which environment is the system to operate?

The result of the analysis phase is a specification of the users purposes and information they need, as well as the functions and information that is required by the system. A problem that is often encountered in the analysis process of IUIs is the 'paradox of change'. Since there are hardly any common, functional IUIs, it is difficult to analyze how users will interact with them. On the other hand, if these interfaces are developed and become widely used, there is the risk that those systems will influence the analysis process. Wizard of Oz studies can be carried out to overcome this problem. In this kind of study, data is collected from a user who is led to believe that they are working on a fully functional and automatic system while, in fact, the system is being controlled by another human.

The second step is **development and implementation**.

The process of developing new interaction techniques and metaphors is mainly one of creativity. The best way is just to go out and try new concepts and ideas. Of course, there are many general guidelines for interface design that it is necessary to keep in mind. [10] Unfortunately, most of these guidelines were developed for DM-interfaces and are difficult to apply to IUIs. Some DM guidelines, such as consistency and user control, are violated by IUIs. This is also the reason that many DM-interface designers heavily criticized some IUIs concepts. On the other hand, other guidelines are better served by IUIs than by DM interfaces. For example, using natural language, IUIs can 'speak the user's language' much better than DM systems. Also, many IUIs try to reduce the short-term memory load of users by taking over problems. The result of the development and implementation process is a user interface that has a 'look-and-feel' that the designer thinks will suit the users and fulfill the requirements of the analysis phase.

The third step is **evaluation**.

In the evaluation stage of the design process we return to the questions of the analysis phase. The requirements that were drawn up in the analysis phase should be met, and the effectiveness of the prototype system has to be investigated. To determine this effectiveness, usability measures should be specified. These measures may include the number of errors, task completion time, the user's attitude towards the interface, etc. A very important but subjective usability criteria is user satisfaction. Since the user needs to work with the interface they have to say about whether it is a good design and is pleasant to work with.

The fourth step is **Refinement and tools**.

Based on the problems encountered in the evaluation stage, a number of design improvements will be made to the current prototype. Then, a new round of design, implementation, and evaluation is started. This iterative process will run until the result is satisfactory. If proven successful the final interface technique of metaphor can be incorporated into existing user interface design tools.

Kong et al. [11] proposed an approach to develop adaptive multimodal interfaces. The approach quantifies the user preference of each modality. The framework takes the specification of interaction contexts (user, device, and environment), the modality space, the requirements of each modality, and a mapping between modality space and preference space as inputs. The approach proposes the following steps to design the interface:

- to analyze problems and design the modality space (available input/output modalities) — to elicit user requirements and identify problems;
- to determine interaction contexts — to create interaction scenarios and determine interaction contexts (user, device, and environment);
- to assess the preference score of a modality under an interaction context — to evaluate and quantify (using a formula) the preference score of a modality.

A **framework for user interface adaptation** is proposed for the development of context-sensitive user interfaces [12]. It includes six steps:

- user interface modeling (description of the abstract user interface);
- default user interface design (default version of a concrete user interface);
- supplemental user interface1 design (extend or replace the default user interface) — this step is omitted when the system generate the default user interface automatically;
- context of usage instantiation (identification and instantiation of the context of usage — user model, device model, and environment model -– by the platform);
- user interface accommodation — system-drive -– (adaption of the user interface at runtime to match a particular context of usage);
- user interface customization — user-drive — (customization of the user interface by user operations).

For each step, the authors represent a description and examples of methods and techniques that can be used through the user interface development.

Based on the analysis of existing design techniques for adaptive intelligent multimodal interfaces, we can conclude that there are no generally accepted methods and design tools, while it is possible to identify common stages that are proposed by all authors:

- analysis of the context of usage and user problems;

- interface design and development;
- evaluating the quality of the designed interface.

Disadvantages when designing user interfaces are:

- the knowledge on each stage of design is held by different specialists in an unformalized, non-uniformized form;
- the absence of a formalized documentation phase of the design steps leads in the future to the need to create separate help-systems for users, developers, etc.;
- lack of comprehensive automation of the interface design process.

III. Proposed approach

To eliminate the disadvantages of existing solutions, it is proposed to use the ontological approach based on a semantic model in the design and implementation of an adaptive intelligent multimodal user interface. Such an interface is proposed to consider as a specialized subsystem for solving user interface problems, consisting of a knowledge base and a problem solver of interface problems. It is proposed to describe the model of knowledge base and problem solver on the basis of a universal unified language of knowledge representation, which will ensure compatibility between these components.

The architecture of the interface of such a system was considered in [13]. The proposed methodology for designing adaptive intelligent multimodal user interfaces will include:

- analysis of the user, their needs and purposes, and the context of usage;
- analysis of user interface requirements;
- user interface modeling;
- default user interface design;
- development of the user interface;
- analysis of the user interface and its adaptation.

Since knowledge about a particular stage is usually held by different experts, a **feature** of the proposed approach is the **necessary** formalized documentation of knowledge in a unified form and the usage of the component approach at each of the stages.

A library of reusable components of the knowledge base, problem solver, and interface is proposed for the component approach.

Thus, **results of the first stage**, such as the model of a particular user, their needs and the context of system usage (device, environment) should be formalized within the appropriate knowledge base ontologies of the intelligent interface. In this process of formalization, if necessary, components of the knowledge base should be reused from the library of reusable components and new components can be added to the same library.

Results of the second step are the final requirements for the interface, which must be formulated with respect to the user model and its purpose, as well as with respect to the context of usage. The results should also be formalized, and existing knowledge base components from a reusable component library can be used in the execution process.

In accordance with the requirements for the user interface, a model of an adaptive intelligent multimodal user interface is constructed, which is the **result of the third stage**. Such a model will include a formalized model of the knowledge base and the problem solver.

The **result of the fourth step** is a model-based designed user interface. Interface, knowledge base, and problem solver components can be used in the design. Such components will be written in a unified form, which will ensure their automatic compatibility.

The **result of the fifth step** is the implementation of the designed user interface. In this case it is necessary to use ready interface components from the library of reusable interface components.

At the **stage of user interface analysis and adaptation**, ready-made components of the problem solver are used.

This will form a knowledge base of the designed interface, which can automatically be used as a **help-system** for users, developers, etc.

Thus, based on the above, the following demands can be made to the technology, on the ground of which this approach can be implemented:

- the technology should support a component approach to creating semantic models;
- the technology should allow the simple integration of various semantic models within a unified system;
- the technology should provide an opportunity to describe different semantic models and their components of various types of knowledge in a single format.

Among the existing system design technologies, the *OSTIS Technology* meets the specified requirements, among the advantages of which it is also possible to additionally highlight the presence of a basic set of ontologies that can serve as the ground for the IUI model being developed.

Thus, within this approach, in the article, an option for implementing a framework for building UIs is proposed, which is based on the *OSTIS Technology*, providing a universal language for the semantic representation (encoding) of information in the memory of intelligent computer systems, called an *SC-code*. Texts of the *SC-code* (sc-texts) are unified semantic networks with a basic set-theoretic interpretation. The elements of such semantic networks are called *sc-elements* (*sc-connectors* and *sc-nodes*, which, in turn, can be *sc-edges* or *sc-arcs*, depending on the orientation). The *Alphabet of the SC-code* consists of five main elements, on the ground of which SC-code constructions of any complexity are built, as well as more particular types of sc-elements are introduced (for example, new concepts). The memory that

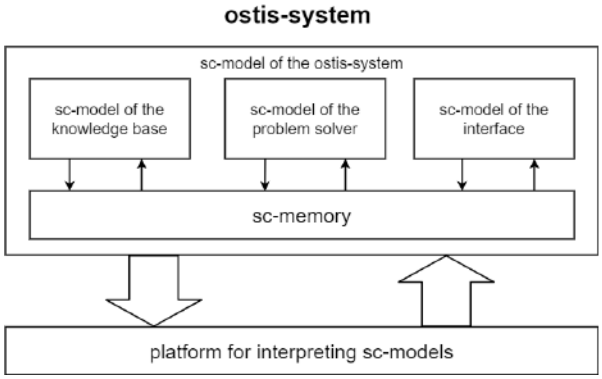

Figure 1. The architecture of the ostis-system

stores SC-code constructions is called semantic memory, or *sc-memory* [14].

The architecture of each ostis-system includes a platform for interpreting semantic models of ostis-systems as well as a semantic model of the ostis-system described using the SC-code (sc-model of the ostis-system). In turn, the sc-model of the ostis-system includes the sc-model of the KB, the sc-model of the interface, and the sc-model of the problem solver. The principles of the design and structure of KBs and problem solvers are discussed in more detail in [15] and [16], respectively. Within this article, the sc-model of the UI will be considered, which is included in the sc-model of the interface. Its principles were described in the article [17], the development of which is this work.

The architecture of the ostis-system is shown in Figure 1.

A library of reusable ostis-system components already exists within the OSTIS Technology.

It is important to note that all of its components are compatible with each other and stored in a single form of representation.

Within library of reusable ostis-system components there is the following hierarchy of components.

reusable ostis-systems component
⇒ *subdividing**:
{• *reusable knowledge base component*
⊃ *semantic neighborhood*
⊃ *subject domain and ontology*
⊃ *knowledge base*
⊃ *template of a typical ostis-systems component*
∋ *Template for the subject domain description*
∋ *Template for the relation description*
• *reusable problem solver component*
⊃ *atomic knowledge processing agent*
⊃ *knowledge processing program*
• *reusable interface component*
⊃ *reusable user interface component for display*
⊃ *interactive reusable user interface component*
}

Any ostis-system can integrate an intelligent interface according to the proposed architecture. But it is also important to clarify the concept of user interface in the context of the OSTIS Ecosystem.

Within the OSTIS Ecosystem, there is the concept of a personal ostis-assistant, an ostis-system that is a personal assistant to the appropriate human who is a part of the OSTIS Ecosystem, i.e. an ostis-system that mediates the human interactions with the members of all the collectives (ostis-communities) of which the human is a member.

Since user interaction with the OSTIS Ecosystem only takes place via a personal assistant, an adaptive intelligent multimodal user interface is required not for all ostis-systems but only for ostis-systems that are personal assistants.

A model of the user, their activities, etc. in this context should only be stored within the user's personal assistant and shared with other systems as needed.

The personal assistant must be able to retrieve the interface model of other ostis-systems and display it to the user.

Proposed approach will allow:
- unifying the methods and tools for designing user interfaces, providing the ability to reuse already developed components;
- ensuring the extensibility of the interface components;
- designing tools to help the user to interact with the interface of the system in connection with the design phase of the interface itself;
- ensuring that interface design tools and the system for which it is designed will be compatible, providing effective integration of any interface into any system;
- using the help system, which is an intermediary in communicating with the system.

IV. Conclusion

In the article, the methods of designing interfaces of next-generation intelligent computer systems are considered.

As a result for the analysis of existing methods of designing adaptive intelligent multimodal user interfaces, it was concluded that there are no generally accepted methods and means of designing user interfaces, however, there are the following general stages of design:
- analysis of the context of usage and user problems;
- interface design and development;
- evaluating the quality of the designed interface.

Among the disadvantages of the reviewed methodologies for the design of user interfaces were the following:

- the knowledge on each stage of design is held by different specialists in an unformalized, non-uniformized form;
- the absence of a formalized documentation phase of the design steps leads in the future to the need to create separate help-systems for users, developers, etc.
- lack of comprehensive automation of the interface design process.

To address these disadvantages, within the article, it is proposed to introduce a necessary stage of the formalized documentation of knowledge in a unified form, as well as an ontological approach based on a semantic model in the design and implementation of an adaptive intelligent multimodal user interface based on the OSTIS Technology is considered, which will allow:

- unifying the methods and tools for designing user interfaces, providing the ability to reuse already developed components;
- ensuring the extensibility of the interface components;
- designing tools to help the user to interact with the interface of the system in connection with the design phase of the interface itself;
- ensuring that interface design tools and the system for which it is designed will be compatible, providing effective integration of any interface into any system;
- using the help system, which is an intermediary in communicating with the system.

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Методика и средства компонентного проектирования интерфейсов интеллектуальных компьютерных систем нового поколения

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В статье рассматривается методика проектирования интерфейсов компьютерных систем нового поколения. Описаны этапы проектирования адаптивных интеллектуальных мультимодальных пользовательских интерфейсов и применение этих этапов в контексте Технологии OSTIS.

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