The structure of next-generation intelligent computer system interfaces

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***Abstract*—This article deals with the structure of adaptive multimodal interfaces of next-generation intelligent computer systems, which provide a transition from the paradigm of literate user to the paradigm of equal cooperation between the user and the intelligent system, which will increase the efficiency of human-machine interaction.**

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

I. Introduction

The organisation of user interaction with computer systems (including intelligent computer systems) has a significant impact on user experience, user satisfaction, and the effectiveness of the automation of human activity.

One of the key properties of next-generation intelligent computer systems is their **interoperability** - the ability to interact effectively. Such systems are autonomous and self-sufficient actors on par with humans. However, at the core of modern organization of user interaction with a computer system is the paradigm of **literate 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 particular system and learn the principles of interaction with it in order to solve the required tasks.

The current stage of the field of Artificial Intelligence requires the transition from the paradigm of competent control of the tool used to the paradigm of **equivalent cooperation, partner-like interaction** of intellectual computer system with its user to increase the efficiency of interaction. The friendliness of the user interface should be determined by the ability of the system to adapt to the characteristics and qualifications of the user, its ability to resolve any problems the user might experience during the dialogue with the intelligent computer system, and the way it is concerned with the improvement of the user's communication skills. Consequently, it is necessary to move away from adapting the user to the system (by teaching them how to use it) towards the adaptation of the interface itself to the goals, tasks and characteristics of a particular user in real time. [1]

Thus, the key problems at the current stage are:

- the necessity for the user to learn how to interact with each particular system;
- the lack of partnership between the user and the system (the system is controlled by the user), which leads to the user having to be a constant initiator of interaction;
- tha lack of a system's adaptation to each individual user and the environment in order to maximise the user's comfort while using the system.

In order to solve these problems, this article discusses the principles of organising partner-like interaction between a user and an intelligent system, as well as the principles of building next-generation intelligent computer system interfaces that provide a transition to the paradigm of equal cooperation.

II. State of the art

An interface is a set of technical, software and methodological (protocols, rules, conventions) tools, which enable the exchange of information between the user and devices and programmes, as well as between devices and other devices and programmes. [2]

Broadly speaking, it is a way (standard) of interacting between objects. In technical terms, an interface defines the parameters, procedures and characteristics of interaction between objects.

Interfaces come in many varieties. They differ in the nature of the systems that interact with each other, implementation, and functions.

Regardless of the type of interface, the interaction of the computer system with its environment is facilitated by sensors and effectors.

A sensor (or receptor) of a system is a component of a cybernetic system that generates information in the system's memory about the current value of a property (characteristic, parameter) corresponding to that component of the physical environment of the cybernetic system that is directly adjacent to the said component.

An effector is a component of a cybernetic system that is able to change its state in order to directly affect its physical shell and the external environment.

It is customary to distinguish the following types of interfaces:

- physical interface;
- software interface;
- user interface.

A physical interface is a device that converts signals and transmits them from one piece of equipment to another. A physical interface is defined by a set of electrical connections and signal characteristics.

A software interface is a system of unified connections designed to exchange information between components of a computer system. The software interface defines a set of required procedures, their parameters and how to call them.

A user interface is the combination of hardware and software that enables the exchange of information between a user and a computer system. [3]

This article will focus on the user interface, although many of the principles can be applied to other types of interfaces. A distinction is made between the following types of user interfaces:

- command user interface;
- WIMP interface;
- SILK interface. [4]

A command user interface is a type of interface in which a person gives "commands" to a computer and the computer executes them and prints the result to the person. The command user interface is implemented in the form of batch technology and command line technology.

A WIMP interface (graphical user interface: Window, Image, Menu, Pointer) is an interface in which program functions are represented by graphical screen elements. A characteristic feature of this type of interface is that the dialogue with the user is not with the help of commands but with the help of graphic images - menus, windows, and other elements. Although this interface also gives commands to the machine, this is done "indirectly", through graphic images. This type of interface is implemented on two technological levels: there can be simple graphical interfaces and "pure" WIMP interfaces.

The features of a simple graphical interface are as follows: highlighting screen areas; overriding keyboard keys depending on the context; using manipulators and keyboard keys to control the cursor. A WIMP interface proper is characterised by the following features: all interaction with programs, files and documents takes place in windows; all objects are represented as icons; all actions with objects are performed using menus; extensive use of manipulators to point to objects.

A SILK interface (natural language interface: Speech, Image, Language, Knowlege) is an interface in which the user dialogs with the system in natural language. This type of interface is closest to the usual, human form of communication. The system finds commands for itself by analyzing human speech and finding key phrases in it. The result of the commands is also converted into a human-understandable form.

Figure 1. The context-of-use for adaptive UI

Dialogues form the basis of interaction in the user interface. Dialogue in this case is understood as a regulated exchange of information between the user and the system, carried out in real time and aimed at completing a specific task collaboratively. The exchange of information is carried out by transmission of messages.

Tasks to be solved by interfaces (interface tasks) include:

- analysing input information;
- managing effectors.

The quality with which a cybernetic system solves tasks is conditioned by:

- the cybernetic system's ability to understand sensory information;
- the cybernetic system's ability to understand the messages it receives;
- the ability of the cybernetic system to operate independently in the external environment.

The interface of next-generation intelligent computer systems must be able to interact with the user on an equal footing, adapt to the user's characteristics, and accept different types of information input. This kind of interface design is often described as *adaptive*, *intelligent* and *multimodal*.

An adaptive user interface is a set of software and hardware that allows the user to use the system in the most efficient way by automatically adapting the interface to the user's needs and context. [5]

Generally, the context-of-use consists of user, platform, and environment, as shown in Figure 1. [6]

Functionality and parameters of the interface can be adjusted either manually by the user or automatically by the system based on the information about the user. Thus a distinction must be made between adaptive and adaptable systems, terms that are not synonymous, although it is quite common to see these terms used interchangeably in the literature. [7]

In adaptive systems, any adaptation is predefined and can be changed by users before the system starts up. In contrast, in adaptive systems any adaptation is dynamic, i.e. it occurs at the same time as the user interacts with the system, and depends on the user's behaviour. But a system can also be adaptive and adaptive at the same time. [8]

The disadvantage of editing the interface manually is that the user needs to be reasonably familiar with both the system itself and the means to modify its interface.

The term adapted interface can also be found in the literature. Adapted user interfaces [9] are user interfaces adapted to the end-user at design time, with no adaptation changes occurring in run time.

Intelligent User Interface (IUI) - a user interface that can assume what actions the user could perform next and present information based on this assumption. [10]

An intelligent interface should perform the following functions:

- communication function. Communication can take place on the basis of text messages, all kinds of voice input/output systems, graphical interaction tools, etc.
- automatic programme synthesis function. The user message must be converted into a working programme that the computer system can execute.
- justification function. A user who has little or no knowledge of how a computer system converts his task into a working program and what methods it uses to arrive at a solution should be able to know how the system arrived at the resulting solution. He can ask how his task was converted into a program, what method was used to find the solution, how this solution was arrived at, and how it was interpreted in the output. Thus, the justification function includes both an explanation function and a trust function, the purpose of which is to increase the user's trust in the system.
- education function. Next-generation intelligent computer systems must have special means by which the user gradually learns how to use the system and the subtleties of successful communication with it. [11]

As we have seen, the terms "intelligent interface" and "adaptive interface" are different. However, in various articles these concepts are treated as synonyms.

The term intelligent user interface is often used along with various adapt* terms, as reported by a meta-study conducted by Volkel et al. [12], where authors confirmed that the studies might call an entity both "intelligent" and "adaptive". The concurrence can even be observed in use of the term adaptive intelligent user interfaces. Though this term is used infrequently, it describes user interfaces with intelligent adaptive mechanisms capable of monitoring the user behavior and adapting the user interface accordingly, outside of the predefined rules. Many intelligent interfaces can be described as adaptive interfaces, though not all adaptive interfaces are intelligent. IUIs can be associated with intelligent systems, i.e., systems that give appropriate problem-solving responses to problem inputs, even if such inputs are new and unexpected.

An often-made mistake is to confuse an IUI with an intelligent system. A system exhibiting some form of intelligence is not necessarily an intelligent interface. There are many intelligent systems with very simple non-intelligent interfaces and the fact that a system has an intelligent interface does not say anything about the intelligence of the underlying system (Figure 2).

Unfortunately, the boundary between a system and its interface is not always very clear. Often the technology used in an IUI is also part of the underlying system, or the IUI may even form the entire system itself. For example, a speech recognition system can be part of an intelligent interface to a system, but it can also be the complete system depending on how you look at it. If an IUI can be regarded as a system on its own, then it is by definition an intelligent system.

A multimodal interface is a user interface designed to handle two or more combined modes of user input, such as speech, pen, touch, hand gestures, gaze, etc., in a manner coordinated with the output of a multimedia system.

Interaction with most traditional computer systems is done via keyboard and mouse (touchpad, stylus). The user interface of such systems generally does not store information about the user model, the history of the user's actions, and the model of the subject domain. Traditional user interfaces also do not contain an adaptation module. Figure 3 shows the architecture of traditional user interfaces.

The overall architecture of an adaptive intelligent multimodal user interface, in turn, generally looks as shown in Figure 4.

Input coming from the keyboard, mouse, microphone, camera, or possibly some other input device is recorded and then (pre-)processed. Processing includes labeling of events and other interesting input features. After each input modality has been analyzed, the separate modalities are fused together and evaluated. Note that in some cases it is desirable to do the fusion of input streams before the input processing, depending on the application and the features that need to be detected. Once we know what input is coming in, we can start to determine the necessary course of action. First we have to evaluate what to do in the current situation. If there is information

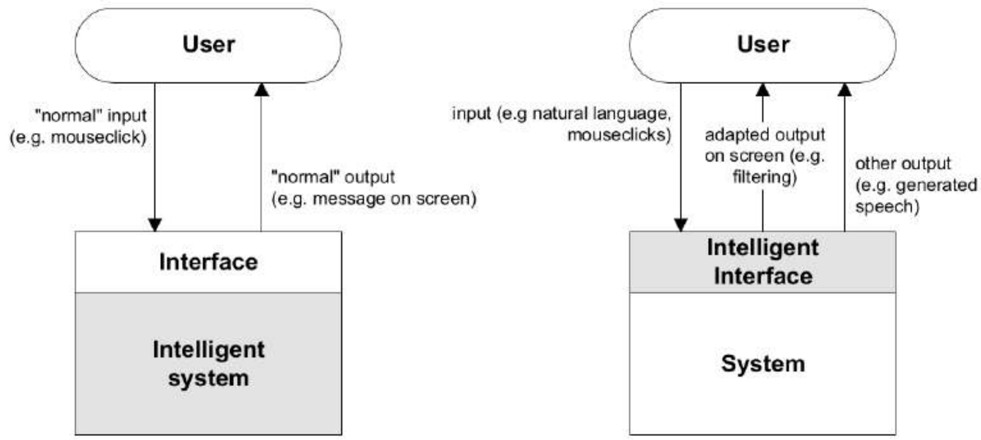

Figure 2. An intelligent system versus an intelligent interface

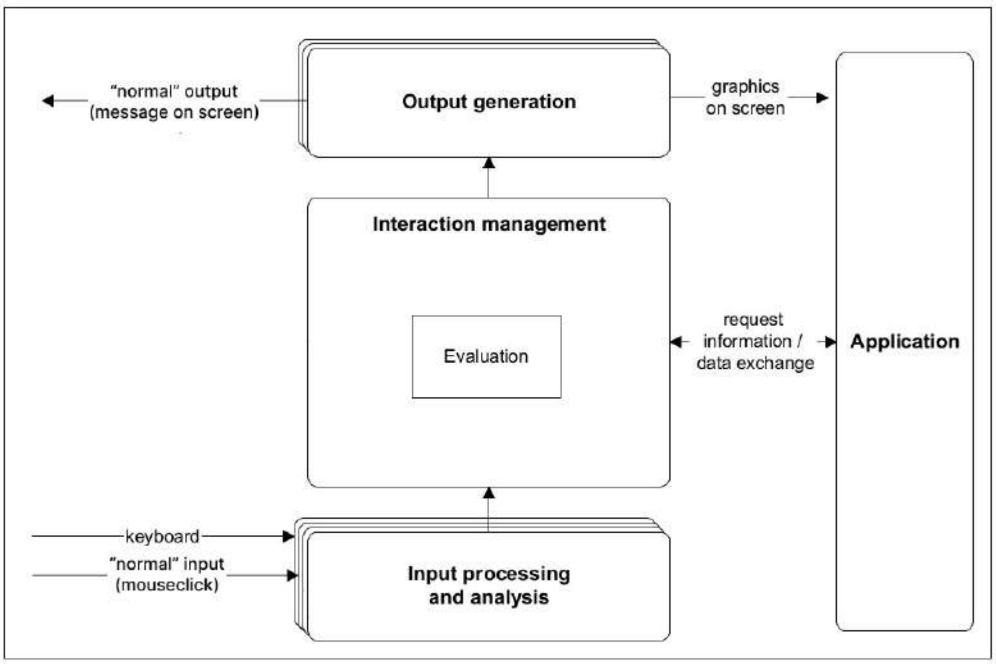

Figure 3. Traditional user interface architecture

missing or if the user has requested information (e.g. the recorded speech contained a question from the user) this information will be requested from the application or some other external source. Usually there is an inference mechanism that draws up conclusions and updates the system's information: the user model, his interaction history, and information about the application domain. Once, all the necessary information is available and updated, the system must decide the best alternative for action. In the figure above we have called this adaptation, since usually some form of adaptation of the interface is chosen. Often, evaluation and adaptation occurs simultaneously using one inference engine for both, making the distinction between the evaluation and adaptation process is not quite clear. The chosen action still has to be generated, which is being done in the output generation part. Most IUIs can be created with or fitted in this architecture, although often not all parts need to be explicitly modeled. [13]

Among modern tools for creating adaptive user interfaces, the following can be highlighted, as shown in Figure 5. [14]

Regardless of the means of creating adaptive intelligent multimodal user interfaces, such systems must effectively store and process knowledge about the user, the interaction with the user, and other relevant information. Most of

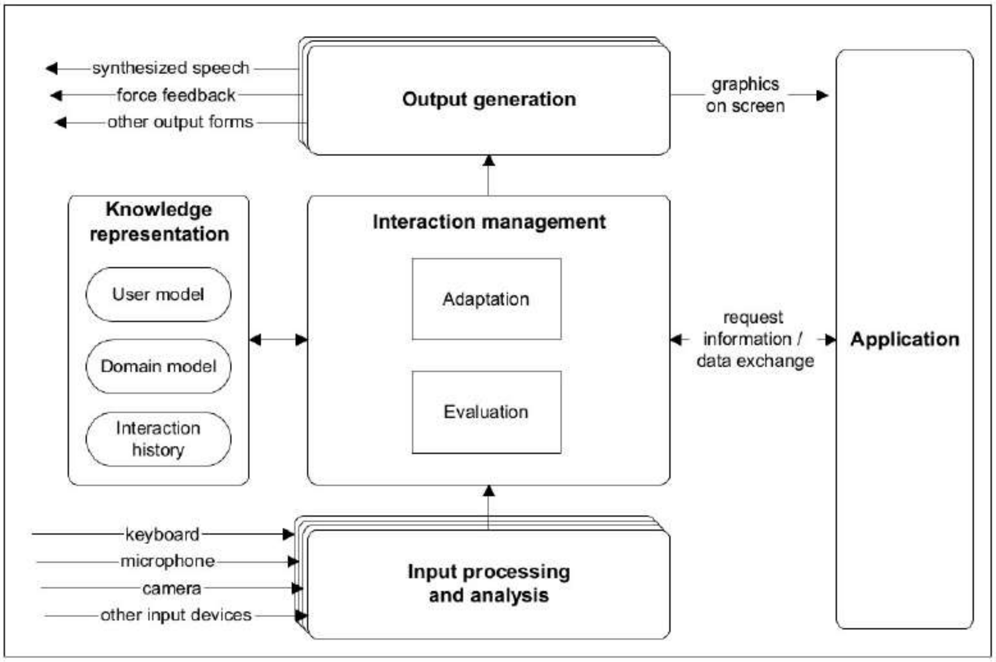

Figure 4. Intelligent user interface architecture

Legend
- ● Completely
- ◑ Partially
- ○ Does not
- ◌ Not Specified

	Multimodal data source	Directed and indirect adaptation	Modeling approach	Context			Supporting Tool	Adaptation Aspects			User Feedback on Adaptation
				User	Platform	Environment		Presentation	Navigation	Content	
3-Layer Architecture	◑	◑	◑	●	●	●		◌	◌	◌	◑
CAMELEON-RT	●	●	◌	◑	◑	◑	●	◌	◌	◌	○
CEDAR	●	●	●	●	●	●	●	◑	●	●	●
Malai	◑	●	◑	○	●	○	●	●	●	◑	○
TRIPLET	◑	◑	●	●	●	●	◌	●	●	●	◑
Egoki system	◑	◑	●	●	●	○	○	●	●	●	◑
SUPPLE	◑	●	●	●	●	○	●	●	◑	○	○
MyUI	●	◑	●	●	●	●	●	●	●	◑	◑
Roam framework	◌	◑	●	○	●	○	◌	●	○	○	○
XMobile	◌	◑	●	○	●	○	◑	●	◑	○	◌
AUI-UXA	●	●	●	●	●	●	●	●	●	●	●

Figure 5. Existing tools for creating adaptive user interfaces

adaptive UI system use ontological models for storing the information to tailor the UI. It is the ontological approach that allows to:

- create the most complete unified description of the different aspects of the user interface;
- easily integrate various aspects of the user interface;
- make it easier to reuse the interface model.

In ontological approach, it is common to distinguish ontologies and subject domains. The knowledge base of an adaptive intelligent multimodal interface should include at least the following domains:

- Subject domain and ontology of user model;
- Subject domain and ontology of interface components;
- Subject domain and ontology of interface actions;
- Subject domain and ontology of context of use.

Among already existing **user model ontologies**, we can highlight the GUMO ontology [15]. This user model ontology differentiates between:

- physiological state - can change within seconds;
- mental state - can change within minutes;
- emotional state - can change within hours;
- characteristics - can change within months;
- personality - can change within years;
- demographics - can't normally change at all.

H. Paulheim, F. Probst [16] discusses **an interface component ontology**, with the following component types at the top level:

- presentation user interface component;
- decorative user interface component;
- interactive user interface component;
- data-input-component;
- presentation-manipulation-component;
- operation-trigger-component
- container;
- window;
- modal-window;
- non-modal-window.

An ontology can also include a class of component properties that define the appearance of interface elements, ranging from simple properties, such as font, colour, element size, to composite properties, containing sets of interface solutions. [17]

Classification of **interface actions** is presented in [16] and contains the following main classes:

- mouse-action;
- speech-action;
- tangible-action;
- touch-action;
- pen-base-action.

An ontology of context usage is discussed in [18] and describes:

- Users' status:
  - Motion (standing, sitting, walking);
  - Able to listen (yes, no);
  - Able to type (yes, no);
  - Able to talk (yes, no);
  - Able to read (yes, no);
- Natural environment:
  - Lighting (bright, moderately lit, dark);
  - Noise (noisy, quiet)Wind (strong, light, no wind);
  - Weather (sunny, cloudy, rainy);
  - Temperature (hot, warm, cold);
  - Location (in an office, in an airport, on a street, ina library, at home, at a shopping mall);
- Device features:
  - Screen size (big, small);
  - Type of screen (monochrome, colored);
  - Keyboard (large, small, virtual).

It is common to use **intelligent agents** to manage user interaction with the system.

An intelligent agent is one that is capable of flexible autonomous action in order to meet its design objectives. According to this definition, flexible means three things:

- Reactivity: intelligent agents are able to perceive their environment, and respond in a timely fashion to changes that occur in it in order to satisfy their design objectives;
- Pro-activeness: intelligent agents are able to exhibit goal directed behavior by taking the initiative in order to satisfy their design objectives;
- Social ability: intelligent agents are capable of interacting with other agents (and possibly humans) in order to satisfy their design objectives.

Intelligent agents are directed towards a single goal, but they possess more knowledge about reasoning within the space of their activity. Knowing when to use other resources (other agents), the preferences of the user or client, constructs for negotiation deals, and other abilities are the marks of an intelligent agent.

The following conclusions can be made, based on our analysis:

- To move to a paradigm of equal cooperation between user and system, interfaces need to be adaptive, intelligent, and multimodal. Existing solutions allow such interfaces to be designed but have a number of shortcomings, which will be presented below.
- The structure of intelligent interfaces includes a knowledge base, a module for managing user interaction with the system.
- Ontological approach is actively used in the design of knowledge bases and some ontologies that are used in the design of intelligent interfaces have already been implemented.
- The module for managing user interaction with the system is usually implemented based on a multi-agent approach.

Disadvantages of existing solutions include:

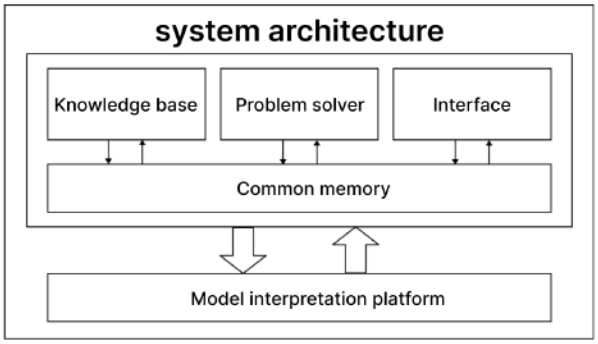

Figure 6. Intelligent system/intelligent interface architecture

- Existing solutions generally involve a question-and-answer principle of interaction.
- Still relevant is the problem of compatibility between the intelligent interface and the intelligent system for which it is being created, due to different tools and methods being used in design and implementation.
- The compatibility of the intelligent interface components (knowledge base and interaction management module) with each other remains a relevant problem.

III. Proposed approach

To address the shortcomings of existing solutions, it is proposed to use an ontological approach based on a semantic model in the design and implementation of an adaptive intelligent multimodal user interface. We propose to view such an interface as a specialized subsystem for solving user interface problems that consists of a knowledge base and an interface problem solver. The model of knowledge base and solver can be described on the basis of a universal unified knowledge representation language, which will ensure compatibility between these components.

An intelligent system for which an intelligent interface is to be created should have a model described using the same unified language as the intelligent interface itself. This will ensure that the intelligent system and its intelligent interface are compatible.

An intelligent interface problem solver should be based on a multi-agent approach, and the agents themselves should be able to initiate actions and messages to the user and other agents.

The architecture of such an intelligent system and an intelligent interface based on the same principles would look as follows (Figure 6).

Thus, we can formulate a list of requirements that the technology necessary to implement this approach should satisfy:

- the technology should support component approach to creating semantic models;
- the technology should allow straightforward integration of various semantic models within a unified system;
- the technology should make it possible to describe different semantic models and various types of knowledge therein using a single format.

As compared to other existing system design technologies, the *OSTIS Technology* meets all the specified requirements. Another advantage of the technology that can be highlighted is that it includes a basic set of ontologies that can serve as the ground for the IUI model being developed.

Thus, within this approach, we propose base the implementation of a framework for building UIs on the *OSTIS Technology*. This technology provides a universal language for the semantic representation (encoding) of information in the memory of intelligent computer systems, called *SC-code*. Texts written in *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 subdivided into *sc-edges* or *sc-arcs*, depending on the directivity). The *SC-code alphabet* consists of five main elements that can be used to create SC-code constructions of any complexity as well as to introduce more specific types of sc-elements (for example, new concepts). The memory that stores SC-code constructions is called semantic memory or *sc-memory*. [19].

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 SC-code (sc-model of the ostis-system). In turn, the sc-model of the ostis-system includes sc-model of the knowledge base, sc-model of the interface, and sc-model of the problem solver. The principles of the design and structure of knowledge bases and problem solvers are discussed in more detail in [20] and [21], respectively. This article describes the sc-model of the UI, which is included in the sc-model of the interface. Its principles were described in the article [22], which this paper builds upon.

The architecture of the ostis-system is shown in Figure 7.

The proposed architecture for an adaptive intelligent multimodal user interface is shown in Figure 8.

The subject domains of user, context of use, user interface actions, and interface components is proposed to be formalised in the same way as the ontologies discussed in section 2.

The subject domain of user interface is a formalised typology of user interfaces. An example of a fragment of this domain in a user interface knowledge base would look as follows.

user interface

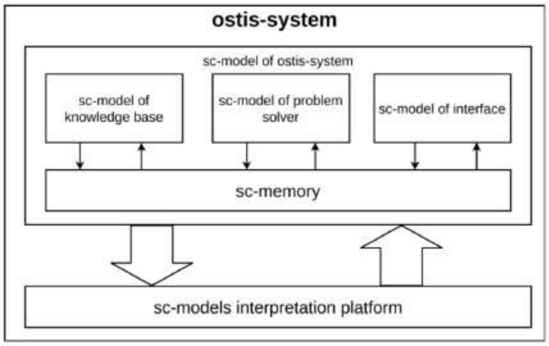

Figure 7. The architecture of the ostis-system

⊃ *graphical user interface*
  ⊃ *WIMP interface*
    ⊃ *ostis-system user interface*
⊃ *command-line interface*
⊃ *SILK interface*
  ⊃ *natural-language interface*
    ⊃ *speech interface*

Within the subject domain of interface design methodologies, it is proposed to formalise the various existing interface design methods, such as:

- designing user interfaces based on ontologies (ontology-driven user interface design);
- ergonomic design methodology;
- goal-oriented design methodology.

Within the interface design tools subject area, it is proposed to formalise existing interface design tools such as:

- tools to support the creation of an interface by writing code;
- interactive tools;
- tools based on creating an interface by linking separately created components.

[23]

The subject domain of messages is a formalised typology of messages such as declarative, interrogative, etc.

Within the subject domain of logical rules for interface adaptation, it is proposed to formalise a typology of logical rules on the basis of which interface adaptation to the user will take place.

The subject domain of internal interface agent actions describes the classification of possible actions in the ostis system [3]. A fragment of the knowledge base containing this domain is given below.

action in sc-memory
⊃ *action of interpreting a program stored in sc-memory*
⊃ *action of setting the mode of the ostis-system*
⊃ *action in sc-memory initiated by a question*
⊃ *action of editing a file stored in sc-memory*
⊃ *action of editing the ostis-system knowledge base*

In [24], a problem solver model has been described. The problem solver model should also include a user interface adaptation and evaluation module.

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.

The OSTIS Ecosystem is a socio-technical network of interactions between:

- ostis-systems themselves;
- users of the specified ostis-systems (both end-users and developers);
- some computer systems that are not ostis-systems (they can be used as additional information resources or services).

The objectives of the OSTIS Ecosystem are:

- rapid implementation of all agreed upon changes in ostis-system;
- permanent maintenance of a high-level mutual understanding between all the systems that make up the OSTIS Ecosystem and all their users;
- corporate solution of various complex tasks requiring the coordination of several (most often a priori unknown) ostis-systems, and possibly some users.

The OSTIS Ecosystem has a concept of a personal ostis-assistant, which is an ostis-system that is a personal assistant to a member of OSTIS Ecosystem, i.e. an ostis-system that mediates the person's interactions with the members of all the collectives (ostis-communities) of which the person is himself a member.

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

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

IV. Conclusion

The article discusses the principles of organising partne-like interaction between a user and an intelligent system and the principles of constructing interfaces for next-generation intelligent computer systems that provide a transition to the paradigm of equal cooperation between a user and a user interface.

The following conclusions have been drawn as a result of the analysis:

- In order to move to a paradigm of equal cooperation between a user and a system, interfaces need to be adaptive, intelligent, and multimodal. Existing solutions allow such interfaces to be designed but have a number of shortcomings, which will be presented below.

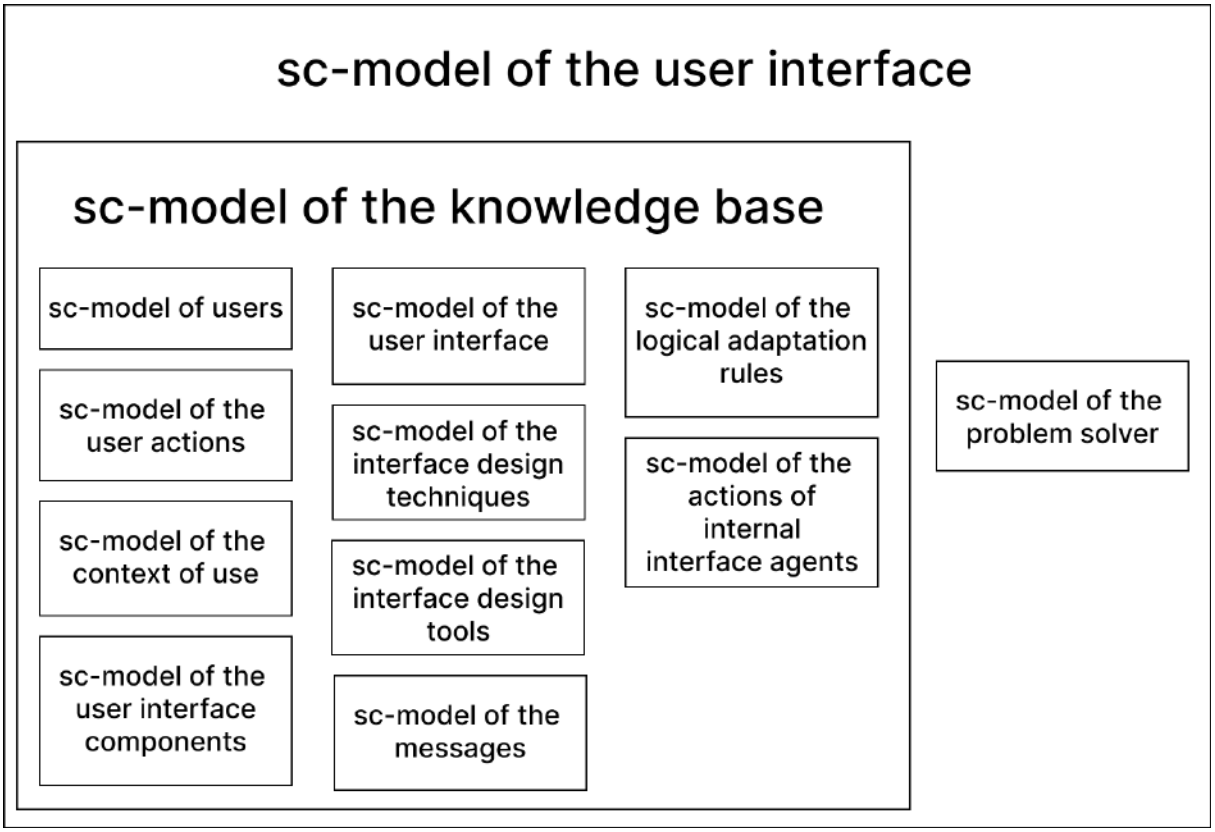

Figure 8. Intelligent interface architecture

- The structure of intelligent interfaces includes a knowledge base and a module for managing user interaction with the system.
- Ontological approach is actively used in the design of knowledge bases, and some ontologies have already been implemented and utilized in the design of intelligent interfaces.
- The module for managing user interaction with the system is usually implemented based on a multi-agent approach.

The following shortcomings of existing solutions have been highlighted:

- Existing solutions generally involve a question-and-answer principle of interaction.
- Still relevant is the problem of compatibility between the intelligent interface and the intelligent system for which it is being created, due to different tools and methods being used in design and implementation.
- The compatibility of the intelligent interface components (knowledge base and interaction management module) with each other remains a relevant issue.

We proposed an ontological approach based on a semantic model that can be used in the design and implementation of an adaptive intelligent multimodal user interface. The approach is based on the OSTIS Technology, which will provide:

- compatibility of an intelligent interface with an intelligent system;
- compatibility of an intelligent interface components with each other;
- user interaction with the system through an intelligent interface on the principle of equality.

The architecture of an intelligent interface was proposed, its components and its application in the context of the OSTIS Ecosystem have been discussed in detail.

V. Acknowledgment

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Структура интерфейсов интеллектуальных компьютерных систем нового поколения

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В работе рассматривается структура адаптивных мультимодальных интерфейсов интеллектуальных компьютерных систем нового поколения, обеспечивающих переход от парадигмы грамотного пользователя к парадигме равноправного сотрудничества пользователя с интеллектуальной системой, что позволит повысить эффективность человеко-машинного взаимодействия.

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