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OBJECT TECHNOLOGIES OF DESIGNING CORPORATE INFORMATION SYSTEMS OF MASS MEDICAL SERVICE

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The paper deals with the fundamental issues of designing corporate mass medical service systems. Basic principles of design of infological models of object domains and potentialities of object technologies for structural analysis and logic design of distributed applications are considered.

Keywords: *mass medical service, medical computer-aided system, corporate information system, object technology, analysis and design of distributed systems.*

1. BASIC PROBLEMS OF DESIGN OF COMPUTER-AIDED SYSTEMS OF MASS MEDICAL SERVICE

A modern trend in clinical medicine is the integration of diagnostic operations into a unified and continuous technology, according to which the process of estimation of the state of a person and formulation of recommendations concerning a correction of this state depends not so much on the opinion of one expert (even of the highest qualification) as on the corporate interaction among medical experts accompanying the diagnostic trajectory of the person on all its levels. On this basis, we can claim that a solution of this problem is possible only as a result of reorganization of the methodology of diagnostic processes (DP) consisting of the transition from individual workstations (WS) of doctors of particular specialties to technologies of the use of corporate integrated computational and diagnostic resources relating various information systems of clinical diagnostics (CnD) by means of a unified technological space of a computer-aided system of mass medical service (CASMMS) [1]. Such corporate infrastructures are created on the basis of local area networks (LAN) by integrating them into a wide area network (WAN) of data transmission, in which a CASMMS occupies a definite segment [2, 3]. However, creators of information systems based on corporate medical computer networks (CMCN) face the following three serious problems: to ensure the validity of the data being accumulated, to overcome the heterogeneity of initial components, which frequently not only are written in different languages but also are supported by different platforms, and to design a general means for storage and processing of incoming diagnostic information (DI) in the form of a distributed databank (DDB) under the conditions of an initially distributed DP.

Solution of these problems can be promoted by a fast-paced area of programming, namely, the creation of object middleware (OMW), which, irrespective of the form of its architecture (the Distributed Component Object Model (DCOM) of Microsoft or Common Object Request Broker Architecture (CORBA) of the OMG consortium), makes it possible to organize a unified information space whose elements can communicate with one another independently of their registration in the distributed environment, their platforms, and their implementation languages [4]. Taking into account the fact that DCOM is mainly designed for Windows, and the fact that medical applications are supported, as a rule, by different operational platforms, we will mainly consider CORBA in what follows. Despite the fact that the initial objective of the Object Management Group (OMG) was the simulation of the outside world on the basis of the notion of an object, the development of object technologies also demonstrated another aspect of the object paradigm, namely, the possibility of creation of OMW of a new type that establishes relations between sets of components within the framework of a unified

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information environment (IE) supporting the interaction between the components rather than by inflexible schemes of data export–import and organization of bridges connecting them by means of SQL, IPC, TP, and Groupware (i.e., by controlling unstructured data such as texts, faxes, email messages, etc.) or Message Oriented Middleware (MOM).

The construction of systems of the CASMMS class, which are based on the wide use of the technology of distributed data processing, is a multistage and labor-consuming process. Since the expenses for the correction of errors made at any stage of the life cycle of a CASMMS are smaller by a factor of ten than those for their correction at the next stage, the following two initial stages are most critical: the analysis of the object domain (ObD) of the CASMMS and its design (the definition of objects, modules, and the entire architecture). In such an ObD of clinical medicine as CnD with its inherent complicated hierarchy and plenty of centers of gathering and processing of DI, the design of a DDB should begin with a preliminary infological analysis of the generality of ObDs for a considered set of participants in a DP. A full-scale design can be realized only by means of object technologies, which allow one to take into account distinctive features not only of CnD but also the variety of DI characterized by a high degree of uncertainty and multivaluedness.

The integration of all component parts of CnD into a unified and continuous technology is the necessary condition of creation of a functional model of a CASMMS, within the framework of which the system of interaction between objects of object domains of LANs for clinical diagnostics in the CASMMS is described by tools of IEs with the use of the To-Be notation (specifying the sought-for model) [5, 6].

2. INFORMATION ENVIRONMENT OF A DIAGNOSTIC PROCESS

2.1. The Nature of Medical Information. The domain of informatization considered in this article consists of basic CnD operations at the stages of gathering, transmission, and processing of clinical information [7]. The methodological basis of the class of CASMMSs consists of technologies of processing data and knowledge. Computer-aided CnD systems of this class use the following sources of primary data:

(1) *systems of identification of patients*, supporting the gathering of numerical and symbolic medical data (passport data, risk factors, etc.);

(2) *systems of adaptive interviewing*, supporting the gathering of only symbolic medical data (anamnesis, complaints, etc.);

(3) *systems of distributed computer-aided examination*, supporting the gathering of medical data of various types beginning with the results of current examinations (such as electrocardiography (ECG), clinical and biochemical analyses, roentgenography, etc.) obtained within the framework of capabilities of functional modules (FM) of an institution and ending with the results of special investigations carried out by several FMs within the framework of scientific programs of different institutions (such as a genetic register, cancer register, etc.), as well as indications such as traumas, operations, pregnancy, blood donors after giving their blood, etc. [8, 9];

(4) *Status Presens systems are sources of primary and secondary diagnostic data;* after examining the functional systems of a person, the doctor refines the diagnosis, checks the efficiency of a DP, and corrects his further strategy.

In medical informatics, along with the notion of diagnostic information, there exist notions such as data and objects that must be differentiated. The first level of DI is the outside world of clinical physiology, in which conceptual objects reflect and represent an objective state of a patient or a person being examined; the state can change its functional optimum, and some deviations from the optimum are characterized as pathologic changes or a disease described by clinical classifications.

At the second level of DI, the relation between general notions used by patients and experts in different medical fields is realized. We note that the clinical information fixed by a patient in the form of his complaints, is not, in essence, a DI since it is not structured. Only after the fixing and interpreting of this information by a doctor does it represent diagnostically significant symptoms of a state, which become data after some computer transformation.

At the third level, the structure of DI, i.e., data fixed “objectively” by means of instrumental methods of examination, is the same for a doctor and a programmer.

In accordance with the ANSI/X3/SPARC concept of data representation, to the first level corresponds the conceptual level and to the second (external) level corresponds the infological and datalogical descriptions of data [10]. On the infological sublevel, a general logical description of organization of classes and types of objects is presented; the description is obtained as a result of coordination and integration of user concepts into a unified generalized ObD structure for the subsequent design of logical schemes of the corresponding DB. The initial stage of design of the DDB of a CASMMS is the process of structurization of the set of information elements (IEl), i.e., the smallest logically indivisible data fragments that can be treated independently, and formation of a canonical (infological) structure of the ObD. The structure reflects the most typical and stable properties of data, representing their intrinsic distinctive features (invariant with respect to types of DBMSs) in the form of objects. The process of construction of an infological structure consists of the following stages: the isolation of objects and representation of their characteristics, determination of types of relations between the objects, description of typical cycles of processing data, and analysis of user requests for information [11].

2.2. Object Representations of IEs. The combined interaction of four types of CASMMS subsystems occurs within the framework of an information environment I, i.e., some information space common to all the objects functioning in the environment and providing their interrelated activity:

$$I = \{W, Y, K, T\},$$

where $W = \{W_1, W_2, \dots, W_n\}$ is the set of objects, $Y = \{y_1, y_2, \dots, y_m\}$ is the set of operations (properties or attributes) describing an object $W_j \subset \{1, \dots, l\}$, $K = \{k_1, k_2, \dots, k_m\}$ is the set of types of concrete operations on an object that support the tracing of an IE with a view toward estimating an information situation, and $T = \{t_1, t_2, \dots, t_m\}$ is a step of system operation.

The unified semantic standard of CORBA object control includes the following four basic concepts: an object, properties (operations) characterizing the object, its type (class), and subtype [12]. According to the object paradigm, objects are understood to be only elements (of IEs) whose internal structure must not be considered in a given information situation and whose declarative parts can be written by a finite collection of attributes. Taking into account the identity of the conceptual and infological levels in CORBA, an object can be considered as an intelligent program unit, i.e., an independent component that is a complete code. An object can contain data attributes reflecting the state of material entities (for example, the state of a patient or a person examined or that of hardware components of registration, transmission, and storage of DI) and nonmaterial ones (for example, anamnesis data, an image to be diagnosed or searched for, etc.).

Basic objects of a CASMMS are states of persons and diagnostic methods. Each method supported by some FM also contains objects representing the state of hardware components of gathering, transmission, and storage of DI. The total number of initial objects is designed by the method proposed, according to which, for eight instrumental methods, at least 41 objects are monitored and controlled in an IE [5].

A nominal collection of certain IEls can form a data aggregate as an independent object, in which the set of IEls has its own hierarchy of relations. For example, the date of an examination is an aggregate containing the following three elements of data: a year, a month, and a day, and a diagnostic method, for example, a method of ECG with 12 taps, each of which includes five or six cycles of physiological curves, contains, in turn, more than 60 amplitude-phase elements of data.

In view of a discrete time of examination, at a moment t_i, $i = 1, \dots, n$, each operation y_j of a concrete object W_j^k assumes a definite value $y_j^k(t_i)$ that is localized within the limits $[f_1, f_2]$ of possible values of this operation and serves as a subtype of the operation. Thus, each person examined in the course of diagnostics within the framework of a CASMMS at a concrete moment t_i of examination can be represented by some subset $M_j(t_i)$ of the set $M(t_i)$ given below, i.e.,

$$M_j(t_i) \subset M(t_i) = \bigcup_{q=1}^{m} \bigcup_{k_i \in K} y_j^{k_i}(t_i),$$

where $y_j^{k_i}(t_i)$ is the jth attribute of the k_ith subtype of the Kth type at the moment of examination t_i, and m is the number of functionally independent diagnostic modules at the nodes of a CMCN (Sec. 2.1).

According to the terminology of Aristotle, an object itself is the first entity, and its type is the second entity with which the quality begins. Depending on methods of storage and processing, objects are divided into the following types: temporal, written, constant, and data objects. The registration information on constant objects is stored in an aliased object, which is an element of the system repository and is represented by a record storing the following complete information on the object: its unique identifier, complete, shorthand, and physical name, owner object, class, creation and modification time-stamps, and user. Such basic properties of objects as inheritance of methods and data structures, polymorphism, encapsulation, and aggregation are precisely the principles that underlie the standard of cooperative operation.

2.3. Network Monitoring and Resource Management. Low accuracy of primary data is the basic problem of corporate diagnostic systems with a large number of computer-aided devices for recording DI. The check of the validity of measured information determines the reliability of estimation of states of persons examined in systems with large numbers of objects and a variety of relations between them. At the present time, in the developing technology of programming corporate infrastructures, monitoring and control over objects functioning in an IE is provided by network monitoring means (NMM). In corporate networks supporting the interaction between objects on the basis of the TCP/IP protocols, NMMs are standard basic means of a network management tool, i.e., a Network Management Framework. Let us list the following three components of this framework:

— RFC 1155 (RFC 1212 in subsequent versions) specifies a SMI, i.e., mechanisms of describing and naming objects to provide subsequent monitoring and control over them [13];

— RFC 1156 (RFC 1213) defines a MIB, i.e., a database of object control over a set of protocols of interaction between networks [14];

— RFC 1157 defines a simple network management protocol (SNMP) and supports simultaneous communication of a Network Management System (NMS) with all remote objects and their monitoring [15, 16].

It is relevant to note that a MIB is, in essence, an administrative database for resource management in a network whose objects are described in the language ASN.1 defined in SMI. Each object has its identifying name, source code, and code. Objects are subdivided into several groups, such as statistics, history, alarm, storage matrix, choice filter, event, and life cycle. To realize the basic problem of diagnosis of an information situation on a definite segment of a network, the following algorithm is proposed: under conditions of remote monitoring, an alarm object compares the obtained statistics with the preassigned values and generates an event in the case of exceeding of a threshold value.

In order to solve monitoring problems, special probes RFC 1573 of Remote Monitoring (RMON) [17] can be used in a CMCN. The accepted standard RMON-2 makes it possible to extend the possibilities of MIB from the network level to the applied one. This allows one to use the technology of network monitoring for monitoring and control over all objects of an IE irrespective of their nature. However, the increase in the complexity of corporate infrastructures requires not only the improvement of means of a network resource but also the change in basic management principles. The passage from rigid restrictions of hardware commutation components to the maximum satisfaction of needs of users of a CMCN on the basis of intelligent decisions is a dominant trend in developing systems of new generations for control over network resources. Rule-based control systems use mechanisms making it possible, under the conditions of constant monitoring of the state of a network, to automatically change one of its characteristics or another in order to provide business objectives. At the present time, the possibility of dynamic autoreconfiguration based on the analysis of the behavior of a network is represented by package CoS of the 3COM company and by the technology of the “Satisfaction Guaranteed” service QoS proposed by the Microsoft and realized in Windows 2000. Base elements of such technologies make it possible to support traffic monitoring not only for main network devices such as servers and commutators but also for each user workplace.

2.4. Basic Principles of Construction of IEs. The support of processes of design and interrelated operation of such multicomponent systems as CASMMSs is the basic function of DCOM and CORBA. In addition to the object interaction technology itself, its integration with the principles of construction of distributed client–server systems seems to be extremely important for the design process. The CORBA architecture is based on the so-called Object Request Broker (ORB), which is an object bus operating on the principle of the old OMW technology of Remote Procedure Call (RPC) supporting the process of interaction between local and remote objects. However, the ORB mechanism supports the interaction between objects within a unified IE rather than on the basis of rigid schemes.

In the CORBA information environment, formats and templates of common data for interaction through ORB are defined according to the standard of object interaction General Inter ORB Protocol (GIOP), which acts over the transport level of any network protocol. For example, the GIOP over a TCP/IP protocol is called the Internet Inter ORB Protocol (IIOP) [6].

A physical realization of an ORB for a CMCN consists of the following two components: a collection of libraries, including client and server codes, and demon processes establishing connections between clients, servers, and the ORB. In solving CnD problems, this scheme assumes the following form: if the event “ATS > 170 mm Hg and ADD > 130 mm Hg” occurs in the system of monitoring and control of a DP on the WS of a therapeutist, then the procedure of remote search for data on the albumen test in the clinical urinalysis of the person being examined is automatically begun; if the test is positive, then, in the DDB of the DB of the corresponding clinical laboratory, its server starts the procedure of search for data on nephropathy as a client and finds them in the DB of a nephrologist in the form of data on inflammatory nephropathy. The nephrologist, in turn, triggers the search for a pathological process previous to or parallel with this disease and finds some information, for example, on tonsillitis in the DB of an otolaryngologist. As a result, this sequence of messages comes back to the WS of the therapeutist as the above-mentioned causes of the state being considered as its aetiology and a scheme of progressive development of the disease as its pathogenesis. Such a representation of a hypothesis for a probable diagnosis makes it maximally justified, which, in turn, allows a doctor to choose a maximally relevant and, hence, efficient treatment adequate to the state.

As is obvious, the capabilities of object technologies make it possible not only to support the process of formation and actualization of DDBs of examined persons on the basis of valid data obtained from all the modules of a CMCN, but also to reveal the causal dependence of some state being diagnosed, i.e., its causal conditionality, which allows one to predict more exactly the further development of a clinical situation. Such capabilities can be realized only on the technological basis of systems of processing analytical information, such as OLAP and ROLAP, as well as on servers supporting decision making (DSS). The server MicroStrategy of large-scale support is the most well-known DSS product, which, in addition to a data warehouse DtW, contains an intelligent portal, including a server of personified voice messages that provides remote users access to information by means of voice mail, mobile telephones, or other communication facilities (DSSTelecaster). In the immediate future, such technologies in systems of hospital type will make it possible, for any patient having the corresponding diagnosis formulated by the system and using any available communication facility, to obtain information such as instructions concerning the doctor, the laboratory, and the time for further examination in the form of intelligent dialogue with the system of monitoring and control over DPs. This system is capable of independently designing the scope of an examination and of monitoring the course of its realization depending on the form of a disease and character of its run. Using tools of automatic monitoring and control, it is possible to estimate not only the course and efficiency of a DP but also those of the stages of medical treatment and rehabilitation.

On the whole, all problems of IEs can be reduced to the solution of three basic problems related to the hardware support of DPs, general functionability of CMCNs, and network and specific applications.

3. THE STRUCTURE OF A MODEL OF A CASMMS

3.1. A Generalized External Model of an ObD. The boundaries of interaction between objects of a node and the external environment are determined, to some extent, by the ObD being used. In this article, a model of an ObD is a parametrically formalized representation of the process of information circulation and processing in the control loop of CnD; the representation reflects actual problems of DPs in the unified technological space of a CASMMS. In terms of IEs, a model of an ObD is a collection of objects represented by their information simulated in the nodes of a CMCN. The basic components of description of an ObD are its component IEls, the relations between them, and the procedures of processing them. To describe the volume of ObDs of each type of user, it is necessary to use a bounded but, at the same time, sufficient number of objects described by the set of operations and satisfying basic requirements of information completeness, adequacy of technical and diagnostic means being used, and the possibility of accounting for the time factor for dynamic estimation of ObD objects during the entire DP. The basic problem of construction of the infological model of a CASMMS consists of the integration of ObDs of users into a generalized data model. Let $U = \{U_1, U_2, \dots, U_m\}$ be the set of users of a DDB who accompany a DP and are distributed among the nodes of a CMCN, and let $D_k = \{d_{k1}, d_{k2}, \dots, d_{kn}\}$ be the set of IEls describing the ObD of the kth user; the latter set is a subset of IEls of the considered totality of users U of the CMCN. As a result of integration of subsets D_k, the set D is ordered in such a manner that identical IEls belonging to different sets of users are replaced by one IEl. Thus, we have

$$D = \bigcup_{k=1}^{m} D_k .$$

In the generalized model, in addition to information on the set of users, data on its spatial distribution are also topical for ObDs. The topology of a DDB represents a set of geographically distributed local DBs, reflects the capabilities of messaging between them, and is specified in the form of the binary matrix $L = \|l_{ij}\|$, $i, j = 1, \dots, m$, indexed by the set of nodes $Q = \{q_1, \dots, q_m\}$ of the CMCN. If nodes q_i and q_j are interconnected, then a matrix element l_{ij} assumes the value 1; otherwise, it assumes the value 0. The specificity of information support of DPs in CnD problems consists of the presence of a large number of DB inquiries, which not only simultaneously emerge in the automatic mode of search for diagnostic images in real time but also are generated by users of off-line computers; in view of this specificity, one should make a provision for the creation of not only a DDB but also a data warehouse DtW, which can be designed by a special method called MDM (see the DFD model in Sec. 3.3).

3.2. Semiotic Aspects. In addition to the standard stages of construction of an infological structure on the basis of object models, a distinctive feature of the design procedure is its orientation toward the description of semantic properties of data and relations between objects of an ObD as a new development stage of the theory of constructing and investigating semantic data models of DBs [18]. From the semiotic viewpoint, an information situation reflecting a state of simultaneously interacting objects of an IE represents, first of all, a system of symbols that model and represent the situation and are in different relations. In CnD, in accordance with the basic principles of semiotics, each symbol can be treated in the following three independent but interrelated aspects: *code/name, value, and meaning* [19].

Code is an alternative short name of a symbol. For example, "systolic arterial tension" is a *name* and ATS is the code for this name.

Value of a symbol reflects various properties of an object of diagnostics in a definite system of symbols; in the simplest case, it is the juxtaposition of an obtained result with the domain of an attribute. For example, ATS = 190 mm Hg is understood to be an increased arterial tension since the systolic tension is 30 mm Hg higher than the normal one.

Meaning is the result of the process of understanding of the entity represented by a symbol; this understanding reflects the logical-conceptual and figurative essence inherent in the symbol, as well as the practical activity directed toward the mastering of the entity. For example, ATS = 190 mm Hg is already understood to be not only an increased arterial tension (AT) but also the hypertension of the second degree, i.e., a hypertension stroke of the second degree, which requires a prompt medical assistance with due regard for its form and course.

Relations between symbols can be of the following three types:

— *syntactic*, i.e., relations between codes; for example, the ATS of an examined person whose number is 121 equals 210 mm Hg.;

— *semantic*, i.e., relations between codes and values; for example, the ATS of an examined person is equal to 210 mm Hg.; it is 50 mm Hg higher than the normal one and is classified as a hypertension stroke (see above);

— *pragmatic*, i.e., relations between values and their meaning; for example, let the ATS of an examined person be equal to 210 mm Hg; this fact is classified as a hypertension stroke, and the initial level of the parameter should be restored by a method prescribed by a concrete clinical situation (such as the type of instability of circulation, circulation complications, etc.).

Since the initial information of the step-by-step process of integrating objects of a model of the ObD of a DDB is contained in semantic adjacency matrices of external models of users, its generalized structure can also be presented in the form of a semantic adjacency matrix $A_k = \| a_{ij}^k \|$, $i, j = 1, \ldots, n_k$, as a binary matrix indexed by the set of IEls $D_k = \{ d_i^k,\ i = 1, \ldots, n_k,\ k = 1, \ldots, K \}$, where

$$a_{ij}^k = \begin{cases} 1, & \text{if } d_i^k \, R \, d_j^k; \\ 0 & \text{in the opposite case;} \end{cases}$$

n_k is the number of IEls in the set D_k, and R is a relation that relates IEls d_i^k and d_j^k represented by definite symbols. The type of values of the relation R is multiple, namely, these values can be *syntactic*, *semantic*, and *pragmatic*. If the structural elements d_i^k and d_j^k in the kth user requirement on the semantic connectedness of elements are related by R for which the element d_i^k extends or supplements the semantic contents of the element d_j^k, then $a_{ij}^k = 1$; otherwise, $a_{ij}^k = 0$.

Information technologies of DBs realize only syntactic relations, and an IE designed in accordance with the main principles of object-oriented technologies with the use of the three types of relations makes it possible to create ITs for processing not only data but also knowledge. This means the emergence of new possibilities for the creation of intelligent CMCNs, for example, an intelligent monitoring and control system of a DP that is required to control CASMMSs of new generations [20].

3.3. Structural Analysis. At the present time, there exist several technological systems of object-oriented programming. The package Platinum Paradigm Plus of the Platinum Technology Corporaion and the package Rational Rose of the Rational Software Corporation are the most well-known program packages [21]. These tools allow one to construct object models in various representations (OMT, OOSE, UML, etc.) and, on the basis of the model obtained, to generate applications in the programming languages C++, Java, Ada, etc. Since code generation is based on knowledge of an ObD rather than on relational data structures, object models reflect more completely the business logic of a designed ObD. By the criterion cost effectiveness, the CASE tools BPwin and ERwin of Platinum Technology are preferable for analyzing, designing, and generating codes at the present time. The technology BPwin as a tool of structural analysis and logic design supports methodologies of the functional model EDEF0, the WorkFlowDiagram model EDEF3, and the DataFlowDiagram model DFD. The tool ERwin is a means of physical design. It should be noted that, despite the fundamental distinction of the technology of designing DBs on the basis of the model On-line Transaction Processing Systems (OLTP), which is optimized to execute transactions, from the model On-line Analytical Processing (OLAP), which is optimized to process inquiries on the basis of which DtWs are designed, the possibilities of the BPwin design technology allow one to create DBs and DtWs.

The EDEF0 model includes fragments As-Is (the existing processes) and To-Be ("as should be").

As-Is. In the existing clinical practice, the whole available information on patients is accumulated on medical WSs, and the messaging between WSs is realized by means of paper carriers (extracts from case histories, various reports, etc.). This leads to the repeated duplication of data and makes it impossible to generalize them in real time of examinations. The time division of processes of state estimation denudes clinical processes of responsiveness, which leads to a decrease in the efficiency of not only DPs but also medical processes.

To-Be. In a CASMMS, the final clinical information obtained as a result of the diagnostic operations performed is formed as an aggregate or a virtual object distributed in a CMCN and integrating the entire DI accumulated at its various nodes for subsequent logical treatment; this DI consists of identification data, risk factors, complaints, and other anamnesis data, the results of various methods of instrumental examination, etc. At the first stage of a DP, the ultimate objective of such a treatment is the automatic obtainment of estimates (within the scope of a preliminary conclusion) of the functional status of a person examined and the formation of a trajectory of further examination aimed at the refinement of a priority hypothesis of a possible diagnosis proposed by the method of generation and differentiation of hypotheses (MGDH) [20]. This information can be used by any doctor of the corresponding CMCN who, at the next stage of the DP, examines the patient and his overall status presens and, in the case of the disagreement with the diagnosis formulated by the system, refines the scope of an additional examination and monitors its course and efficiency, as well as makes a decision on the choice of a method of correction of the identified current state from the collection of methods proposed by the system.

Within the framework of the functional model EDEF0, a sequence of step-by-step decompositions is performed, beginning with the description of the system as a whole with the differentiation of its internal and external environments (context diagrams) and ending with final concept-objects of the initial sets of subject knowledge (decomposition diagrams). Before the model EDEF0 was taken as a federal standard in the USA, it was called a Structured Analysis and Design Technique (SADT) [21]. Process charts are used (in the DFD model) to describe the circulation of documents and various functions of information processing, as well as external references supporting the interface with objects that are outside of a simulated node of the system. The DFD model also includes a behavioral model of the system. Within the framework of EDEF3, a methodology of simulation of sequential interaction between components of the system being designed (crossroad scripts) is realized.

3.3.1. Architecture of classes of data. Information flows consisting of objects from the set called ObD are determined by the architecture of classes of data D, X, and B. This architecture is described in terms of basic elements d, x, and b of a local node.

$D=\{d_1, d_2, \dots, d_m\}$ is the common class of input data. These data are formed from the data of FMs of a system (see Sec. 2.1). This data array is called a registration log and the number of its modifications in a DB is a multiple of the number of accesses of persons examined in a CASMMS;

$X=\{x_1, x_2, \dots, x_m\}$ is the collection of gathered and processed primary data; these data are stored in the DB of a system and are updated every few years;

$B=\{b_1, b_2, \dots, b_k\}$ is the class of output data that contain the results of cycles of processing information (CPI), and the number of its modifications is a multiple of the number of accesses.

Output data are summarized data that are subdivided into the following three types: *intermediate*, *interactive*, and *final.*

Intermediate (systolic) data are obtained as a result of treatment of a cycle of processing incoming information and are used as the initial data for others CPIs or are transferred to external users U and N and internal users P.

Interactive data are data or knowledge transferred to users of any level in answer to their inquiries.

Final (archive) data are aggregate results of operation of a CASMMS and form the basis for preparing output documents.

Note that $U=\{u_1, u_2, \dots, u_s\}$ is the collection of the levels of hierarchy in the CASMMS being considered. In this system, the following seven levels are designed: on-line and current medical monitoring, a clinical department, a public health institution, a municipal and a regional information system, and the national network. The first three levels belong to the loop of clinical control ($u_1 - u_3$), and the other four levels belong to the executive administration vertical of the system of public health service ($u_4 - u_7$) [7].

The external component $N = \{n_1, n_2, \dots, n_q\}$ can be understood to be a collection of DBs of Q interacting DDB nodes whose information is topical for a definite ObD, for example, systems of the type of the Chernobyl' register, a cancer-register, epidemiological and genetic monitoring, a thyroid register, a DB of blood transfusion or inoculations, etc. [23].

We assume that $P = \{p_1, p_2, \dots, p_m\}$ is the collection of m internal components of the ObD of a DDB node. Among these are all the objects W^k of a node Q. Their estimation in the current information situation in the CPIs C_1—C_3 considered below is the problem of on-line monitoring and control over the objects of an IE.

The database of the system (its internal class) includes the following three types of data: *basic*, *archive*, and *auxiliary*.

Basic data are formed as a result of processing registration data. They include data on persons examined, estimates of revealed changes in the functional status of persons, and data on the state of measuring and processing hardware components of DI, communication channels, and network tools of commutation, i.e., the data required for solution of basic problems of operation of the CASMMS being considered, i.e., the estimation of the degree of decline in health, determination of the causes of a pathology detected, formulation of recommendations concerning the necessary scope of investigations according to the profile of a revealed pathology with maximum efficiency and minimum expenses for computational and diagnostic resources.

Archive data are stored in the DB and are used not only in solving the above-mentioned problems of CASMMS but also for the subsequent estimation of dynamic changes in the functional status of persons examined.

Auxiliary data serve as a normative material of the considered ObD of the CASMMS and contain the objectives of the system, examination programs, methods of processing of accumulated information, standards, classifiers of states recognition, a list of possible recommendations, etc., that represent the essence of a register of CnD.

A list $Z = \{z_1, z_2, \dots, z_n\}$ specifies basic functions supported by the system being considered. For systems of the CASMMS type, these functions are generalized as systems of monitoring and control over information situations of DPs within the framework of CPI problems.

3.3.2. Cycles of processing information. Since systems of the CASMMS type operate in real time of DPs, the execution of a large number of logical operations under the conditions of time deficiency requires the preliminary decomposition and differentiation of the types of IE objects depending on execution of their standard logical operations within the framework of unified CPIs. Each isolated cycle has its objective function of processing information and a relevant collection of algorithms supporting the process of gathering the initial information, processing it, and transferring it to the next cycle according to a given protocol. Using the terminology of mathematical informatics proposed by A. V. Chechkin, we can call a CPI an ultrasystem whose main distinctive feature is the transformation of information of the form $(p)\,\delta(x)$ about an object $x \in X$ into information of the form $(q)\,\beta(y)$ about an object $y \in Y$ [24]. In view of the variety of objective functions of a CASMMS, we isolate the following types of CPIs:

C_1 is the cycle of monitoring of data of IE objects. The major function of the cycle is the monitoring of the information situation and lies in accumulating diagnostic data on the persons being examined and estimating their validity;

C_2 is the cycle of derivation, in which each vector of an object $W_j(t_j)$ is semantically interpreted and the corresponding class (type) of its states is determined. Estimates of the vector of obtained results of examination can be placed into the norm, pathology, or diagnosis (preliminary, clinical, and final) class. If the states of objects of hardware components of data gathering, transmission, or storage are estimated, then the topology of a probable failure is established in the network;

C_3 is the cycle of making decisions; in this cycle, a pragmatic analysis of the results of the cycle C_2 is performed and recommendations are formulated that regulate the further actions of the system and person being examined. An example of a recommendation is as follows: to refine this diagnosis, it is necessary to additionally examine the ECG of the patient, 02.13.2001, 11.00-11.30, room 7.

The cycles $C_1 - C_3$ are necessary components of IEs of systems of the CASMMS type. Their combined interaction forms some completed technological block (Fig. 1). The validity of a physiological signal obtained by a diagnostic method is checked in C_1. If the signal does not satisfy agreed norms, the method of registration is improved again. In contrast to standard problems of monitoring networks, in which the validity of incoming data is determined on the basis of histories of statistics, the validity of data in a CASMMS is checked in each diagnostic cycle.

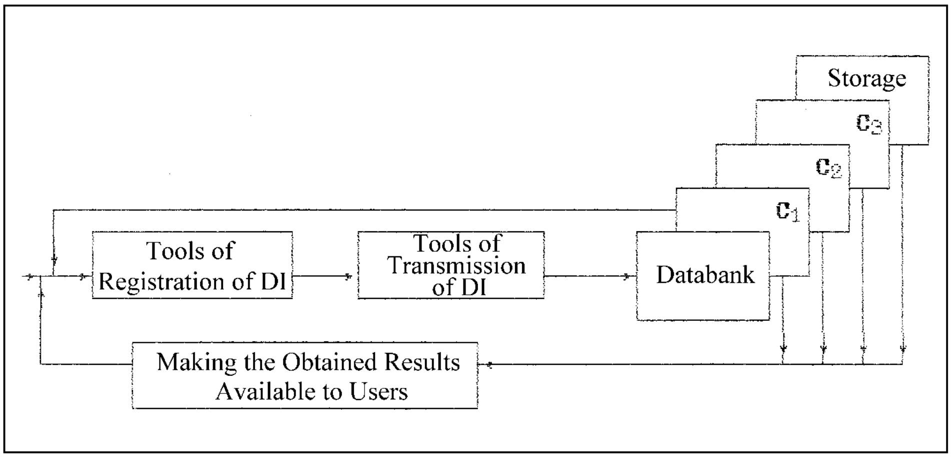

Fig. 1. A functional diagram of a diagnostic cycle.

4. PRODUCTIVITY OF CMCNs

An estimate of the productivity of the CMCN of a CASMMS is expressed by the body of circulating information per unit time. At the same time, the following three basic characteristics of messaging should be known: the timing of devices at network nodes, data transmission rate, and requirements on the type of connections. To choose a technology of transmission of information circulating in a CMCN, it is necessary to estimate the throughput of its communication channels. In the generalized external model, these parameters are specified as a collection of matrices and vectors. The throughput of communication channels is represented by a matrix $C = \|c_{ij}\|$, $i, j = 1, \ldots, r$, where c_{ij} is the throughput of the channel between nodes q_i and q_j and the quantity determining the capacity of memory required for the server at a node of the network is specified by the elements of a vector $\eta^{\mathrm{ES}} = \{\eta_i^{\mathrm{ES}}\}$. Cost parameters are also specified in the form of a matrix of expenses for information transmission $E = \|e_{ij}\|$, $i, j = 1, \ldots, r$, where e_{ij} is the cost of transmission of an information unit between nodes q_i and q_j of a CMCN.

Despite the fact that CASMMSs are stochastic systems, the ATM technology supports the asynchronous mode of operation. The transmission rate depends on the body of information being transmitted. In the body of information about a patient, irrespective of the number of his visits, texts occupy up to 8 Kb, and most of the diagnostic data consist of medical graphic images such as USI images, roentgenograms (additional projections), and physiological curves (ECG, RCG, FCG, EEG, etc.) occupying up to 10 Mb [25]. Therefore, if we can choose between the existing gradations, i.e., small (10 Mbps) and large (100 Mbps) data transmission rates, then a rate equal to 100 Mbps should be used in systems of the CASMMS type. In fact, if 70 persons simultaneously make scheduled visits to a polyclinic, then, in view of the heterogeneity of scopes of examination of different patients, the total volume of messaging exceeds 100 Mbps. Taking into account the corporate nature of DPs, in which a concilium is used by medical personnel as a standard method of solving problems, the service grade should be up to class A (teleconferences), and the type of switching should be set-to-set ($M{:}M$) [26].

5. RESULTS OF OPERATION OF A CASMMS

In accordance with the requirements of structural analysis and logical design of an ObD, a complete collection of specifications of medical support of DPs must be prepared at the stage of its infological description; this collection should take into account a representative list of technologically distributed operations to be automated and satisfy the requirements and restrictions imposed on the specifications by the unified register of an automated process (RAP) of CnD.

We present the following concise list of operations performed by a CASMMS: (1) integration, accumulation, and storage of DI at the nodes of the CMCN of the CASMMS; (2) (preliminary and clinical) estimation of the state of a person; (3) determination of a diagnostic trajectory representing a program of additional examination and its initialization; (4) formation of groups based on the results of examination; (5) solution of problems of recovery to health, estimation of the sickness rate, work capacity, and statistical reporting; (6) documentation of examinations made; (7) data transmission within the CMCN; (8) fixing and monitoring of all diagnostic procedures; (9) meeting the information needs of doctors and other experts.

To realize these functions, a system operating in the supervisor mode should be created. During the first iteration, the estimate of the state of the person being examined and the entire amount of information on the examinations made, on the basis of which the further diagnostic trajectory is constructed, is fixed in the final object of the DDB of CASMMS. The capabilities of object technologies allow one to design systems capable of not only efficiently controlling the course of a DP and suggesting a priority hypothesis and required additional examination in its support to doctors but also independently forming a strategy of search for the relevant information at various nodes of the CMCN or starting the program of an examination to be made. Such capabilities bring practical medicine to a fundamentally new qualitative level.

An important component of an external model of data is the result of differentiation of the total list of performed operations as a description of the following two sets of procedures: the set of inquiries $I_k = \{i_1^k, i_2^k, \dots, i_n^k\}$, $k = 1, \dots, K$, to the DDB and the set of user requirements $L_k = \{l_s^k\}$, $s = 1, \dots, S_k$, $k = 1, \dots, K$, on reading and updating of DB information. For users of different types, the following requirements can be topical: a person (a patient) (item 6); a doctor (items 2, 3, 4, 5, 6, and 9); the system manager (items 1, 6, 8, and 9); officials of the executive vertical (items 4, 5, and 9).

In conclusion, it should be noted that the infological stage of design of DDBs is important from the viewpoint of the decrease in the redundancy and increase in the reliability of DDBs. At the same time, the considered tools of IEs allow one, on the basis of object technologies, to design information systems capable of solving CnD problems that are beyond the reach of existing DP technologies; for example, to monitor and control the efficiency of spatially distributed diagnostic procedures taking into account the time and complexity parameters of an examination required depending on distinctive features of a diagnosis, the form of a disease, or the group of dispensary follow-up. Moreover, there is the possibility of realization of intelligent monitoring of vital functions during functional tests, surgical operations, and reanimation procedures, as well as control over the process of introduction of medicinal preparations under the condition of monitoring the state of functional systems, etc. The intelligent tools of a network resource can be tuned to specific requirements of users of DPs in various applications, going beyond given device configurations. Moreover, the utilization of DtW technologies in a CMCN is a variation of the use of the technologies of the Analytical Center in practical public health services.

Under the conditions of a CMCN, clinical diagnostics assumes an unprecedented large scale and promptiness in servicing. Missing data needed for a reliable estimate of the state of a patient can be found by the system at any DDB node irrespective of its territorial remoteness and transmitted over the network to experts who can use it in order to pass from a plausible diagnosis to a reliable one. However, there will be little sense in transmitting data about patients even in the case of the most perfect computer-aided recorders and local, regional, and national corporate networks until experts perform the semiotic analysis of primary diagnostic data and doctors develop a unified terminology and a classification of indications, symptoms, and diseases to reach the initially necessary mutual understanding of all users and, as a result, the efficiency of corporate medical computer network technologies in a future model of public-health services.

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