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RESEARCH ARTICLE

Logical integration of information systems based on expert systems

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Abstract

Objectives. The study set out to develop fundamental methodological principles for the logical integration of information systems (IS) in organizations and to quantitatively assess the topological significance of the IS integration process.

Methods. Methods based on expert systems were used for the logical integration of information in conjunction with data-mining approaches based on various IS. In order to quantitatively assess the topological significance of the IS integration procedure, graph theory methods were used. Discrete topology methods were also employed for calculating the topological invariants of the IS interconnection topology.

Results. Issues and challenges involved in the integration of IS in large organizations are considered in terms of integration methods based on physical and logical principles. While IS integration approaches based on logical principles offer distinct advantages over physical integration approaches, new problems arising in the context of logical integration approaches require innovative solutions. The proposed scheme for the logical integration of IS includes an algebraic method for quantitatively assessing the topological significance of integration, comprising an important numerical indicator in the logical integration of IS. Methods based on learning expert systems, which represent a fundamental solution for organizing the logical integration of IS for intelligent data analysis, are reviewed.

Conclusions. When integrating IS in organizations, it is advisable to use a logical integration approach that preserves the logic of existing information systems. The application of logical integration enables intelligent data analysis using various IS. The use of expert systems in logical integration enables the creation of a new logical layer for providing decision support within the organization.

Keywords: information systems, systems integration, expert systems, data mining, information systems topology

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НАУЧНАЯ СТАТЬЯ

Логическая интеграция информационных систем на основе экспертных систем

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Резюме

Цели. Целью статьи является разработка принципиальных основ для методов логической интеграции информационных систем (ИС) в организациях, а также получение количественной оценки топологической значимости процесса интеграции ИС.

Методы. Использованы методы экспертных систем для логической интеграции информации, а также методы интеллектуального анализа данных из различных ИС. Для количественной оценки топологической значимости процедуры интеграции ИС используются методы теории графов, а для вычисления топологических инвариантов топологии взаимной связи ИС – методы дискретной топологии.

Результаты. Рассмотрены вопросы и проблемы интеграции ИС в крупных организациях, а также методы интеграции ИС, основанные на физическом и логическом принципах. Показаны сложности, которые возникают при физической интеграции ИС, и преимущества их интеграции на основе логических принципов. Установлено, что логическая интеграция обладает рядом важных достоинств, но при этом возникают новые проблемы, которые необходимо решать. Предложены схема логической интеграции ИС и алгебраический метод количественной оценки топологической значимости интеграции – важного числового показателя при логической интеграции ИС. Рассмотрены методы обучающихся экспертных систем для интеллектуального анализа данных. Использование экспертных систем является принципиальным решением для организации логической интеграции ИС.

Выводы. При интеграции ИС в организациях целесообразно использовать логическую интеграцию, сохраняющую логику отдельных ИС. Применение логической интеграции позволяет проводить интеллектуальный анализ данных, используя различные ИС. Использование экспертных систем при логической интеграции дает возможность создать новый логический слой для осуществления поддержки принятия решений в организации.

Ключевые слова: информационные системы, интеграция систем, экспертные системы, интеллектуальный анализ данных, топология информационных систем

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INTRODUCTION

The ongoing digitalization of the economy and business processes involves the increasing use of various information systems (IS) for decision-making support in which basic information about the organization's activities is stored and processed [1–3]. While different IS have distinct purposes and may be based on different information technologies, the important task of integrating existing IS arises due to their extensive interrelation. However, challenges involved in the full-scale integration of large IS involve complex technical, financial, and organizational issues [4–8]. In addition, some IS cannot be integrated due to the potential violation of information security rules.

The present work proposes a logical approach to IS integration based on the creation of an intelligent information environment. Logical integration of IS, which offers a number of advantages over physical integration approaches [9], involves the use of various data mining methods to reveal additional (hidden) information. The use of learning expert systems to create a unified information field in the organization represents a new logical level of IS integration.

1. IS INTEGRATION METHOD

Many organizations simultaneously maintain several IS, which are connected by unified information flows. A characteristic feature of these IS consists in their mutual intersection by various objects, whose corresponding information must be stored and processed. Such objects may include employees, material objects, customers, etc. Since, for objective reasons, such IS are created at different times and using different technologies, a number of problems arise related to the integrity of information, its reliability, as well as issues related to the potential violation of information security rules [10]. The task of integrating different IS into a single information platform methods can approached based on either of the following principles:

1. Physical integration.
2. Integration based on business logic.

The physical integration of more than one IS implies the creation of an IS that fulfills all the functions of the merged systems. In this case, it is necessary to refactor the structure of databases and the corresponding logic of all software. While this process can provide a full-fledged integration of IS, it is generally very labor-intensive, in some cases comparable to the creation of a new IS [11].

IS integration carried out on the basis of business logic, which can thus be referred to as logical integration of IS, is understood not only in terms of the integration of databases, but also the creation of a single logic of combining information across different IS (Fig. 1) [12, 13].

IS integration sets out provide a unified logic of the merged IS without significant changes in the IS architecture [14, 15]. The advantages of logical integration of IS over physical integration approaches can include the following factors:

1. Lower cost.
2. Preserving diversity.
3. Technological heterogeneity.
4. Ability to process data at a higher level.

The use of a common logic in IS integration is based on the use of special protocols for mutual communication between existing IS. The development of such protocols should be based on a specially developed formal language [16].

2. SYSTEM INTERACTION DURING LOGICAL INTEGRATION

During the logical integration process, it becomes necessary to provide mechanisms of interaction between the merged IS. Such interaction can be described using a formal finite-automata language. The task of the interaction mechanism is to provide mappings of objects in one IS into the objects of another IS. However, the main difficulty that arises in this connection is that the mapped objects may have information overlap. For example, there may be information related to employees of an organization in different IS, but this information may be represented in different ways in different systems. An addition problem may arise due to the different scales used when describing the same objects in different information bases.

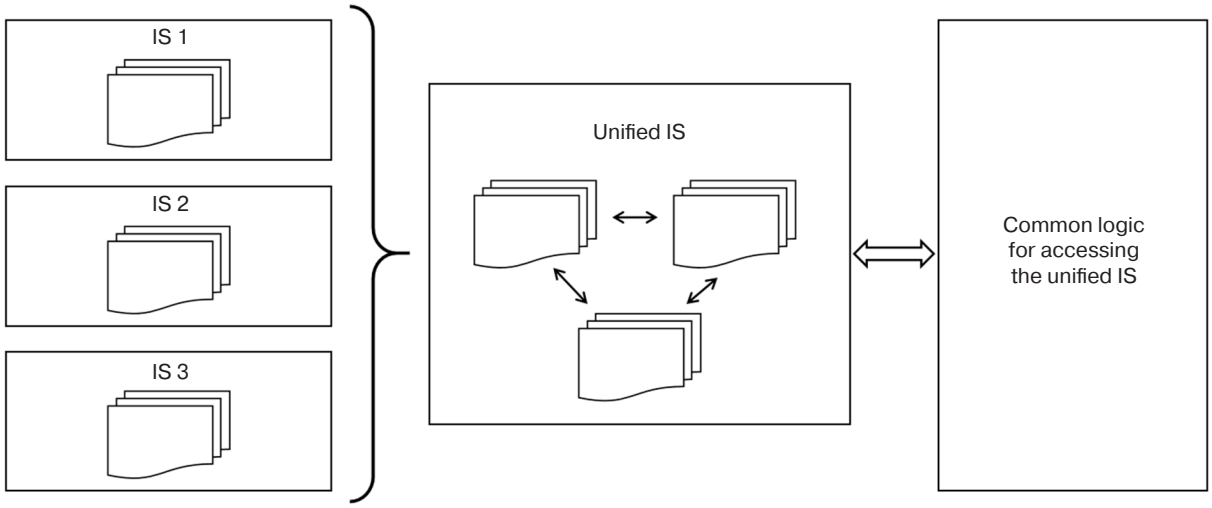

Fig. 1. Logical integration of IS

Thus, when designing and implementing an IS integration procedure, one of the main tasks is to create a mechanism for logical mapping of the different IS. Figure 2 shows an object-mapping scheme for application during logical integration.

For the logical display of the various objects in the different IS, it is advisable to use an intelligent environment for integration of information objects. This environment, which uses semantic information-processing methods, can be used to realize the mechanism of displaying objects in the IS.

3. CHANGING AN ORGANIZATION'S INTERCONNECTIVITY TOPOLOGY

When integrating different IS in an organization, an important issue arises in terms of changing the topology of mutual connection of these systems. The main point here is that, in order to obtain qualitative changes during IS integration, it becomes necessary to provide changes in the topology of their interconnection.

The topology of IS interconnection is described by an undirected graph, whose vertices are individual IS, while the edges represent information links between systems [17]. Since it is only the presence of a connection that is important for the topology of the IS network, i.e., irrespective of the direction of flow, we will consider undirected graphs. Here, the salient point consists in the fact that that even unidirectional flows include not only the data flow, but also the corresponding request for this data.

Figure 3 shows an example of the IS communication topology.

In this example, IS numbered 1–8 are linked by information links, while IS number 9 is not linked to the other IS. Two IS will be referred to as incident if there is an information link between them. We will define two IS S and P as connected if a chain of sequentially connected

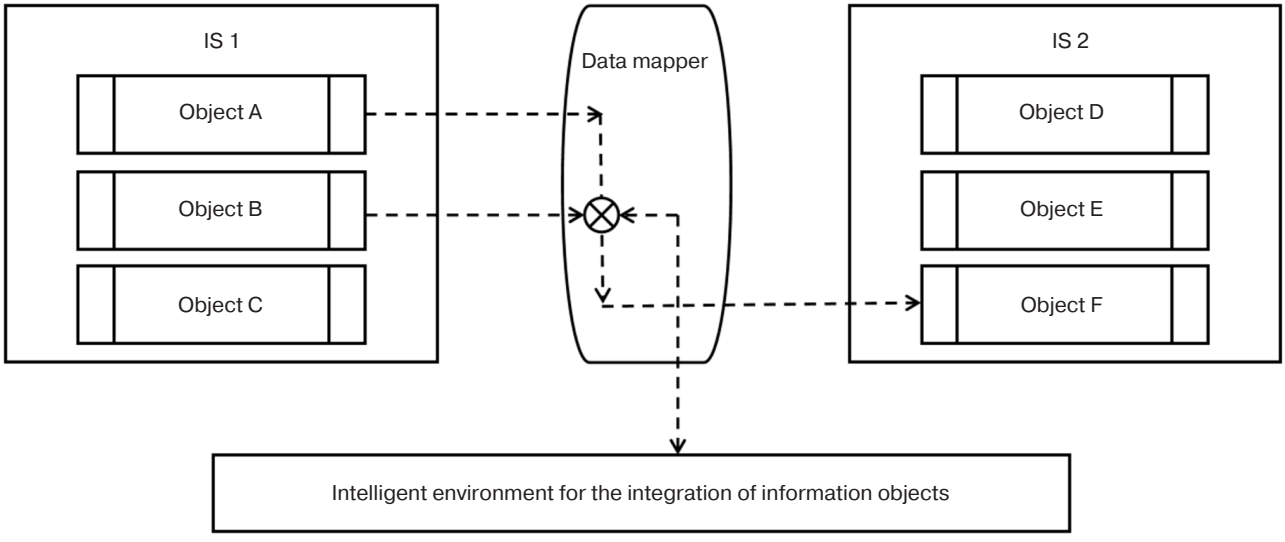

Fig. 2. Diagram of the logical object display mechanism

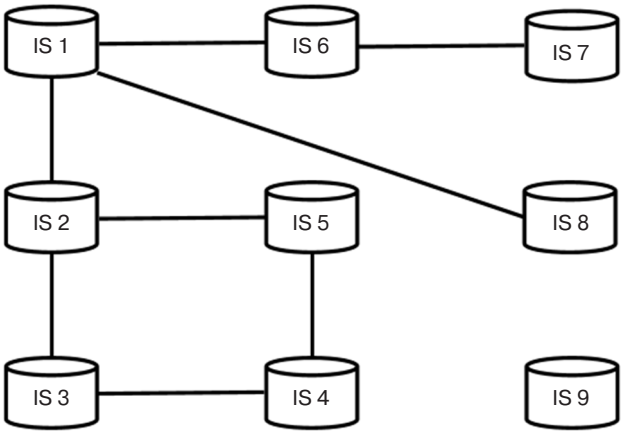

Fig. 3. Example of the IS communication topology

IS can be constructed from S to P. The entire IS network can be represented by connectivity components, where each connectivity component represents a set of individual IS that are connected in pairs.

We will consider the process of IS integration as a sequential operation of merging neighboring nodes (incident IS). In this case, the unified IS inherits all the information links of the united vertices.

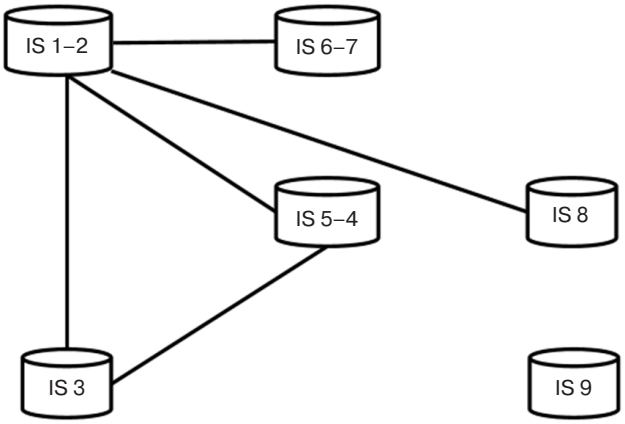

Fig. 4. Topology following IS unification

Figure 4 shows the IS topology following IS unification:

$$[1, 2] \rightarrow [1–2],$$
$$[4, 5] \rightarrow [5–4],$$
$$[6, 7] \rightarrow [6–7].$$

In order to distinguish significant changes in the IS communication topology, we will use topological invariants. As an example of such a variant, let us consider the fundamental group for the graph describing the IS communication topology. We will define the fundamental group as the set of equivalence classes of homotopy loops in the graph [18]. For the connected component of the IS network, the fundamental group defines the number of loops. If a connected graph representing the IS communication topology has N cycles, then the fundamental group is isomorphic to the $\mathbb{Z}^N$ group [19].

The presence of cycles in the organization's IS network indicates the need to integrate IS, since the presence of cycles in the network of information links implies risks of ambiguity in the presentation of information to the organization during information requests due to the possibility of ambiguous ways of transferring information between different IS.

While no new cycles can arise when integrating IS, existing cycles can be opened. In the language of the fundamental groups of the IS communication graph, this means that the following change in the representation of the fundamental groups occurs during the process of IS integration:

$$\mathbb{Z}^N \rightarrow \mathbb{Z}^{N-k}.$$

In this interpretation, we can define the topological significance of the IS integration procedure as the number k by which the degree of the fundamental group decreases.

4. USE OF EXPERT SYSTEMS FOR IS LOGICAL INTEGRATION

While the logical integration of IS in an organization may have various objectives, the main aim is to create a unified information field. This problem cannot be solved using "mechanical" methods since samples from different IS must be brought to a "common denominator" in order to obtain uniform information. Another challenge that arises in this connection consists in the need to obtain additional information about the organization's activities based on the heterogeneous information in the different IS.

In order to solve these problems inherent in the logical integration of IS, it is proposed to use trainable expert systems and knowledge bases. The objects described in the IS are used as the subject area of the knowledge base.

Figure 5 presents a scheme for the application of an expert system in logical integration of IS. The key element of the proposed scheme consists in the use of the IS query router and the intellectual environment of the integrated IS. The logical integration of IS implies an intellectual environment since it provides a means to obtain information from different sources on the incoming request for further logical integration of heterogeneous information. In order to determine which IS should form the basis for information queries, a query router is used to identify the most appropriate data sources based on the display of information in different IS.

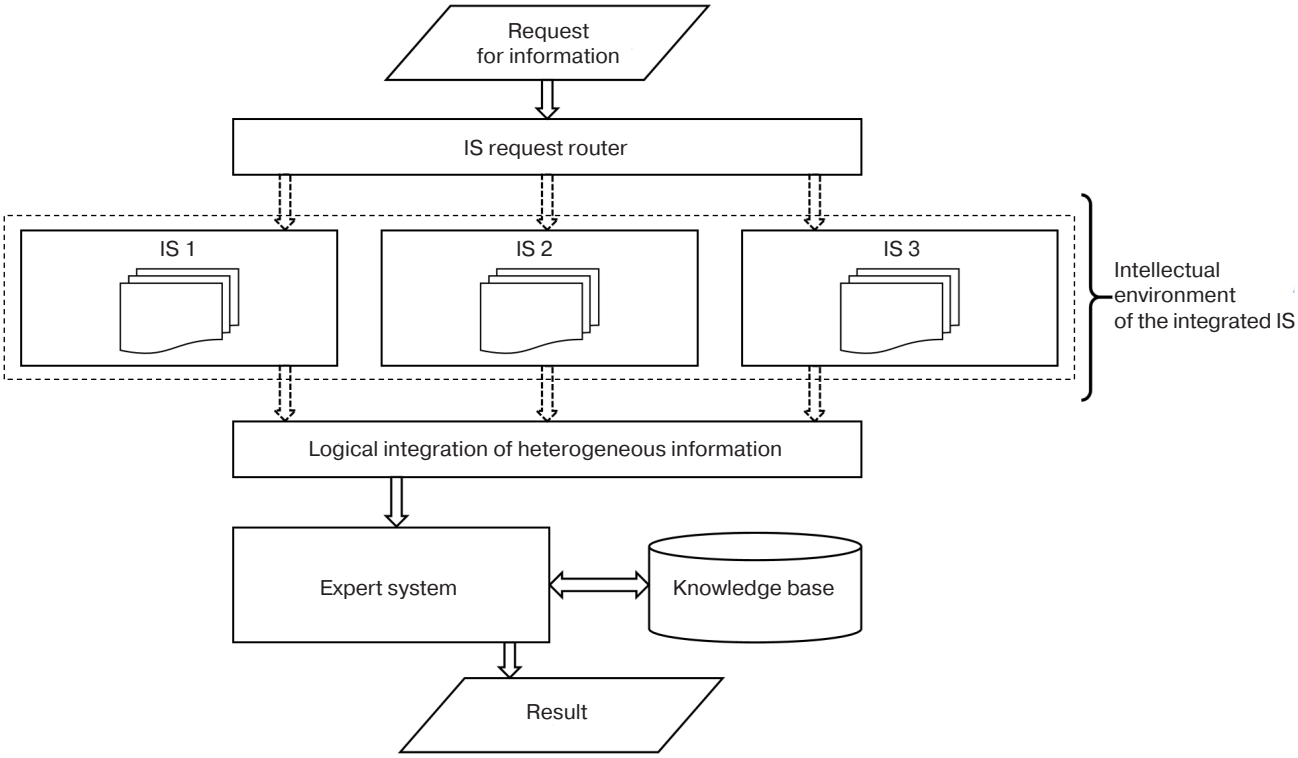

Fig. 5. Diagram of the expert system application

Following the realization of logical integration of information from different IS, a meaningful query is formed to the expert system, which forms the result according to the received query using the knowledge base [20, 21].

The architecture of an expert system depends on the nature of objects described by the IS, as well as on the completeness of information for each object [22]. The general scheme of the architecture of the expert system and knowledge base is presented in Fig. 6.

The architecture of the expert system includes a mechanism for performance-based learning as a means of improving the data-mining procedure on integrated data.

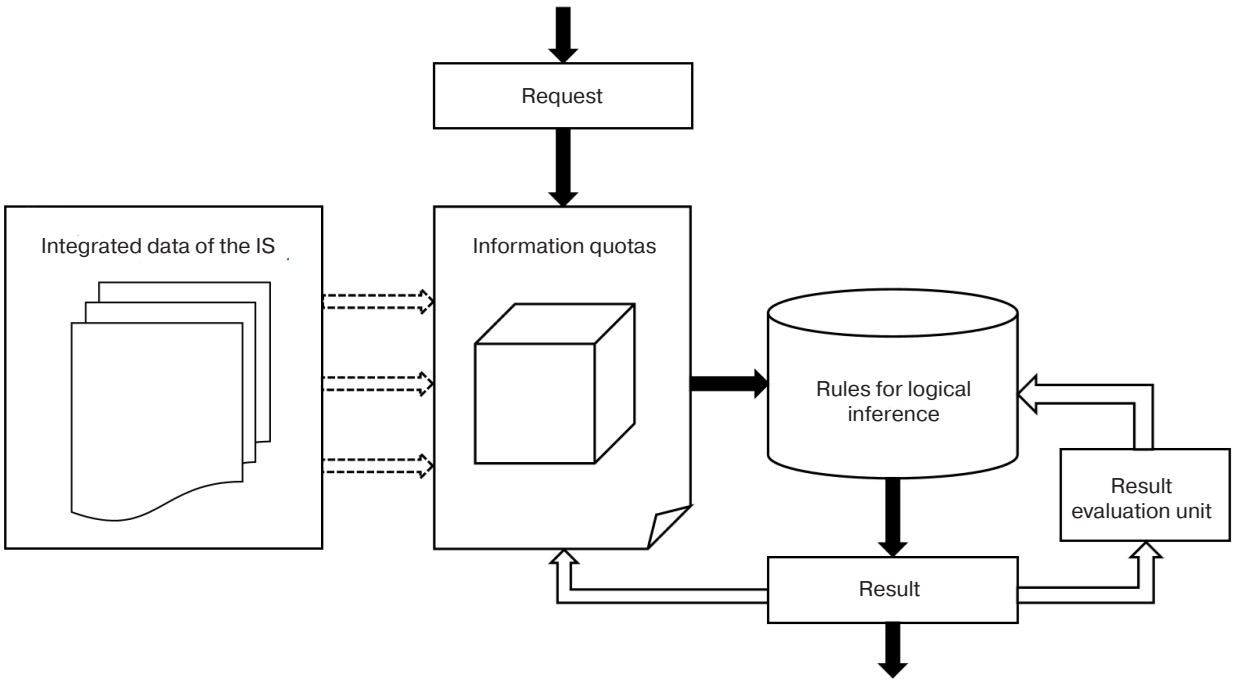

Fig. 6. Architecture of a learning expert system

In Fig. 6, solid arrows depict the sequential process of calculating and obtaining the result of the expert system operation, while data transferred to implement the training procedure of the expert system are represented by contour arrows. Dashed arrows show the data flow for the expert system from the integrated IS.

Within this scheme, a fundamental principle concerns the use of information quanta to represent integrated information from IS. The specific realization of the procedure of data representation in the form of information quanta depends on the nature of objects in IS and the structure of their interaction.

In order to implement the training process of the expert system, a result-evaluation block is used. This block can either be implemented using feedback from the user of the expert system or based on the evaluation by the artificial intelligence system. In cases where an artificial intelligence method is used (neural network, Bayesian networks, decision trees, etc.), training can be realized on the basis of machine learning methods with suitable reinforcement [23].

CONCLUSIONS

The present work considers fundamental issues of IS integration in organizations on the basis of intellectual methods. The introduced concept of logical IS integration is suitable for integrating heterogeneous IS. Issues connected with the topological significance of the logical IS integration procedure have also been considered.

The logical integration of IS and creation of a unified information environment involves the use of an expert system, which responds to queries associated with the operation of integrated information flows. Such an expert system allows a basis for intellectual analysis of the data to be provided.

The proposed architecture of expert systems includes mechanisms for training (self-learning) of the knowledge base of the expert system, by means of which the results of IS integration in the organization can be further improved.

Authors' contributions

E.S. Shevtsov—conceptual model of integration of information systems based on the creation of an intelligent information environment.

R.V. Shamin—mathematical model of integration of information systems based on the creation of an intelligent information environment.

REFERENCES

1. Spiridonov E.S., Klykov M.S., Rukin M.D., Grigoriev N.P., Balalaeva T.I., Smurov A.V. *Informatsionnaya ekonomika* (*Information Economy*). Moscow: URSS; 2021. 286 p. (in Russ.).
2. Kalyanov G.N., Lukinova O.V., Levochkina G.A., Vasilev R.B. *Strategicheskoe upravlenie informatsionnymi sistemami* (*Strategic Management of Information Systems*). Moscow: Prosveshchenie/Binom; 2019. 510 p. (in Russ.).
3. Prokhorov A., Konik L. *Tsifrovaya transformatsiya. Analiz, trendy, mirovoi opyt* (*Digital Transformation. Analysis, Trends, World Experience*). Moscow: KomN'yus Grup; 2019. 368 p. (in Russ.).
4. Loiko V.I., Lutsenko E.V., Orlov A.I. *Sovremennaya tsifrovaya ekonomika* (*Modern Digital Economy*). Krasnodar: KubSAU; 2018. 508 p. (in Russ.).
5. Chursin A.A., Yudin A.V. *Kiberekonomika v praktike: sozdanie radikal'no novoi produktsii v tsifrovuyu epokhu* (*Cybereconomics in Practice: Creating Radically New Products in the Digital Era*). Moscow: Ekonomika; 2021. 301 p. (in Russ.).
6. Belalova G.A. Analysis of information systems integration methods. *Tsifrovye modeli i resheniya = Digital Models and Solutions*. 2023;2(3):61–68 (in Russ.).
7. Karev A.N., Fedosin S.A. Ontological approach to information systems integration. *Perspektivy nauki = Science Prospects*. 2023;168(9):26–29 (in Russ.).
8. Belyaev A.K., Kritskaya S.N. Integration of information systems in action. *Informatsionnye tekhnologii v UIS = Information Technologies in the Penal System.* 2022;1:34–40 (in Russ.).
9. Weber R.H., Burri M. *Classification of Services in the Digital Economy*. Berlin, Heidelberg: Springer; 2012. 144 p.
10. Babash A.V., Baranova E.K. *Aktual'nye voprosy zashchity informatsii* (*Current Issues of Information Security*). Moscow: INFRA-M, RIOR Nauka; 2023. 111 p. (in Russ.). ISBN 978-5-36901-680-0
11. Martin R. *Chistaya arkhitektura. Iskusstvo razrabotki programmnogo obespecheniya* (*Clean Architecture. The Art of Software Development*). St. Petersburg: Piter; 2022. 352 p. (in Russ.).
12. Chernyak L. Data integration: syntax and semantics. *Otkrytye sistemy. SUBD = Open Systems. DBMS.* 2009;10 (in Russ.). Available from URL: https://www.osp.ru/os/2009/10/11170978
13. Antamoshin A.N., Bliznova O.V., Bobov A.V., Bolshakov A.A., Lobanov V.V., Kuznetsova I.N. *Intellektual'nye sistemy upravleniya organizatsionno-tekhnicheskimi sistemami* (*Intelligent Control Systems for Organizational and Technical Systems*). Moscow: Goryachaya liniya – Telekom; 2006. 160 p. (in Russ.).
14. Norenkov I.P. *Avtomatizirovannye informatsionnye sistemy* (*Automated Information Systems*). Moscow: Bauman Press; 2011. 344 p. (in Russ.).

15. Mazepa R.B., Mikhailov V.Yu. *Osnovy informatsionnykh tekhnologii. Vvedenie v protsessy informatsionnogo vzaimodeistviya* (*Fundamentals of Information Technology. Introduction to Information Interaction Processes*). Moscow: Vuzovskaya kniga; 2012. 60 p. (in Russ.).
16. Magazov S.S. *Teoriya formal'nykh yazykov. Regulyarnye yazyki* (*Theory of Formal Languages. Regular Languages*): eBook. Moscow: Bauman Press; 2023. 52 p. (in Russ.).
17. Harary F., Palmer E. *Perechislenie grafov* (*Graphical Enumeration*): transl. from Engl. Moscow: Mir; 1977. 328 p. (in Russ.). [Harary F., Palmer E. *Graphical Enumeration*. New York, London: Academic Press; 1973. 271 p.]
18. Fomenko A.T., Fuks D.B. *Kurs gomotopicheskoi topologii* (*Course on Homotopic Topology*). Moscow: URSS; 2024. 512 p. (in Russ.).
19. Hatcher A. *Algebraicheskaya topologiya* (*Algebraic Topology*): transl. from Engl. Moscow: MTsNMO; 2011. 688 p. (in Russ.).
[Hatcher A. *Algebraic Topology*. Cambridge University Press; 2005. 556 p.]
20. Giarratano J., Riley G. *Ekspertnye sistemy: printsipy razrabotki i programmirovanie* (*Expert Systems: Principles of Development and Programming*): transl. from Engl. Moscow: Vil'yams; 2007. 1152 p. (in Russ.).
[Giarratano J., Riley G. *Expert Systems: Principles and Programming*. Thomson Course Technology; 2005. 842 p.]
21. Bodrov O.A., Medvedev R.E. *Predmetno-orientirovannye ekonomicheskie informatsionnye sistemy* (*Subject-Oriented Economic Information Systems*). Moscow: Goryachaya liniya – Telekom; 2013. 244 p. (in Russ.).
22. Ruchkin V.N., Fulin V.A. *Universal'nyi iskusstvennyi intellekt i ekspertnye sistemy* (*Universal Artificial Intelligence and Expert Systems*). St. Petersburg: BKhV-Peterburg; 2009. 224 p. (in Russ.).
23. Sutton R.S., Barto A.G. *Reinforcement Learning: An Introduction*. Cambridge, Massachusetts: The MIT Press; 2018. 526 p.

СПИСОК ЛИТЕРАТУРЫ

1. Спиридонов Э.С., Клыков М.С., Рукин М.Д., Григорьев Н.П., Балалаева Т.И., Смуров А.В. *Информационная экономика*. М.: URSS; 2021. 286 с.
2. Калянов Г.Н., Лукинова О.В., Левочкина Г.А., Васильев Р.Б. *Стратегическое управление информационными системами*. М.: Просвещение/Бином; 2019. 510 с.
3. Прохоров А., Коник Л. *Цифровая трансформация. Анализ, тренды, мировой опыт*. М.: ООО «КомНьюс Груп»; 2019. 368 с.
4. Лойко В.И., Луценко Е.В., Орлов А.И. *Современная цифровая экономика*. Краснодар: КубГАУ; 2018. 508 с.
5. Чурсин А.А., Юдин А.В. *Киберэкономика в практике: создание радикально новой продукции в цифровую эпоху*. М.: Экономика; 2021. 301 с.
6. Белалова Г.А. Анализ методов интеграции информационных систем. *Цифровые модели и решения*. 2023;2(3):61–68.
7. Карев А.Н., Федосин С.А. Онтологический подход к интеграции информационных систем. *Перспективы науки*. 2023;168(9):26–29.
8. Беляев А.К., Критская С.Н. Интеграция информационных систем в действии. *Информационные технологии в УИС*. 2022;1:34–40.
9. Weber R.H., Burri M. *Classification of Services in the Digital Economy*. Berlin, Heidelberg: Springer; 2012. 144 p.
10. Бабаш А.В., Баранова Е.К. *Актуальные вопросы защиты информации*. М.: ИНФРА-М, РИОР Наука; 2023. 111 с. ISBN 978-5-36901-680-0
11. Мартин Р. *Чистая архитектура. Искусство разработки программного обеспечения*. СПб.: Питер; 2022. 352 с.
12. Черняк Л. Интеграция данных: синтаксис и семантика. *Открытые системы. СУБД.* 2009;10. URL: https://www.osp.ru/os/2009/10/11170978
13. Антамошин А.Н., Близнова О.В., Бобов А.В., Большаков А.А., Лобанов В.В., Кузнецова И.Н. *Интеллектуальные системы управления организационно-техническими системами*. М.: Горячая линия – Телеком; 2006. 160 с.
14. Норенков И.П. *Автоматизированные информационные системы*. М.: Изд-во МГТУ им. Н.Э. Баумана; 2011. 344 с.
15. Мазепа Р.Б., Михайлов В.Ю. *Основы информационных технологий. Введение в процессы информационного взаимодействия*. М.: Вузовская книга; 2012. 60 с.
16. Магазов С.С. *Теория формальных языков. Регулярные языки*. М.: Изд-во МГТУ им. Н.Э. Баумана; 2023. 52 с.
17. Харари Ф., Палмер Э. *Перечисление графов*: пер. с англ. М.: Мир; 1977. 328 с.
18. Фоменко А.Т., Фукс Д.Б. *Курс гомотопической топологии*. М.: URSS; 2024. 512 с.
19. Хатчер А. *Алгебраическая топология*: пер. с англ. М.: МЦНМО; 2011. 688 с.
20. Джарратано Дж., Райли Г. *Экспертные системы: принципы разработки и программирование*: пер. с англ. М.: ИД Вильямс; 2007. 1152 с.
21. Бодров О.А., Медведев Р.Е. *Предметно-ориентированные экономические информационные системы*. М.: Горячая линия – Телеком; 2013. 244 с.
22. Ручкин В.Н., Фулин В.А. *Универсальный искусственный интеллект и экспертные системы*. СПб.: БХВ-Петербург; 2009. 224 с.
23. Sutton R.S., Barto A.G. *Reinforcement Learning: An Introduction*. Cambridge, Massachusetts: The MIT Press; 2018. 526 p.

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