

Ontological Approach to the Formation of Subject-Oriented Knowledge Bases in Computer Science

¹***MAKSUTOVA Kundyž**, Doctoral Student, qunkabai@gmail.com,

¹**NIYAZOVA Rozamgul**, Cand. of Tech. Sci., Associate Professor, rs.niyazova@gmail.com,

¹NPJSC «L.N. Gumilyov Eurasian National University», Satpayev Street, 2, Astana, Kazakhstan,

*corresponding author.

Abstract. An ontological approach to structuring content and evaluating the competencies of IT specialists using the Protégé software is presented. The proposed methodology identifies and analyzes the requirements of professional standards and educational programs to create a model tailored to students' and the labor market's needs. The research focuses on developing and testing an ontological model for assessing student competencies in business solutions within IT. Methods include structuring educational roles, integrating standards, and creating individualized learning trajectories. The model improves the formalization of knowledge, personalizes educational programs, and enhances specialist training, contributing to the optimization of distance learning processes.

Keywords: ontological modelling, ontological model, Protégé, knowledge base, ontological knowledge base, requirements for learning outcomes, assessing learning outcomes, professional standards.

Introduction

The rapid growth of computer science knowledge necessitates efficient management systems to capture, organize, and retrieve information. This paper explores using ontological approaches to create subject-oriented knowledge bases in computer science, enhancing knowledge accessibility and understanding for researchers, practitioners, and educators. By employing domain-specific ontologies, the paper aims to represent computer science concepts, relationships, and contexts in a structured way, enabling efficient knowledge discovery and utilization [1].

The paper explores the benefits and challenges of ontological modeling, detailing how subject-oriented knowledge bases are constructed and their impact on the computer science community. It presents a methodology for structuring and evaluating ICT competencies in higher education, emphasizing two key aspects: defining competency boundaries within a flexible framework and addressing individual student needs for personalized training. This approach improves educational quality and competency development. The development of ontological models and knowledge bases is crucial in fields like information science, AI, and data management, facilitating efficient knowledge organization and retrieval [2].

Ontologies are structured representations defining concepts, relationships, and properties within a domain, crucial for effective knowledge bases. This review covers methodologies for developing ontological models, starting with domain analysis and using tools like OWL or UML. It includes top-down, bottom-up, and middle-out approaches, and highlights the importance of reusing existing ontologies to enhance development [3].

Ontological models and knowledge bases have extensive applications, such as in biomedical domains (e.g., Gene Ontology for data integration and hypothesis generation) and information retrieval (e.g., semantic web technologies for efficient knowledge retrieval and interoperability). The development of these models and knowledge bases is essential for effective knowledge representation and use. Literature on ontology development covers stages from domain analysis to knowledge base formation, various methodologies, tools, and evaluation techniques, reflecting ongoing advancements in data management, AI, and information sciences.

Background

In computer science, creating and organizing knowledge bases is essential for applications like information retrieval, expert systems, knowledge management, and data

mining. These bases store and retrieve critical information, aiding problem-solving and decision-making. Traditional methods, such as relational databases and object-oriented programming, focus on structuring information but often struggle to capture the complex semantics and relationships in intricate domains like computer science [4].

The ontological approach overcomes these limitations by offering a more expressive and flexible framework for knowledge representation. Ontologies explicitly define the conceptualization of a knowledge domain, capturing relationships between concepts, properties, and individuals. This approach enables better knowledge sharing and reuse, providing a common vocabulary for domain experts and enhancing collaboration. In computer science, ontologies are used to define and represent domain-specific concepts and relationships, facilitating more effective knowledge base formation and management [5].

The ontological approach to knowledge base formation offers key advantages over traditional methods. It allows for the representation of complex relationships between concepts, enabling more accurate knowledge retrieval and reasoning. Ontologies provide a machine-readable framework and can be combined with others for a more integrated knowledge base. The process involves domain analysis, ontology design, knowledge acquisition, population, and validation, ensuring a comprehensive and effective knowledge base in computer science [6].

Domain analysis involves identifying key concepts, relationships, and properties within a specific domain. Ontology design and development define the structure, including classes, attributes, and relationships. Knowledge acquisition formalizes information from sources like experts and research, mapping it to the ontology. Validation ensures the knowledge base is correct, complete, and consistent, accurately representing the domain and meeting its intended use [7].

Overall, the ontological approach to the formation of subject-oriented knowledge bases in computer science offers a powerful and flexible solution for capturing, organizing, and accessing knowledge. It provides a rich representation of concepts and relationships, enhancing the effectiveness and usability of knowledge bases in various applications. The systematic and iterative process involved in the formation of such knowledge bases ensures that they are accurate, comprehensive, and aligned with the intended domain [8].

Problem statement

This research is crucial due to the rapid im-

pact of IT revolutions on modern society and industry. IT skills are now essential not just for technical experts but for professionals across various fields. As IT permeates every aspect of life, the demand for skilled IT specialists grows exponentially. Training highly qualified IT personnel is vital, guided by regulatory documents, competence frameworks, and professional standards to build a strong, competitive IT workforce. The need for better methods to align labor market demands with education has driven efforts in management theory and knowledge engineering to develop and assess IT competencies.

Methodology

The creation of an ontological model in Protégé aims to assess and develop students' competencies in «IT solutions for business», based on a system of invariant and variable criteria from relevant documents.

1. *Development Stage:* Introduce concepts and establish links between standards and their competencies.

2. *Structuring Stage:* Apply a structured approach to align educational prescriptions with labor market needs, creating a coherent system of variables.

3. *Implementation Stage:* Integrate disciplinary concepts into the model, develop test materials, and prepare educational resources to enhance student skills.

The final stage focuses on refining conceptual structures and their relationships to support personalized learning paths. Students begin with an entrance test to assess their initial competence, then receive tailored educational materials and resources to guide their self-study effectively [9].

It is also important to take into account that the student will have to pass an exit certification, as a result of which an individual portfolio of accumulated competencies is formed (Table). This analysis enables the assessment of the depth of mastering the materials presented within the framework of the educational process.

If the student has successfully overcome the exit control stage, it signals that the chosen area of knowledge is included in his interests and hobbies, and allows diving deeper into this area. But if the results left much to be desired, then he faces a choice: overcome his shortcomings through repeated assimilation of the material or go in search of new horizons, perhaps even more exciting, taking into account his hobbies and preferences.

The fourth stage of our journey is the creative process of deriving conceptual images for the analysis of inexhaustible resources that go beyond the narrow framework of «IT solu-

An approximate view of the portfolio			
LC	Mastered Competencies	Undeveloped Competencies	Resources to study
Formation of requirements for AS	OSC-1, OSC-8, WS-4		
Development of the AU concept	OSC-1, OSC-8, OSC-9, WS-4	WS-1	Programming course: learning from scratch Computer Science Curricula http://www.acm.org/education/CS2013-final-report.pdf
Technical specification	OSC-2, OSC-3, OSC-4, OSC-8		
Preliminary design	OSC-2, OSC-6, OSC-8, WS-2, WS-3	OSC-7	Training of programmers Lesson 2 of 30 Computing Curricula http://www.acm.org/education/curric_vols/CC2005-March06Final.pdf
Technical Project	OSC-2, OSC-8		
Working Documentation	OSC-3, OSC-4, OSC-8, WS-3, WS-7		
Implementation	OSC-5, OSC-8, OSC-9, WS-5, WS-6		
AU support	OSC-8, OSC-9, WS-6		

tions for business». These images are a kind of maps that help our students to penetrate the essence of this profession at a deeper level [11]. They, like torches in a dark cave, illuminate the path of understanding and open up the opportunity to make adjustments to their professional trajectory [10].

Results of the application of the ontological model

The task of developing an ontological model aimed at structuring and evaluating the competencies of university students in the Protege was analyzed. Based on the proposed methodology, a detailed dissection of the process of formation and analysis of competencies in this specific area has been carried out. Following the described methodology, the process of forming an ontological structure began with the creation of invariant and variable documentary concepts, followed by the completion of the required abstractions. The ontological framework was constructed using the Protégé software tool using a frame representation of cognition. Figures 1, and 2 show the created classes and their properties.

According to Figure 1, «Applied Informatics» and «Competencies» are subcategories of the «SYSTEM_CLASS» class. These subcategories are further subdivided into more specific

classes that describe various aspects of competencies, such as «Universal Competencies» and «Professional Competencies».

The highest level of the structure is represented by these classifications. The «PC_System_Analyst» class is important in the model because it covers the main components of a systems analyst's responsibilities, including job functions, classification levels, and necessary skills and knowledge.

The figure also shows other professions, including software development manager, information systems specialist, IT project manager and programmer. The working functions and abilities of these classes are reflected in their respective subcategories. In addition, students are provided with subjects and educational materials, including tests and teaching materials, which are aimed at developing their abilities. «Maximum Competence» is a tool that helps to assess the degree of compliance of students' competencies with professional standards. Ontological models make it possible to develop training programs that are compatible with modern standards and requirements, facilitating the planning and analysis of professional competencies. [11].

As part of the task, the classes provided will be quite enough for the in-depth development of competence in the field of «IT solu-

tions for business». The subclasses of professional standards will have a uniform structure, and for this reason, Figure 3 reflects only the structure of the PC_SYSTEM_ANALYST class.

In the ontological model, Figure 2 illustrates the structure of categories for the «PC_SYSTEM_ANALYST» class. Slots facilitate the establishment of connections between classes, enabling the description of their properties and

functions. In this paradigm, slots encompass a variety of components that are pertinent to the professional requirements, knowledge, skills, and abilities of system analysts.

The ontological model organizes IT specialist qualifications using key terms such as «competence code», «skills», «knowledge», «work functions», and «experience requirements». It supports adding new terms and components,

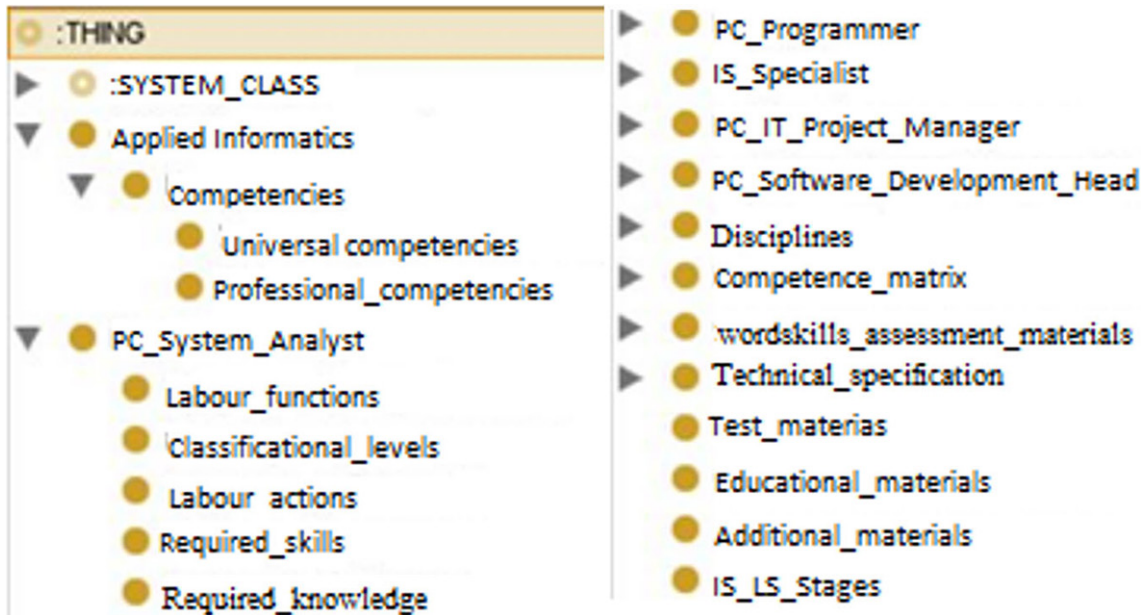


Figure 1 – Classes of the ontological model



Figure 2 – Fragment of the list of slots structure of the PC_system_analyst class

maintaining system stability. This approach is essential for effective modeling and knowledge management in system analyst training, offering flexibility while preserving system integrity. The developed ontological model is illustrated in Figure 3.

Figure 3 illustrates the ontological paradigm developed by the Protégé software for the formulation of content and evaluation of competencies. A multitude of links connecting different classes and their characteristics originate from the «THING» element located at the core of the mathematical model. The model's fundamental elements, including competencies, training materials, professional positions, and specialized requirements, are interconnected through these relationships.

The model includes classes like «PC_System_Analyst», «PC_Programmer», and «PC_IT_Project_Manager», which cover various aspects of professional activities, such as required knowledge, skills, responsibilities, and educational resources. Competency evaluation classes, such as «Test Materials» and «Maximum Competencies», are essential for assessing whether knowledge and abilities meet professional standards.

This comprehensive model demonstrates the interconnections among different ontology components, facilitating effective knowledge

management. It supports the responsive adaptation of educational programs to evolving job market needs, enhancing the alignment of educational outcomes with professional demands.

Conclusions

The ontological model aligns with the goals of harmonizing professional training requirements, enhancing educational programs, and supporting individualized learning. It also allows for expansion to include preparation for official certification exams.

To keep the model relevant, continuous monitoring and updating are essential due to changes in regulations and evolving market and technological trends. Just as a vigilant guardian ensures their post is secure, the model requires ongoing maintenance and adaptation to stay valuable and effective.

To maintain the relevance of the ontological model, constant vigilance is needed to monitor changes in regulatory standards and other evolving factors. This includes staying updated on both major shifts and subtle developments in additional resources, as technological and market dynamics continually evolve. Therefore, the ontological model requires ongoing maintenance and updates to remain effective and aligned with current standards and needs.

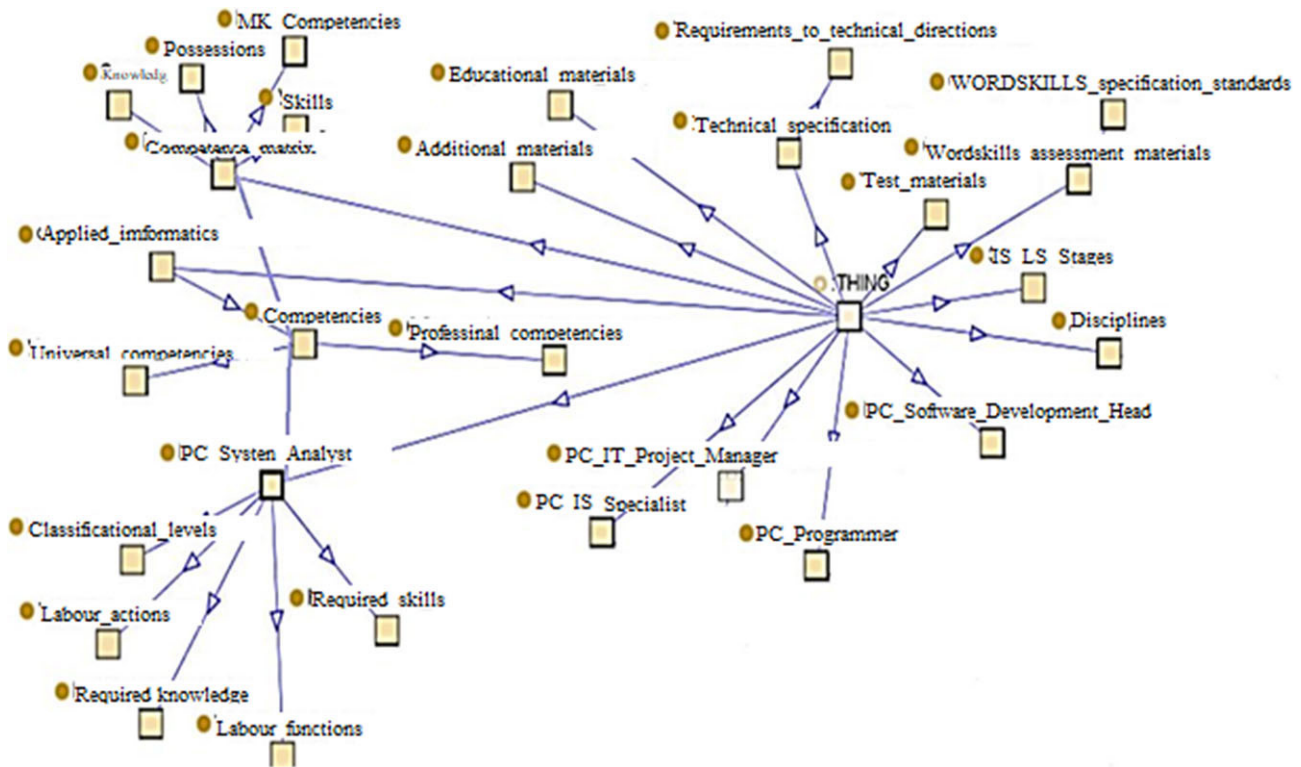


Figure 3 – The ontological model of content formation and competence assessment in the Protege software

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**Информатика саласындағы пәндік-бағдарланған білім базаларын
қалыптастырудағы онтологиялық тәсілі**

¹***МАКСУТОВА Кундыз Мухтаровна**, докторант, qunkabai@gmail.com,

¹**НИЯЗОВА Розамгуль Сериковна**, т.ғ.к., доцент, rs.niyazova@gmail.com,

¹«Л.Н. Гумилев атындағы Еуразия ұлттық университеті» КеАҚ, Сәтбаев көшесі, 2, Астана, Қазақстан,

*автор-корреспондент.

Аңдатпа. *Protégé* бағдарламалық жасақтамасын қолдана отырып, мазмұнды құрылымдауға және АТ мамандарының құзыреттілігін бағалауға экологиялық көзқарас ұсынылған. Ұсынылған әдістеме студенттердің және еңбек нарығының қажеттіліктеріне бейімделген модель құру үшін кәсіби стандарттар мен білім беру бағдарламаларының талаптарын анықтайды және талдайды. Зерттеу студенттердің бизнес-шешімдердегі құзыреттіліктерін бағалаудың онтологиялық моделін әзірлеуге және тестілеуге бағытталған. Әдістемелерге білім беру рөлдерін құрылымдау, стандарттарды біріктіру және оқытудың жеке траекторияларын құру кіреді. Модель қашықтықтан оқыту процестерін оңтайландыруға ықпал ете отырып, білімді ресімдеуді жетілдіреді, білім беру бағдарламаларын дербестендіреді және мамандардың дайындығын арттырады.

Кілт сөздері: онтологиялық модельдеу, онтологиялық модель, *Protégé*, білім базасы, онтологиялық білім базасы, оқу нәтижелеріне қойылатын талаптар, оқу нәтижелерін бағалау, кәсіби стандарттар.

Онтологический подход к формированию предметно-ориентированных баз знаний в области информатики

¹***МАКСУТОВА Кундыз Мухтаровна**, докторант, qunkabai@gmail.com,

¹**НИЯЗОВА Розамгуль Сериковна**, к.т.н., доцент, rs.niyazova@gmail.com,

¹НАО «Евразийский национальный университет имени Л.Н. Гумилева», ул. Сатпаева, 2, Астана, Казахстан,

*автор-корреспондент.

Аннотация. Представлен экологический подход к структурированию контента и оценке компетенций ИТ-специалистов с использованием программного обеспечения Protégé. Предлагаемая методика выявляет и анализирует требования профессиональных стандартов и образовательных программ для создания модели, адаптированной к потребностям студентов и рынка труда. Исследование сосредоточено на разработке и тестировании онтологической модели для оценки компетенций студентов в области бизнес-решений в рамках ИТ. Методы включают структурирование образовательных ролей, интеграцию стандартов и создание индивидуальных траекторий обучения. Модель улучшает формализацию знаний, персонализирует образовательные программы и повышает качество подготовки специалистов, способствуя оптимизации процессов дистанционного обучения.

Ключевые слова: онтологическое моделирование, онтологическая модель, Protégé, база знаний, профессиональные стандарты, компетенции, оценка результатов обучения.

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