Evolution of Semantic Mechanisms from Web 2.0 to Web 3.0 and Web 4.0

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***Abstract*—The evolution and development of the Internet and semantic mechanisms represent a significant challenge in the field of computer science and modern information systems. This paper presents a comparative analysis of semantic mechanisms in Web 2.0, Web 3.0 and Web 4.0, with an emphasis on their impact on semantic formalization, interoperability, machine readability and intelligent data processing. The main contribution of the paper is the development of a structured qualitative comparative approach for analyzing the evolution of semantic technologies and mechanisms across different web generations. The research is based on the systematization, comparative analysis and interpretation of key technologies and concepts such as RDF, OWL, SPARQL, ontologies, knowledge graphs and intelligent agents. The results show a gradual increase in semantic maturity, interoperability and intelligent information processing from Web 2.0 to Web 4.0. Additionally, the analysis shows that Web 4.0 enables the integration of intelligent and contextually adaptive mechanisms that form the basis for the development of modern intelligent systems and adaptive digital environments.**

Keywords—semantic, interoperability, Web 2.0, Web 3.0, Web 4.0, semantic mechanisms, interoperability

I. INTRODUCTION

The Internet has gone through several evolutionary phases during its development, namely Web 2.0, Web 3.0 and Web 4.0, which represent a transformation in the way of creating, connecting, structuring and using information within the framework of modern information systems. Each web generation is identified through specific characteristics and technologies. Web 2.0 is established as a paradigm based on social interaction, user-generated content and marking of information through tags, which enables high availability and dynamism of information [1]. Although this approach allows for intensive interaction and content creation, at the same time limitations arise in terms of interoperability and formal representation of the meaning of data [1].

The transition from Web 2.0 to Web 3.0 represents a significant step in the development of the semantic web by introducing models, ontologies and knowledge graphs, which make data structured and machine-readable [2]. The technologies RDF (Resource Description Framework), OWL (Web Ontology Language) and SPARQL enable formal representation, semantic consistency and intelligent processing of data, which is a significant difference compared to the approach in Web 2.0 [2],[3]. Such technologies enable the development of integrative information systems in which data is linked, formalised and adapted according to the communication context and the needs of users.

With the further development of web technologies, Web 4.0 emerges, which is an intelligent and contextually adaptive web environment based on the integration of intelligent agents, machine learning, decentralized technologies, and automated information processing [3]. Unlike previous web generations, Web 4.0 enables autonomous communication between systems, intelligent data interpretation, and personalized digital services.

The main research question of this research is how the evolution of semantic mechanisms from Web 2.0 to Web 3.0 and Web 4.0 affects interoperability, machine readability and intelligent data processing. The main contribution of the paper is a structured qualitative comparative approach for the analysis of semantic mechanisms through criteria such as semantic formalization, interoperability, machine readability, intelligent processing and contextual adaptation. Through a comparative analysis of Web 2.0, Web 3.0 and Web 4.0, a theoretical and conceptual positioning of the role of semantics in modern intelligent systems is enabled, as well as the identification of limitations and future directions for the development of semantic technologies [3].

II. WEB 2.0

Web 2.0 is an evolutionary phase of the Internet characterized by interactivity, user-generated content, and dynamic communication between users and web platforms [4]. Unlike previous web generations, where users were mostly passive consumers of information, in Web 2.0 users become active creators of content, data, and digital interactions. This approach enables rapid data development and the creation of informal semantic structures and metadata [4].

A. Characteristics of Web 2.0

Web 2.0 is characterized by collaborative platforms, limited semantic consistency, and the use of metadata. Collaborative platforms such as blogs, forums, social networks, and wiki systems enable interaction and information exchange between users [4]. In these systems, the user is not just a recipient of content, but actively participates in the process of creating, sharing, and organizing information.

One of the main characteristics of Web 2.0 is the limited interoperability that results from the high heterogeneity of data and the informal way of organizing it. Users use tags, categories and labels to classify content, which allows for easier searching and communication, but at the same time creates limitations in the formal semantic processing of data [5]. Metadata in Web 2.0 represent informal structures that allow for basic organization of content, but without precise machine interpretation and semantic consistency [5].

B. Technologies and Advantages of Web 2.0

The most commonly used technologies in Web 2.0 are HTML, CSS, JavaScript and AJAX, while semantic technologies are minimally represented [6]. With the introduction of RDFa, the first attempts to structure data and reuse it in different systems appear [6].

Activities based on user interaction represent one of the greatest advantages of Web 2.0 because they enable rapid creation and exchange of content. However, this approach also has disadvantages. The large amount of unstructured data and the informal organization of information lead to limited formalization and poor interoperability between systems [5].

Research shows that tags and user-generated interactions create implicit semantics that represent a significant source of knowledge and a basis for further development of semantic technologies [7].

The analysis suggests that Web 2.0 emphasizes rich, interactive, and collaborative data, but has limited semantic formalization and automation in the data management process. It is these limitations that form the basis for the emergence and development of Web 3.0 as the semantic web.

III. WEB 3.0

Web 3.0, also known as the semantic web, is an evolutionary phase of the Internet in which data is organized and structured in a way that enables machine understanding and intelligent processing of information [8]. The emergence of this phase brings new technologies and concepts that overcome the limitations present in Web 2.0, especially in the domain of interoperability, semantic formalization and automated data processing [8]. A characteristic of Web 3.0 is the introduction of ontologies, knowledge graphs and semantic technologies that enable structured representation and linking of information [9].

A. Web 3.0 Technologies

The Semantic Web is based on technologies such as RDF, OWL and SPARQL, which provide a basis for semantic representation and machine processing of data. RDF (Resource Description Framework) is a model for describing and linking resources through semantic relations, enabling structured representation of information [9]. OWL (Web Ontology Language) is a language for defining ontologies and formalizing knowledge, enabling precise semantic interpretation of data [10]. SPARQL is a language for searching and manipulating RDF data and enabling intelligent searching and processing of information in semantic systems [9],[10].

These technologies enable the creation of integrated and machine-readable information systems, in which data can be automatically interpreted, linked, and reused in different contexts.

B. Characteristics of Web 3.0

Web 3.0 is characterized by semantic formalization, interoperability, and the use of knowledge graphs. Knowledge graphs are one of the most important features of this phase because they enable logical connection of information and creation of semantic relations between data [11]. This approach enables more precise interpretation of content and better understanding of information by systems and users.

To enable such connectivity, Web 3.0 uses mechanisms for automatic data validation, integration, and linking of data to existing logical structures [10]. The linking process is followed by formalization of the meaning of the data through ontologies and semantic models. Formalization is the basis for improved interoperability, machine readability, and intelligent information processing [9].

All these features contribute to the more efficient functioning of semantic systems. Knowledge graphs represent a key mechanism for organizing, connecting, and interpreting data [12]. Analyses show that Web 3.0 represents a transition from traditionally documented information to intelligently structured knowledge that can be automatically processed and interpreted by different systems [13].

Despite significant progress, Web 3.0 also has certain limitations. One of the main challenges is the integration of informal and heterogeneous data originating from Web 2.0 platforms [8]. These limitations create the need for additional semantic mechanisms, intelligent tools, and advanced data processing models, which form the basis for the further development of Web 4.0.

IV. WEB 4.0

Web 4.0 represents a new evolutionary phase of the Internet characterized by the integration of intelligent systems, autonomous agents, and contextually adaptive technologies [12]. Unlike previous web generations, Web 4.0 enables intelligent communication between users, systems, and machine agents in order to create data that is understandable, personalized, and automatically interpreted [14]. The main goal of this phase is to provide intelligent information processing and adaptive digital services based on the context and needs of users.

A. Intelligent mechanisms in Web 4.0

Web 4.0 is based on intelligent agents, decentralized architectures, knowledge graphs, and automated information processing technologies. Intelligent agents are components that perform tasks, analyze data, and make autonomous decisions within the system [13]. These agents enable personalized communication and adaptation of content according to user needs.

Decentralized architectures, based on blockchain technologies, enable secure and confidential exchange of data and knowledge between different systems and users [14]. Such architectures contribute to increased security, transparency, and interoperability in modern web systems.

Additionally, knowledge graphs represent an important mechanism for overcoming the limitations present in Web 3.0. They enable the connection, interpretation, and intelligent processing of data in order to provide personalized and adaptive services [15]. Knowledge graphs enable the creation of semantic connections between different sources of information and contextual understanding of data.

Such mechanisms require a high level of semantics, consistency, and interoperability. These requirements are realized through the use of OWL ontologies that enable knowledge formalization, semantic consistency, and intelligent information processing [16]. Research shows that the use of OWL ontologies significantly improves semantic consistency and interoperability in distributed systems [16].

More recent research focuses on the development of web environments that combine intelligent mechanisms, agents, and semantic technologies [17]. Intelligent agents are closely related to artificial intelligence and machine learning, which enables automatic adaptation of information and provision of content according to the context and needs of the user [18]. Machine learning is an important mechanism for upgrading intelligent agents and automated decision-making in Web 4.0 systems [19].

The development and transition from Web 3.0 to Web 4.0 represents a significant step in the evolution of semantic technologies because Web 4.0 integrates intelligent systems, IoT technologies, and contextually adaptive data processing mechanisms [20].

V. Overview of the Most Relevant Research

The literature contains different approaches to defining the semantic web and intelligent systems, which shows the complexity and dynamism of this research area. Research related to Web 2.0 emphasizes the role of interactive and collaborative platforms as a basis for creating user-generated content and dynamic communication between users [4]. Analyses show that Web 2.0 enables a large amount of data and interactions, but at the same time faces limited interoperability and low semantic formalization [6], [7].

Research related to Web 3.0, also known as the semantic web, shows that the introduction of ontologies, RDF models, and knowledge graphs enables improved machine readability and semantic interoperability [8],[9]. Researchers point out that knowledge graphs play a key role in automatically connecting information and making semantic inferences [11]. In addition, semantic technologies enable the formalization and structuring of data, which is the basis for intelligent information processing [10].

In contrast to Web 3.0, research related to Web 4.0 focuses on the integration of intelligent agents, machine learning, blockchain technologies, and decentralized architectures [12], [13], [15]. These technologies enable intelligent data processing, automated decision-making, and contextually adaptive services. Research shows that intelligent agents significantly improve the adaptability and personalization of modern systems [17], [18].

Empirical research shows that the introduction of semantic technologies significantly improves data quality, data processing, and interoperability in distributed systems [21], [22]. Additionally, research shows that the standardization of semantic technologies is an important prerequisite for the sustainability and development of modern web systems [23]. Analyses of knowledge graphs show that they play a central role in the organization, connection, and interpretation of information [24].

More recent research focuses on proactive information processing, automated decision-making, and the integration of intelligent systems as the future of the semantic web [25]-[27]. In modern e-learning systems, the use of artificial intelligence and intelligent modules enables better interaction between the student and the digital environment, personalized learning, and timely adaptation of content [28]. Such research provides a basis for the development of intelligent e-learning systems based on Web 4.0 and semantic technologies.

VI. Research Questions and Research Objectives

The research focuses on the identification, analysis and comparison of key semantic mechanisms in order to determine their advantages, limitations and potential for further development of intelligent and adaptive systems.

The general goal of the research is an analysis and comparative evaluation of the evolution of semantic mechanisms in Web 2.0, Web 3.0 and Web 4.0, with an emphasis on their impact on data interoperability, machine readability and intelligent information processing.

The following specific objectives arise from this general objective:

- Identification of key semantic mechanisms characteristic of Web 2.0, Web 3.0 and Web 4.0;
- Comparison of the degree of semantic formalization and interoperability;
- Analysis of the role of ontologies and knowledge graphs in Web 3.0;
- Examining the impact of intelligent agents and contextual data processing in Web 4.0;
- Identification of limitations and future directions in the development of the semantic web.

In order to achieve the general objective of the research, the following research questions were formulated:

RQ1 : How do semantic mechanisms evolve from Web 2.0 to Web 3.0 and Web 4.0 and how does this evolution affect interoperability and intelligent data processing?

RQ2: What are the main characteristics and limitations of semantic mechanisms in Web 2.0?

RQ3: How does Web 3.0, through ontologies and knowledge graphs, improve semantic formalization and machine readability?

RQ4: What is the role of intelligent agents and contextual data processing in Web 4.0?

RQ5: What are the key differences in data interoperability between Web 2.0, Web 3.0, and Web 4.0?

RQ6: What are the main challenges and future directions in the development of semantic mechanisms?

VII. Research Methodology

The research is conducted as a qualitative comparative study focused on analyzing the evolution of semantic mechanisms in Web 2.0, Web 3.0 and Web 4.0. The qualitative approach was chosen due to the conceptual, technological and contextual complexity of the research subject, which cannot be fully analyzed through exclusively quantitative methods. This approach allows for a deeper interpretation of the characteristics, functions and role of semantic technologies in different web paradigms, with a special emphasis on their impact on interoperability, machine readability and intelligent data processing.

The analysis is organized according to clearly defined analytical criteria, which allows for the identification of similarities, differences and development trends in semantic mechanisms. The research design is descriptive-analytical and allows for a systematic approach to the defined research questions through conceptual analysis, comparison and interpretation.

For the purposes of the qualitative comparative analysis, the following analytical criteria have been defined:

- Semantic formalization – the degree of formal representation of the meaning of data;
- Data interoperability – the ability to exchange, integrate and connect data between different systems;
- Machine readability – the ability of automated systems to interpret and process data;
- Intelligent and autonomous processing – the presence of intelligent agents, automated decision-making mechanisms, and adaptive processes;
- Contextual information processing – the ability of systems to adapt data and services according to the context and needs of the user.

These criteria are defined based on theoretical foundations and previous research related to the semantic web, intelligent systems, and data interoperability.

A. *Qualitative evaluation scale*

For the purposes of the comparative analysis, a qualitative evaluation scale consisting of three levels was used:

- Low–limited semantic formalization, low interoperability, and limited machine interpretation;
- High-presence of formal semantic technologies, improved interoperability and machine readability;
- Very High - intelligent and autonomous data processing, contextual adaptation and a high level of semantic integration.

The level of evaluation is determined by the presence and application of semantic technologies, intelligent mechanisms, ontologies, knowledge graphs, and interoperability mechanisms within each web paradigm.

The analysis procedure is carried out through several consecutive stages:

- Identification of key semantic mechanisms characteristic of each web paradigm;
- Conceptual analysis of Web 2.0, Web 3.0 and Web 4.0 according to defined analytical criteria;
- Comparative interpretation of the similarities and differences between web paradigms;
- Synthesis of results and their connection with relevant scientific literature.

The methodology enables the interpretation of semantic mechanisms in practical environments, such as intelligent e-learning systems and adaptive digital platforms.

The main contribution of the proposed methodology is the development of a structured qualitative comparative model that enables systematic analysis and evaluation of semantic mechanisms across different web generations.

The results of the analysis are presented through textual interpretation and descriptive comparative tables.

VIII. Results And Discussion

This section presents the results of a qualitative comparative analysis of semantic mechanisms in Web 2.0, Web 3.0 and Web 4.0. The analysis conducted is aligned with the overall research objective, which is aimed at examining the evolution of semantic mechanisms and their impact on interoperability, machine readability and intelligent data processing. The results are presented through comparative tables and narrative analysis.

A. *Results by Analytical Criteria*

For the purpose of systematically presenting the results of the qualitative comparative analysis, the table presents the key differences in the semantic mechanisms of Web 2.0, Web 3.0 and Web 4.0 according to the defined analytical criteria. The table represents the basis for achieving the set goal of the research.

TABLE I. Qualitative Comparative Analysis of Semantic Mechanisms

Analytical Criteria	**Web 2.0**	**Web 3.0**	**Web 4.0**
Semantic Formalization	Low	High	Very High
Data Interoperability	Limited	Supported	Intelligent and Automated
Machine Readability	Low	High	Very High
Intelligent and Autonomous Processing	None	Limited	Advanced
Contextual Processing	None	Partial	Complete

The results shown in the table indicate a gradual increase in semantic maturity across different web paradigms. Web 2.0 is characterized by the dominance of informal semantic mechanisms, resulting in low machine readability and limited interoperability. Web 3.0 introduces formalized semantic models that enable improved automated processing and integration of data. Web 4.0 builds on this foundation through the integration of intelligent and autonomous mechanisms that enable dynamic and contextually adaptive information processing.

B. *Analysis by Criteria and Web phases*

To further synthesize the results obtained, the following table presents an overview of the key results according to the analytical criteria and web phases. The table allows for a clearer interpretation of the evolution of semantic mechanisms.

TABLE II. SYNTHETIC ANALYSIS BY CRITERIA AND PHASES

Criteria	Web Phase	Key Finding
Semantic Formalization	Web 2.0	Data are unstructured and organized through informal tags
	Web 3.0	Formalized semantic models enabling machine readability
	Web 4.0	Dynamic and contextually adaptive semantic interpretation
Interoperability	Web 2.0	Limited and dependent
	Web 3.0	Supported by standards
	Web 4.0	Intelligent and automated
Intelligent Processing	Web 2.0	Absent
	Web 3.0	Limited support
	Web 4.0	Autonomous intelligent agents

C. *Use-case Scenario in Intelligent e-systems*

The evolution of semantic mechanisms can be interpreted through their application in intelligent e-learning systems. In Web 2.0 environments, interaction is based on forums, collaborative platforms, user comments and organization of teaching materials through tags. Although this approach allows for intensive interaction and content creation, semantic interoperability and machine interpretation remain limited.

In Web 3.0 environments, semantic technologies such as ontologies, RDF metadata, and knowledge graphs enable structured representation of educational resources and improved interoperability between educational systems. These technologies enable machine-readable educational content and intelligent information retrieval.

Web 4.0 introduces intelligent agents, contextual processing, and adaptive mechanisms that enable personalized learning experiences. Intelligent agents can analyze student behavior, their habits, and contextual information to provide adaptive recommendations and automated support. Such mechanisms are the basis for the development of intelligent and adaptive e-learning systems based on semantic technologies [29].

D. *Interpretation and Discussion of the Results*

The analysis of semantic mechanisms in Web 2.0 shows that informal and user-generated structures for data markup dominate. This approach allows for broad participation and dynamic content creation, but results in a low level of semantic formalization and limited machine readability. These results provide an answer to the research question related to the characteristics and limitations of semantic mechanisms in Web 2.0 (RQ2).

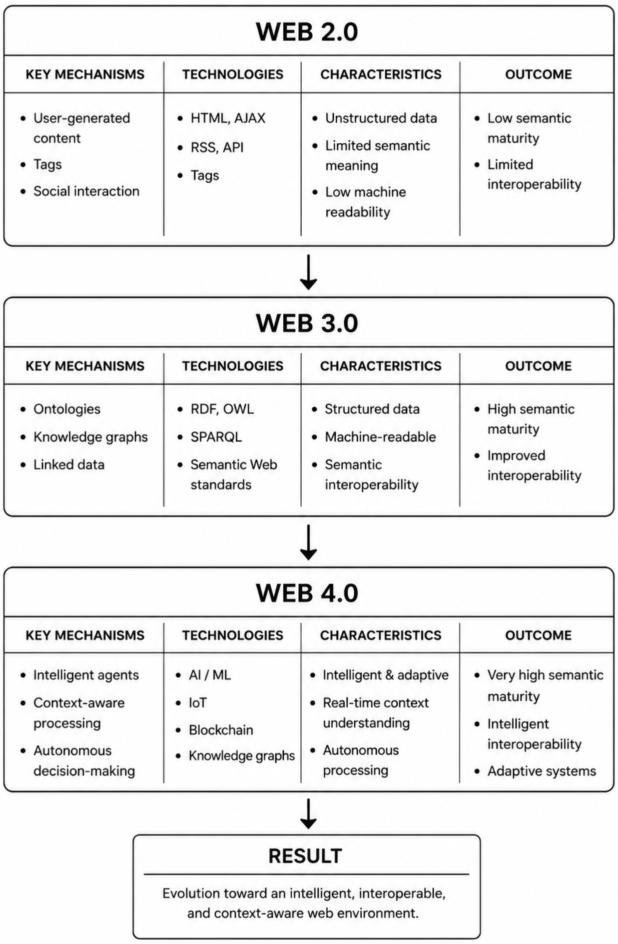

Fig.1. Evolution of Semantic Mechanisms from Web 2.0 to Web 4.0.

The analysis of Web 3.0 shows a significant change in knowledge management through the introduction of ontologies, formal languages, and knowledge graphs that enable structured and machine-readable data. These results provide an answer to the research question related to the role of ontologies and knowledge graphs in improving semantic formalization and machine-readability (RQ3). At the same time, the results show that formalization significantly improves data interoperability.

The results of the analysis of Web 4.0 show the evolution of semantic mechanisms through the integration of intelligent agents and intelligent systems. In this phase, data is not only structured, but also dynamically interpreted and used for autonomous decision-making. These results provide an answer to the research question related to the role of intelligent agents in Web 4.0 (RQ4).

The comparative analysis of interoperability presented in Table II answers the research question related to the differences in interoperability between Web 2.0, Web 3.0 and Web 4.0 (RQ5). The results show that interoperability is closely related to the degree of semantic formalization and the presence of intelligent mechanisms.

The narrative synthesis of the results shows that, despite the progress in Web 4.0, there are still challenges related to system complexity, security, ethical aspects and sustainability. These results provide an answer to the research question related to future challenges and directions in the development of semantic mechanisms (RQ6).

The integration of all results provides a complete answer to the main research question (RQ1), showing that the evolution from Web 2.0 to Web 4.0 represents a gradual increase in semantic maturity, interoperability, and intelligent data processing.

The results of the comparative analysis show that the analyzed semantic technologies have direct practical implications for the design and implementation of modern information systems. The analysis shows that the low level of semantic formalization in Web 2.0 limits interoperability and machine processing of data. The introduction of formalized semantic models, ontologies and knowledge graphs in Web 3.0 enables improved interoperability and more efficient data integration. In addition, the results show that Web 4.0, through the integration of intelligent agents, enables the development of adaptive and intelligent systems.

The research provides a practical basis for the selection and application of appropriate semantic technologies in the development of interoperable and intelligent systems.

IX. Conclusion

This research presents a comparative analysis of the evolution of semantic mechanisms in Web 2.0, Web 3.0 and Web 4.0, with an emphasis on their impact on semantic formalization, interoperability, machine readability and intelligent data processing. The analysis shows that the development of web paradigms represents a gradual transition from informal and limitedly structured data to intelligent, adaptive and context-oriented systems.

The results show that Web 2.0 is characterized by interactive and collaborative platforms based on user-generated content, but with limited semantic formalization and interoperability. Web 3.0 introduces semantic technologies such as RDF, OWL, SPARQL, ontologies and knowledge graphs, which enable structured and machine-readable representation of data. The analysis of Web 4.0 shows that the integration of intelligent agents, machine learning, blockchain and contextual processing enables autonomous and intelligent information processing.

The comparative analysis shows that interoperability and intelligent data processing directly depend on the degree of semantic formalization and the integration of intelligent mechanisms. The research also shows that Web 4.0 is the basis for the development of modern intelligent and adaptive systems, especially in areas such as intelligent e-learning systems, personalized digital services and contextually adaptive information systems.

The main contribution of the paper is the development of a structured qualitative comparative approach for the analysis of semantic mechanisms across different web generations. In addition, the paper provides a systematized interpretation of the role of semantic technologies, knowledge graphs, and intelligent agents in the evolution of the modern web.

Despite the identified progress, significant challenges remain related to system complexity, security, privacy, ethical aspects, and standardization of semantic technologies. Future research should be directed towards practical implementation and evaluation of intelligent semantic systems, as well as towards the integration of adaptive and autonomous mechanisms in modern distributed environments.

With the answers to the research questions posed and the achievement of the defined research objectives, it can be concluded that the evolution from Web 2.0 to Web 4.0 represents a significant step towards the development of an intelligent, interoperable, and contextually adaptive web ecosystem.

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