Knowledge Organization

Knowl. Organ. **2026**; 53(3): 47986
https://doi.org/10.31083/KO47986

Article

An Introduction to the Principle of Cognitive Unity in the Structure of KOSs

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Academic Editor: Natália Tognoli
Submitted: 4 November 2025 Revised: 7 February 2026 Accepted: 26 March 2026 Published: 29 June 2026

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Abstract

This study investigates the cognitive structure of Knowledge Organization Systems (KOSs) and proposes the principle of cognitive unity as a foundational criterion for ranking and evaluating KOSs. The research aims to identify cognitive roots, dynamic cognitive units (data, information, and knowledge), and the forms of unity—both internal and dynamic—that govern their interrelationships. Employing a documentary research methodology, the study synthesizes theoretical frameworks from cognitive science, including Tall's concept of cognitive structure, Skemp's varifocal theory, and the theory of conceptual compression. The analysis integrates Peirce's triadic model for data, Semantic Link Network Theory (SLNT) for information, and Quantum Theory of Knowledge (QTK) for knowledge to delineate the constituent elements of each cognitive unit. The theory of concepts is used to represent the building blocks of knowledge, clarifying how concepts function as foundational units within the cognitive architecture of KOSs. These concepts serve as anchors for semantic and pragmatic structuring, enabling the formation of coherent knowledge systems. The study further applies Mandelblit and Zachar's model of dynamic patterns of correlation among elements to explain how cognitive units interact across levels. This dynamic correlation is complemented by the principle of internal unity, which identifies the structural coherence among constituent elements within each cognitive unit and supports the emergence of dynamic unity across units. The results demonstrate that knowledge, as the highest state of cognition, functions as the cognitive root encompassing the dynamic units of data and information. Each unit exhibits internal unity (Type 2) among its elements and dynamic unity (Type 4) across units, based on patterns of correlation and dialectical synthesis. These findings highlight the layered and interconnected nature of KOSs and affirm the value of cognitive analysis in their classification and development. The study concludes by introducing the principle of cognitive unity as a theoretical basis for ranking KOSs, with future research directed toward formalizing this principle and exploring its operational implications across diverse knowledge domains.

Keywords: Knowledge Organization Systems (KOSs); cognitive structure; cognitive roots; dynamic cognitive units; cognitive unity; the principles of unity; KOSs ranking

1. Introduction

In an era defined by information abundance and computational complexity, the systems we design to organize knowledge are not passive backdrops but active shapers of understanding. From the library classifications that guided centuries of scholarship to the intricate ontologies underpinning modern artificial intelligence, Knowledge Organization Systems (KOSs) perform a crucial epistemic function: they provide structured pathways through the vast landscapes of human knowledge. Yet, a fundamental question persists: How can we move beyond assessing these systems by their surface features or retrieval efficiency to evaluate the very quality of their cognitive design? This study posits that the answer lies not in their output alone, but in their internal cognitive architecture. We introduce and develop the **principle of cognitive unity**, a novel theoretical and evaluative framework asserting that the sophistication and efficacy of a KOS are determined by the coherence and dynamism of the cognitive structures it embodies.

The challenge of organizing knowledge is, at its heart, a cognitive challenge. **Cognition** is the mental process of acquiring, structuring, and applying understanding. It operates through a layered integration of mental constructs. At the base are elemental units, discrete **data** points or concepts, such as the word "red" or the idea of a "traffic light". When these concepts are connected within a specific context (e.g., "red *is a color on* traffic light"), they form meaningful **information**. Further synthesis and application of these informational patterns, governed by rules and goals (e.g., "red light *means* stop, therefore apply brakes"), culminate in actionable **knowledge**. Crucially, this is not a rigid, linear pipeline (as in the often-criticized Data-Information-Knowledge-Wisdom pyramid) but a dynamic, recursive process where knowledge informs the interpretation of new data, and new data can reshape existing knowledge (Burgin, 2004). The field of Knowledge Organization (KO) emerges precisely from the endeavor to systematize this cognitive process externally, developing tools and theories for the "planned construction" of knowledge structures (Dahlberg, 2006).

KOSs, encompassing diverse forms like alphabetical indices, subject heading lists, taxonomies, thesauri, and ontologies, are the practical instruments of KO. While traditionally viewed through a lens of document retrieval, a powerful strand of KO research argues for a **cognitive perspective** (Hjørland, 2013). This perspective recognizes that KOSs are not merely about ordering documents but about modeling and mediating the conceptual structures of a domain. They are external mirrors of, and interfaces to, internal cognitive processes; their design implicitly or explicitly makes assumptions about how humans categorize, relate, and reason with concepts (Gnoli, 2018). Therefore, a deep analysis of a KOS is, in essence, a reverse-engineering of a proposed cognitive model for a particular domain of knowledge.

To perform such a cognitive analysis systematically, we require a robust analytical vocabulary. This paper adapts and synthesizes key constructs from cognitive science. First, we employ the concept of the **cognitive root**, originally developed by Tall (1989) in mathematics education. A cognitive root is an anchoring concept that is intuitively graspable yet rich enough to support the growth of an entire theoretical edifice. We argue that for the meta-domain of KOS analysis, the terms embedded in the acronym itself, "**knowledge**", "**organization**", and "**system**", function as these foundational roots. They provide the intuitive entry points for analyzing any KOS's purpose, activity, and form.

From these roots grow **dynamic cognitive units**. Moving beyond static definitions, we conceptualize these units as "tightly integrated scenes" that can be mentally manipulated as coherent wholes, whose meaning and boundaries are defined by stable patterns of correlation among their elements within a specific context (Mandelblit and Zachar, 1998). The central thesis of this article is that the primary dynamic cognitive units constituting the actionable layer of a KOS's architecture are:

• **Data-as-Concept**: The atomic unit, modeled as a triadic sign (Peirce CS, 1931–1958), combining a representamen (term/symbol), an object (referent), and an interpretant (sense).

• **Information-as-Semantic-Link**: The relational unit formed by connecting at least two data/concepts via a labeled, meaningful relationship (e.g., broader/narrower, part/whole), forming the basic propositional structure of the system.

• **Knowledge-as-System**: The integrative unit where networks of data and information are compressed and structured into a coherent, goal-oriented whole with emergent properties like inferential power and pragmatic utility (Burgin, 2017).

The interplay *within* and *between* these units is governed by different forms of **unity**. We analyze these using a typology from Mandelblit and Zachar (1998), ranging from classical, spatially-bound unity to **dynamic unity (Type 4)**, where elements cohere through correlated activity within a context, not through physical or fixed logical bonds. The "cognitive unity" of a KOS, the principle we propose, is precisely the manifestation of strong, resilient dynamic unity among its data, information, and knowledge units.

However, merely describing this architecture is insufficient. A significant gap exists in KO between rich descriptive theories of knowledge and actionable criteria for evaluating the KOSs that purport to organize it. Current evaluations often focus on algorithmic efficiency, coverage, or user satisfaction in specific tasks, but lack a foundational theory for assessing the intrinsic cognitive-coherence of the system *as a model of knowledge*. This paper aims to bridge that gap. We do not merely present a new taxonomy but construct a multi-part framework for **evaluative theory**:

(1) **A Descriptive-Analytical Framework**: We synthesize theories from distinct epistemic traditions into a coherent lens: Tall's cognitive structures provide the meta-theory of hierarchy and compression; Peircean semiotics models the unit of *data*; Semantic Link Network Theory (SLNT) models the unit of *information*; and the Quantum Theory of Knowledge (QTK) models the emergent, systemic nature of the *knowledge* unit. This synthesis allows us to dissect any KOS across these complementary layers.

(2) **An Operational Principle**: We define the **Principle of Cognitive Unity** operationally as the measurable degree of coherent integration a KOS exhibits across three dimensions: *Structural-Cohesive* (strength of internal and dynamic correlations), *Cognitive-Compressive* (efficiency of bundling complexity into manipulable wholes), and *Pragmatic-Adaptive* (resilience and fitness for domain-specific reasoning).

(3) **A Demonstrative Application**: The framework is grounded through a concrete case study analysis of the Gene Ontology (GO), showing how abstract concepts like dynamic unity translate into observable features of a large-scale, widely-used KOS.

(4) **A Pathway to Ranking**: The principle culminates in a novel schema for ranking KOSs, not by flat superiority, but by their evolved capacity to embody and facilitate cognitive unity across the data-information-knowledge spectrum.

Employing a documentary research methodology, this study synthesizes literature from cognitive science, information science, semiotics, and philosophy to build its case. The following sections will: identify the cognitive roots in KOSs (Section 2); detail the creation and identification of dynamic cognitive units (Section 3); analyze the types of unity within the cognitive structure (Section 4); propose a ranking schema based on this unity (Section 5); and finally, synthesize the descriptive framework into a full evaluative theory, clarifying its theoretical and practical contributions (Section 6).

By arguing that the caliber of a KOS is fundamentally linked to the sophistication of its embedded cognitive architecture, this work seeks to provide scholars, designers, and evaluators with a new and powerful vocabulary for understanding, critiquing, and advancing the tools we use to organize our collective understanding. It moves the conversation from "what a KOS contains" to "how coherently it structures what we know".

1.1 Theoretical Synthesis and Epistemic Coherence

The methodological approach of this study involves the deliberate synthesis of theoretical frameworks from cognitive science, semiotics, information science, and knowledge theory. This interdisciplinary integration is not merely additive but designed to create a coherent, multi-layered analytical lens for examining the cognitive structure of KOSs. Each selected theory addresses a specific stratum of cognitive organization, and together they form a complementary progression from discrete elements to integrated systems.

The analysis begins with Tall's (1989) model of cognitive structure and Skemp's (1979) varifocal theory, which provide the foundational meta-theory for understanding hierarchical organization, conceptual compression, and the very notions of cognitive roots and units. These cognitive science frameworks establish the overarching form of the analysis, the "how" we perceive structures of thought.

Within this formal cognitive framework, distinct theories are deployed to model the specific content of each dynamic cognitive unit. For the unit of data/concepts, Peirce's triadic semiotics (Peirce CS, 1931–1958) is employed. Its strength lies in modeling the fundamental representational act, how a sign comes to signify an object for an interpretant. It captures the static, elemental building block of meaning prior to its relational life (Atkin, 2013).

The analysis of the information cognitive unit is grounded in SLNT (Zhuge, 2004; 2012). SLNT occupies a critical intermediary position in the framework. It directly complements Peircean semiotics: while Peirce's model explains the constitution of a single sign (data), SLNT provides the formal theory for the meaningful relationships between signs. A semantic link, defined as a triad of two nodes (concepts) and a labeled relation, constitutes the minimal unit of information, representing a contextual proposition or statement. This relational layer is essential for the cognitive processes of varifocal navigation and compression. Furthermore, SLNT supplies the structured network of linkages that the QTK then models at a systemic level; the semantic links of SLNT are the relational components that QTK theorizes as integrating into emergent knowledge wholes. Thus, SLNT is the specific theory for the connective tissue of the cognitive architecture, bridging atomic concepts and systemic knowledge.

The QTK (Burgin, 1995; 2017) is then engaged for the unit of knowledge. This is where the unique contribution of the quantum metaphor becomes clear. While SLNT excellently maps the relational network, QTK provides a theory for the coherent integration and emergent properties of that network as a systemic whole. The metaphor of "quantum bricks" and "quantum blocks" is not merely about discreteness but about how discrete informational elements (concepts and links) combine into a new, unified state (i.e., the knowledge system) with properties (e.g., inferential power, pragmatic utility) that are not reducible to the simple sum of its parts. It elucidates the transition from a network of information to a structured system as knowledge.

Therefore, these components are not redundant but operate on a continuum of cognitive complexity: Peircean semiotics explains the atom of meaning (the sign), SLNT explains the molecule (the semantic link/statement), and QTK explains the organized cell or organism (the knowledge system) that emerges from their structured integration. They are bound together by the unifying meta-theory of cognitive structure and the cross-cutting principle of dynamic correlation (Mandelblit and Zachar, 1998), which describes the cohesive force operating within and between these layers. This synthesis creates an epistemically coherent framework capable of describing both the hierarchical levels and the dynamic unities that constitute the cognitive architecture of KOSs.

1.2 Operational Definitions of Core Cognitive Units: Data, Information, and Knowledge

• Within the cognitive framework of this study, the terms data, information, and knowledge refer not to a linear hierarchy but to distinct, dynamic cognitive units that interact to form the architecture of KOSs. They are defined operationally as follows.

• Data refers to the foundational, discrete cognitive units that function as the basic semantic building blocks within a KOS. In this context, data are equivalent to concepts. Each unit of data is modeled as a triadic sign (Peirce CS, 1931–1958), comprising: (1) a representation (a term, symbol, or signifier), (2) an object (the referent or entity in the world), and (3) an interpretant (the sense or meaning generated in the mind). A datum, therefore, is a meaningful, identifiable unit prior to its integration into relational structures (Hjørland, 2009).

• Information refers to the cognitive unit formed by structured relationships between units of data. It emerges when at least two data units (concepts) are connected via a semantic link that specifies a meaningful relationship (e.g., "is a type of", "is part of", "causes") within a specific context (Zhuge, 2012). This unit, a proposition or statement, constitutes a node-link-node structure. Information, in this sense, is contextualized data, where meaning arises from the relational pattern itself (Mandelblit and Zachar, 1998).

Knowledge refers to the highest-order cognitive unit, characterized by the systematic integration and compression of multiple data and information units into a coherent, pragmatically oriented whole (Burgin, 2017). A knowledge unit, or knowledge system, exhibits emergent properties, such as inferential power, explanatory capacity, and decision-support utility, that are not reducible to its constituent data and information parts. It is defined by its internal coherence, resilience, and its capacity to model a domain for a specific purpose (e.g., reasoning, classification, discovery), aligning with the pragmatic dimension of semiotics (Nake, 2002).

These definitions are interdependent and non-linear. They serve as the operational basis for identifying and analyzing the dynamic cognitive units within KOSs, moving beyond the sequential "pyramid" model toward a model of correlated, dynamic unity.

2. The Identification of the Cognitive Roots in KOSs

The initial phase of cognitive analysis within any scientific domain involves identifying and characterizing the nature of cognitive roots. These roots serve to elucidate foundational concepts and construct a generalized representation of the domain in question. Corresponding to Barnard's conception of "cognitive structure" (Barnard and Tall, 1997; Barnard, 1998), Tall (1989) posited that a cognitive root constitutes a distinct type of cognitive unit and originally formulated the cognitive root to be defined as "an anchoring concept which the users find easy to comprehend, yet forms a basis on which a theory may be built". It encapsulates ideas that are both meaningful and contextually rich within a given domain (Ausubel et al., 1978).

As cognitive roots evolve, they acquire increasingly sophisticated internal structures and establish more nuanced connections to related concepts. A well-established cognitive root thus provides a meaningful foundation—comprising fundamental cognitive units—that facilitates conceptual understanding within the domain. Tall (1992) further describes cognitive roots as initial concepts that fulfill a "dual role of being familiar to users and providing the basis for later domain development", particularly in areas targeted for cognitive analysis.

From the perspective of cognitive structural analysis, a cognitive root refers to a concept that is readily comprehensible, supported by a rich internal structure, and capable of forming coherent links to other related concepts within the domain. Feature analysis of cognitive roots, when situated within the framework of cognitive structure, enables the identification and ranking of fundamental cognitive units inKOSs according to contextual relevance.

Barnard (1998) emphasizes that the conceptual power of a cognitive root lies in its dual capacity: it is "smaller" in the sense that it can be retained within the short-term focus of attention, and "greater" in its holistic properties that guide manipulation and understanding. Accordingly, cognitive roots should target the central core of knowledge within the domain as the initial step in cognitive development. As this development progresses, cognitive roots must remain sufficiently robust to support increasingly complex conceptual elaborations (Tall et al., 2000).

Dahlberg (2006) asserts that the concepts of "knowledge"—understood as that which is known—and "organization"—conceived as the activity of constructing according to a plan—constitute the object area of KO. This object area is embedded in the very nomenclature of KO, serving as a basis for identifying its scientific criteria, including its object and activity domains. The object area of KOSs, as a scientific manifestation of KO, is reflected in the title itself. In this context, KOSs encompass fundamental concepts: they organize "knowledge" through the structured activity of "organization" (Dahlberg, 2006), realized in systematized conceptual representations (Arboit, 2018; Dahlberg, 1978a) within the framework of a "system".

Consequently, the three core components embedded in the term KOS—"knowledge", "organization", and "system"—exemplify the characteristics of cognitive roots. These include conceptual simplicity, holistic integration, and the capacity to encompass complex and interrelated ideas within the domain. From the standpoint of cognitive development and analysis, these three concepts are recognized as cognitive roots that define and structure the epistemic foundation of KOSs.

This application of Tall's "cognitive root" from mathematics education to the structural analysis of KOSs requires explicit justification. The transposition is valid because the core epistemic function of the concept remains consistent across domains. In Tall's framework, a cognitive root serves as an intuitive entry point that generatively structures a knowledge domain for cognitive processing (Tall, 1992). Analogously, within the meta-domain of KOSs as cognitive artifacts, the terms "knowledge", "organization", and "system" are not merely lexical items but represent fundamental, intuitive categories that anchor and structure all subsequent analysis of how KOSs function as knowledge-modeling tools. They are "easy to comprehend" as broad, familiar ideas, yet they provide the necessary "basis on which a theory may be built", specifically, the theory of cognitive unity advanced in this paper. Therefore, they fulfill the functional criteria of cognitive roots within the specialized cognitive domain of KOS analysis, guiding the identification of subordinate cognitive units (data, information, knowledge) and the patterns of unity among them.

2.1 Knowledge as a Cognitive Root

The concept of "knowledge" has been defined across philosophical, theoretical, and practical domains; however, this section does not aim to elaborate on those definitional variations. Instead, it focuses on examining "knowledge" as a cognitive root, a comprehensive construct, and a central organizing principle within KOSs, particularly through the lens of its constituent levels and elements.

Hjørland (2012) observes that the terms "knowledge" and "information" are frequently used interchangeably, a tendency reflected in his broader discussions on terminology within the field of knowledge organization (Arboit, 2018). From another perspective, information may be situated within various collective knowledge structures depending on its contextual features—whether subjective, situational, or domain-specific (Hjørland, 1997). Furthermore, concepts—often referred to as "data"—function as the foundational "building blocks" or "units of knowledge" (Dahlberg, 1986), representing the smallest semantic components within KOSs (Stock, 2010).

In cognitive terms, the formation of knowledge within the human mind progresses through distinct levels: mental data, information, and knowledge (Amirhosseini, 2022). Each of these levels can be understood as a cognitive unit that contributes directly to the construction of the cognitive architecture of KOSs. Thus, the term "knowledge" in this context is regarded as a cognitive root—representing the highest level of cognition and encompassing the cognitive units of data, information, and knowledge.

Accordingly, for the purpose of conducting a cognitive analysis of KOSs, particularly in relation to their evaluation and ranking, it is essential to examine these cognitive units and their constituent elements in subsequent sections. This approach enables a deeper understanding of the structural and epistemological foundations of KOSs from a cognitive perspective.

2.2 Organization as a Cognitive Root

Beyond the comprehensive concept of "knowledge" embedded in the title of KOSs—which encompasses the cognitive states or units of data, information, and knowledge—the concept of "organization" also warrants recognition as a cognitive root in the analysis of cognitive structures within Knowledge Organization (KO) and KOSs. The phrase "organization of knowledge", originally introduced by Bliss (1929), laid the foundation for a new scholarly domain that was formally recognized in 1989 (Dahlberg, 1993; 1995; 2006). The term "knowledge organization" itself was first proposed by Soergel (1971) and rapidly gained traction among scholars aligned with this conceptual framework, most notably Dahlberg, who subsequently established the International Society for Knowledge Organization (ISKO) in 1989 (Arboit, 2018).

Dahlberg (2006) emphasized that the German interpretation of "organization" in the context of KO extends beyond the notion of mere "order". It encompasses broader dimensions such as "planned construction", "structure", and "formation" (Arboit, 2018). Moreover, the concept of "organization", as applied in associations and unions, includes both human and non-human entities—namely, people and objects (Ohly, 2020).

The applied dimension of KOSs within the KO field (Broughton et al., 2005; Thellefsen, 2010) is closely tied to the pragmatic construction and evaluation of knowledge organizing tools, including classification schemes, thesauri, and ontologies (Arboit, 2018). In this context, KOSs embody the fundamental principle that "knowledge" is the entity being organized (Broughton et al., 2005), and that "organization" refers to the constructive activity through which systematized conceptual representations are achieved (Dahlberg, 2006; Dahlberg, 1978b; Hjørland, 2009).

Accordingly, activities and processes such as "order", "planned construction", "structure", and "formation" are integral to the systematic representation of concepts within the organization of knowledge, positioning "organization" as a focal element in the cognitive architecture of KOSs. From the standpoint of cognitive analysis, the term "organization" thus qualifies as a cognitive root. However, it does not function independently of the concept of "knowledge", which remains the central focus of KOSs. In this regard, the cognitive root of "organization" is intrinsically linked to, and dependent upon, the primary cognitive root of "knowledge".

2.3 System as a Cognitive Root

Alongside the terms "knowledge" and "organization" embedded in the expression KOSs, the term "system" also functions as a cognitive root in the cognitive development and structural analysis of KOSs. The broader field of KO, including its subdomain KOSs, is fundamentally concerned with theoretical frameworks related to systems and processes that facilitate subject representation and the retrieval of information resources (Thellefsen, 2010).

According to Dahlberg (1978b), KOSs represent modalities of concept systems, designed for the systematic representation and ordering of concepts in accordance with the "theory of concept" (The Theory-Theory of concepts is a view of how concepts are structured, acquired, and deployed (The "Theory-Theory of concepts", by Daniel A. Weiskopf, The Internet Encyclopedia of Philosophy, ISSN 2161-0002, https://iep.utm.edu/theory-theory-of-concepts/)) (Arboit, 2018). These systems are, in essence, structured arrangements of organized concepts (Broughton et al., 2005; Hjørland, 2009). From Dahlberg's perspective, the construction of conceptual systems should enable the perception, comprehension, and acquisition of knowledge concerning the attributes and interrelationships of the concepts being systematized.

Moreover, the development of such conceptual systems must adhere to objective parameters, including clearly defined rules for ordering elements and categories within a predetermined formal structure (Arboit, 2018). Thus, the notion of "system" within the context of KOSs is grounded in the creation of structured frameworks for organizing concepts, ultimately contributing to the formation of knowledge systems and the broader epistemic landscape.

Accordingly, the term "system" assumes the role of a cognitive root in the cognitive development of KOSs. However, similar to the term "organization", it remains intrinsically linked to the primary cognitive root of "knowledge". The interdependence among these roots—knowledge, organization, and system—underscores the integrated nature of cognitive development within KOSs and highlights the systemic foundation upon which knowledge is structured and represented.

2.4 The Knowledge Root as an Integrative Cognitive Structure

Having identified "knowledge", "organization", and "system" as the three primary cognitive roots of KOSs, it is necessary to define a more specific usage central to our cognitive analysis: the knowledge root. In this specialized sense, the knowledge root refers to the overarching, integrative cognitive structure that serves as the hierarchical anchor for the dynamic cognitive units of data, information, and knowledge. It is not merely the lexical concept "knowledge" but the foundational cognitive schema that encompasses the entire progression from discrete conceptual signs (data) to relational links (information) and finally to coherent, pragmatic systems (knowledge). Functioning as the highest-level cognitive unit, the knowledge root provides the architectural principle that binds these sub-units into a correlated, dynamic whole. Therefore, when analyzing the internal cognitive architecture of a KOS, we trace its structure back to this integrative knowledge root, which manifests through the patterns of unity among its constituent data, information, and knowledge units.

3. The Creation of the Cognitive Units

Thurston (1990) posits that when discrete elements of a cognitive structure become interconnected, they give rise to compact yet richly integrated cognitive units through a process known as *compression*. This method enables the condensation of complex ideas into manageable forms, often facilitated by the use of words as tokens that encapsulate intricate meanings. These tokens can be organized hierarchically, thereby supporting the compression process and enabling the formation of cognitive units (Barnard and Tall, 2001).

For illustrative purposes, consider the following example: the isolated percept or sense-datum of 'red color' may be classified under the cognitive unit of *data*; the contextualized notion of a 'traffic light with three different colors' aligns with *information*; and the interpretation of 'red color at a traffic light' as signifying 'stop' constitutes *knowledge*. This progression demonstrates how hierarchical relationships can be established both *within* and *between* cognitive units in a structured cognitive framework (Skemp, 1979). In this context, related elements may be grouped under a single cognitive unit—such as data, information, or knowledge—while cognitive units themselves can be hierarchically interrelated within the broader cognitive structure.

Such hierarchical organization fosters the development of new cognitive links, enabling the construction of nested mental structures that span multiple layers of thought. This approach allows for the simplification and management of structural complexity by consolidating information into a limited number of richly connected cognitive units, thereby facilitating deeper and more precise understanding of complex cognitive architectures.

The theoretical foundation for this process is articulated in Skemp's (1979) *varifocal theory* of cognitive concepts, which supports the hierarchical classification of ideas both within individual cognitive units and across interrelated units. According to this theory, concepts themselves may be understood as schemas—structured networks of connections that function as unified entities. These schemas, in turn, can be interpreted as cognitive units in their own right.

A cognitive unit may consist of core elements or function as a composite entity. For instance, a cognitive unit of *information* may comprise two concepts and a node, collectively forming what is referred to as a *cognitive link*. Such links typically include an object (referent), mental concepts (interpretant), and a representational form (symbols or signs). Within this framework, nodes and their interconnections manifest as a network of hierarchical relationships among broader and narrower cognitive units (Hiebert and Carpenter, 1992).

Therefore, through the application of compression theory and its associated methods, it becomes possible to integrate dispersed elements of a complex cognitive structure into a coherent hierarchy of general and specific cognitive units. This integrative process not only enhances the comprehension of complex structures but also supports a holistic understanding of the cognitive architecture, enabling detailed insight through the lens of individual cognitive units.

3.1 The Identification of Cognitive Units in KOSs: A Process of Conceptual Compression

Identifying the building blocks of thought within a Knowledge Organization System requires a theory of how the mind packages complexity into manageable wholes. This section translates the abstract theories of compression into a practical, example-driven method for pinpointing cognitive units within any KOS.

3.1.1 The Core Mechanism: From Scattered Pieces to Unified Chunks

The foundational idea is compression (Barnard and Tall, 2001). In cognitive terms, compression is the process by which a collection of related ideas, facts, or relationships is bound together so tightly that the mind can treat the entire collection as a single, unified item—a "chunk". This is not merely grouping; it is the creation of a new cognitive entity with its own identity.

• Example: Consider learning about a library. Initially, you might perceive thousands of individual books (discrete elements). Through experience, you compress them into categories like "History", "Biography", and "Science Fiction" (cognitive units). Finally, you further compress these categories into the single, rich concept of "The Library" itself. You don't think of every book when you hear "library"; you think of a unified institution. This is compression in action.

When this process is applied to conceptual knowledge, it is called conceptual compression (Gray and Tall, 1994; Thurston, 1990). It explains how we move from many specific instances to a general, potent concept that encapsulates them all. A KOS facilitates this by providing the structure that allows users to see the forest (the general concept) without being lost in the trees (the specific instances).

3.1.2 Skemp's Varifocal Theory: The "Zoom Lens" of Cognition

Richard Skemp's (1979) varifocal theory provides the perfect model for how we navigate these compressed units. It posits that our understanding of a concept is not fixed but can operate at different levels of focus or granularity, like a zoom lens on a camera.

• Example: The concept of "Democracy".

➢ Wide-Angle View (Macro Unit): At its most compressed level, "democracy" is a single, powerful unit meaning "rule by the people". It is used in high-level discourse and political theory.

➢ Zoomed-In View (Constituent Parts): If we zoom in, this unit decompresses into a network of interrelated sub-units: concepts like "free elections", "civil liberties", "rule of law", "pluralism", and "majority rule with minority rights". Each of these is itself a cognitive unit.

➢ Further Zoom (Micro Units): Zooming in further, "free elections" decompresses into units like "secret ballot", "universal suffrage", "independent electoral commission", and "multiple candidates".

A well-designed KOS should support this varifocal movement. It should allow a user to see a broad category (e.g., "Environmental Science" in a classification scheme), then zoom in to see its major subdivisions ("Climatology", "Ecology", "Conservation"), and zoom in further to see specific topics ("Carbon Sequestration", "Keystone Species").

3.1.3 Identifying Units in a KOS: From Semantic Links to Conceptual Clusters

So, how do we find these compressible chunks within the structure of a KOS? We look for stable, meaningful clusters of relationships. The atomic unit of relationship in a KOS is the semantic link, a triple consisting of two concepts (nodes) and a defined relationship between them (e.g., "Apple *Is a type of* Fruit").

(1) **The Basic Unit (Micro-Cluster)**: The smallest cognitive unit of *information* is often a single, significant semantic link that expresses a core proposition. In a thesaurus, the link Broader Term: Fruit | Narrower Term: Apple is a minimal cognitive unit. It packages a hierarchical fact into a manipulable chunk.

(2) **Forming Larger Units (Compression)**: Cognitive units grow through the integration of multiple semantic links around a central theme. This occurs when several links are so consistently correlated that they can be mentally "fused".

• Example in a Thesaurus (The terms "USE" and "RT" are Thesaurus-specific terminology. USE or "Used For" directs the user from a term that is not the authorized/preferred descriptor to the one that is, while RT stands for "Related Term," referring to a term that is conceptually associated with another): Consider the set of links around Apple:

➢ Apple USE Fruit (Hierarchical).

➢ Apple RT Cultivation (Associative).

➢ Apple RT Juice (Associative).

➢ Apple RT Malus domestica (Equivalence).

➢ While individually these are links, together they form a rich, multi-faceted **cognitive unit** for the concept "Apple". The KOS user or the system itself can compress these distinct relationships into the single, complex idea of "Apple-as-a-defined-thesaurus-term".

(3) **The KOS as a Macro Unit**: Ultimately, an entire KOS or a major segment of it (like the "Medicine" section of a classification scheme) can become a cognitive unit through high-level compression. A domain expert does not think of the thousands of terms in the "Neurophysiology" branch of an ontology; they think of "Neurophysiol-

ogy" as a coherent, integrated body of knowledge that the KOS models. The system's structure has successfully compressed vast complexity into a navigable and conceptually unified whole.

3.1.4 The "Goldilocks" Principle of Cognitive Units: Small Enough, Rich Enough

A key insight from this process is the "Goldilocks" principle for cognitive units (Barnard, 1998). A well-identified cognitive unit is:

• "Small enough" to be held in the mind's short-term focus of attention as a single entity.

• "Rich enough" that, when unpacked (decompressed), it reveals a wealth of structured, interconnected knowledge.

In practice, identifying cognitive units within a KOS involves analyzing its network of concepts and links to find those clusters that meet this criterion. These are the points where the system transitions from listing discrete elements to presenting integrated ideas. It is at these points that the KOS moves from being a repository of data to a facilitator of information and knowledge, actively participating in the user's own process of cognitive compression and understanding. Therefore, the identification of cognitive units is not a mere descriptive exercise; it is the first step in evaluating whether a KOS's structure aligns with and supports the dynamic, chunking nature of human thought.

3.2 The Building Blocks of the Knowledge Root in KOSs

The concept of *knowledge* as a cognitive root—encompassing the levels of data, information, and knowledge within KOSs—can be elucidated through the theory of concept, which Dahlberg (2006) identifies as intrinsically linked to the development of KO and its various KOS modalities (Hjørland, 2009). Dahlberg (2006) emphasizes that knowledge may be represented across multiple degrees of complexity, analogous to the structural hierarchy of matter (e.g., atoms, molecules, compounds, and macroscopic materials).

These degrees of knowledge formation are delineated as follows:

• **Knowledge elements**, constituting the first degree, are instrumental in understanding the attributes of concepts in relation to their referents or objects.

• **Knowledge units**, representing the second degree, emerge from the synthesis of characteristics, referents, and symbolic representations such as words, names, terms codes (i.e., data). In other words, a fully defined knowledge unit (or concept), synthesizing interpretant, object, and sign, functions as the primary, meaningful datum or building block within the cognitive architecture of a KOS, hence its alignment with the cognitive unit of data.

• The **third degree**, referred to as *larger knowledge*, comprises combinations of concepts—manifested as statements, propositions, or semantic links (i.e., information) within a semantic network.

• The **fourth and highest degree** involves the formation of *knowledge systems* (i.e., knowledge in the special sense), which are structured entities composed of knowledge units and selected forms of larger knowledge. These systems are organized according to deliberate and cohesive frameworks, such as the "system position plan" (Diemer, 1968).

Hjørland (2009) advocates for a pragmatic and historical approach to concept theory, asserting that concepts must be interpreted through their semantic relations and associations within specific social and disciplinary contexts (Arboit, 2018; Hjørland and Albrechtsen, 1995). This contextual understanding is particularly vital in the development and evaluation of KOSs.

Accordingly, *knowledge elements* serve as the foundational building blocks for *knowledge units* (i.e., concepts or data), which in turn facilitate the construction of *larger knowledge* (i.e., information). These components collectively contribute to the realization of *knowledge systems*—understood as structured and systematized representations of knowledge in its most comprehensive form. This hierarchical and integrative process reflects the systematic nature of knowledge creation within KOSs and underscores the cognitive architecture that supports their development.

3.2.1 Data as a Cognitive Unit

This section examines the concept in its role as *data*—the smallest semantic unit and a fundamental cognitive unit within KOSs, with "knowledge" serving as its overarching cognitive root. A concept is a mental construct generated by the human mind, functioning as a form of mental data used to model and interpret the world (Sowa, 1984). In cognitive science, mental data are treated as discrete pieces, units, or chunks that underpin cognitive processes (Anderson, 1980).

Within Library and Information Science (LIS), concepts are pervasive, particularly in the domains of information storage and retrieval (Hjørland, 2009). Hjørland (2007a) underscores the importance of conceptual knowledge for research in KO. A concept, when labeled through a word or term (Oram, 2001), is regarded as the "smallest semantic unit", a "building block" (Hjørland, 2010), or a "unit of knowledge" (Dahlberg, 1986) within KOSs (Stock, 2010). In this sense, the cognitive units of KOSs—as systems of concepts—are constituted by concepts or data.

However, concepts cannot be understood in isolation from their intended context. Their meaning is shaped by subjective, situational, or domain-specific interpretations of information (Hjørland, 1997; 2009). The contextual framework in which a concept is situated determines its representation through terms or signs that are semantically linked to relevant domains (Hjørland, 2009). Thus, concepts functioning as data represent one of the core cognitive units under the cognitive root of "knowledge" in the structural analysis of KOSs.

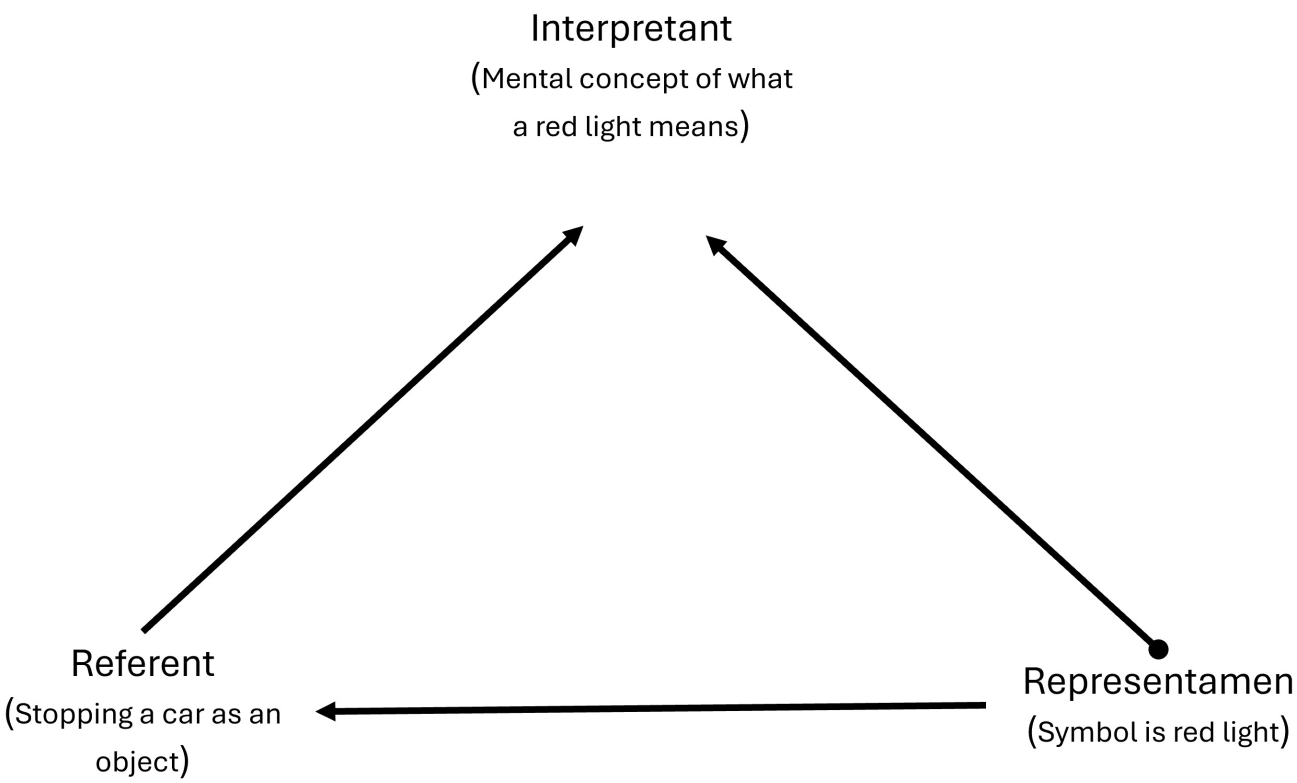

Fig. 1. Peirce's Triadic model.

The intrinsic connection between a concept and its domain necessitates the identification of its constituent components through semiotic theories in linguistics. A concept—equivalent to a knowledge unit or cognitive unit—is understood as a synthesis of three elements: the interpretant (conceptual features), the referent (object), and the representation (linguistic sign) (Arboit, 2018; Dahlberg, 1978a; 1978b; 2006; 2014). According to semiotic theory, the interpretant mediates the relationship between the sign (representamen) and the object (Thellefsen, 2010).

Semiotics, as a discipline closely aligned with LIS and KOSs (Mai, 2000; 2001), concerns itself with the study of signs—defined as anything that stands for something else (Eco, 1976). This perspective reinforces the conceptual model derived from Charles S. Peirce (1839–1914), whose triadic theory of signs remains foundational in semiotic analysis.

Peirce's triadic model, illustrated in Fig. 1, posits that a sign is a triadic unity: it is something that stands to somebody (the interpretant) for something else (the object) (Hjørland, 2007b). Peirce's central claim—that signs consist of three interrelated components: the sign, the object, and the interpretant—is further clarified by Chandler's (2002) example of a traffic signal. In this case, the red light serves as the representamen (symbolizing "stop"), the act of the car halting is the object, and the interpretant is the cognitive understanding that the red light signifies the need to stop (Mudaly, 2014).

In conclusion, the concept—as a cognitive unit in both cognitive studies and semiotic theory—comprises three essential elements: the interpretant, the referent (object), and the representation (sign). These elements collectively position the concept in the role of data within the cognitive structure of KOSs, reinforcing its foundational status under the cognitive root of "knowledge".

3.2.2 Information as a Cognitive Unit

This section examines *information* as a cognitive unit within the cognitive structure of KOSs, situated under the overarching cognitive root of *knowledge*, particularly in the context of evaluating and ranking such systems. As previously discussed, *concepts*, understood as *data*, represent the smallest semantic and cognitive units in KOSs. These concepts must be interpreted within their intended context, shaped by subjective, situational, or domain-specific understandings of information (Hjørland, 1997; 2009). Accordingly, the representation, organization, and semantic structuring of concepts must be grounded in semantic theory (Thellefsen, 2010).

In this context, *information* is intrinsically associated with signs, comprising core elements such as the interpretant (mental concept), the referent (object), and the symbol (term) (Nake, 2002). To understand the nature of information, it must be identified, described, and represented across diverse domains of knowledge (Hjørland, 1997; 2007b). The relationships among concepts, when expressed as *semantic links* (Zhuge, 2012), contribute to the formation of

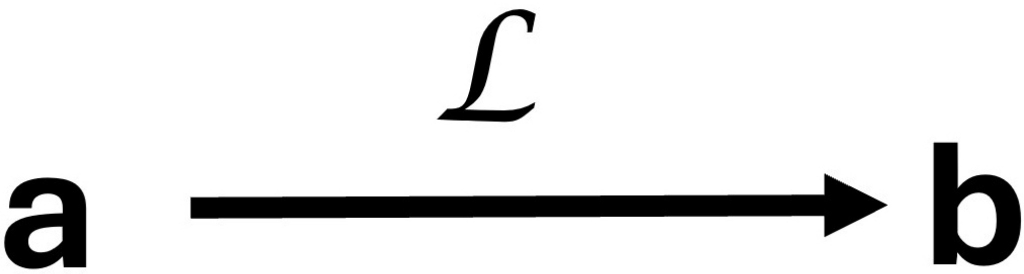

Fig. 2. The graphical representation of the semantic link.

semantic systems—structured networks of meaning within KOSs (Arboit, 2018). These systematic relations among cognitive units serve as the foundation for constructing conceptual and semantic systems (Dahlberg, 2006).

A cognitive unit of information emerges when nodes within a cognitive structure are linked (Tall and Crowley, 1999). This minimal relational block—defined by the connection between two nodes—constitutes a cognitive unit of information within the semantic network architecture of KOSs (Amirhosseini, 2021). As such, this unit is situated under the cognitive root of *knowledge* and contributes to the structural integrity of KOSs.

The foundational components of a semantic link within this cognitive unit can be further explained through SLNT, developed by Hai Zhuge and collaborators (Zhuge, 2004; 2010; 2012; Zhuge and Shi, 2003; 2004; Zhuge and Sun, 2010; Zhuge and Xu, 2011; Zhuge and Zhang, 2010). SLNT aims to construct semantic maps of the Web by modeling semantic networks (Burgin, 2017). According to Burgin (2017), a semantic link is defined as a triad α = (X, α, Y), where X and Y are semantic nodes, and α represents the link connecting them. A graphical adoption of the semantic link is demonstrated in Fig. 2, where "a" and "b" represent the semantic nodes and the link connecting them is shown by the script L:

Semantic links are the elementary units of semantic networks, formed by connecting at least two nodes via a labeled arrow α (Zhuge, 2012). This graphical linkage not only constructs semantic networks but also represents propositions—the informational content of sentences—through structured visual representations (Sowa, 2008). The relationship between a subject and its predicate in a proposition mirrors the semantic link between two nodes (Amirhosseini, 2023).

In conclusion, a semantic link—comprising at least two nodes and one relational element—functions as a minimal unit within a semantic network, facilitating the exchange and representation of information. Within the framework of SLNT, such links can be regarded as cognitive units of *information*, essential for constructing the semantic network structures that underpin KOSs.

3.2.3 Knowledge as Cognitive Unit

Within the cognitive structure of KOSs, *knowledge* performs dual functions: it serves both as a cognitive root and as a cognitive unit. As previously discussed, the cognitive root of "knowledge" is explicitly reflected in the title of KOSs. Simultaneously, "knowledge" and its constituent elements—representing the highest level of cognitive states—can also be conceptualized as a cognitive unit.

The term *knowledge organization* inherently implies that the object of organization is *knowledge* itself (Broughton et al., 2005), which may be broadly understood as a structured corpus of information (Gnoli, 2018) and data (i.e., concepts) (Dahlberg, 2006; 2014; Ohly, 2020). This interpretation suggests that the foundational elements of data (i.e., knowledge units)—namely, the interpretant, object, and sign—as well as the basic components of information (i.e., larger knowledge)—two nodes and a link—play a critical role in the systematic construction of knowledge (i.e., knowledge systems) (Dahlberg, 2006).

The transition from discrete ideas (data and information) to a unified conceptual entity (knowledge) is described as *conceptual compression* (Gray and Tall, 1994; Thurston, 1990). When individual elements such as concepts and semantic links are systematically and integratively connected, allowing fluid movement between them, a cognitive unit is formed through the process of conceptual compression (Tall and Crowley, 1999). This knowledge unit, referred to as a *knowledge systems*, aligns with conceptual theory and theory of concept (Dahlberg, 1974; 1979; 2009) and encompasses multiple dimensions of a single entity (Tall and Crowley, 1999).

Beyond its structural composition, knowledge may also be examined through cognitive, social, and sociocognitive lenses (Barité, 2001; Couzinet, 2012; Dahlberg, 1993; 2006; Hjørland, 2002). Accordingly, a knowledge unit—as a cognitive unit—integrates the essential elements of data and information in a systematic manner. In this sense, the cognitive unit of *knowledge* is situated under the broader cognitive root of "knowledge" in the analytical framework of KOSs.

The foundational elements of a cognitive unit of knowledge can be further elucidated through the QTK, developed by Burgin (1995; 1997; 2004). According to

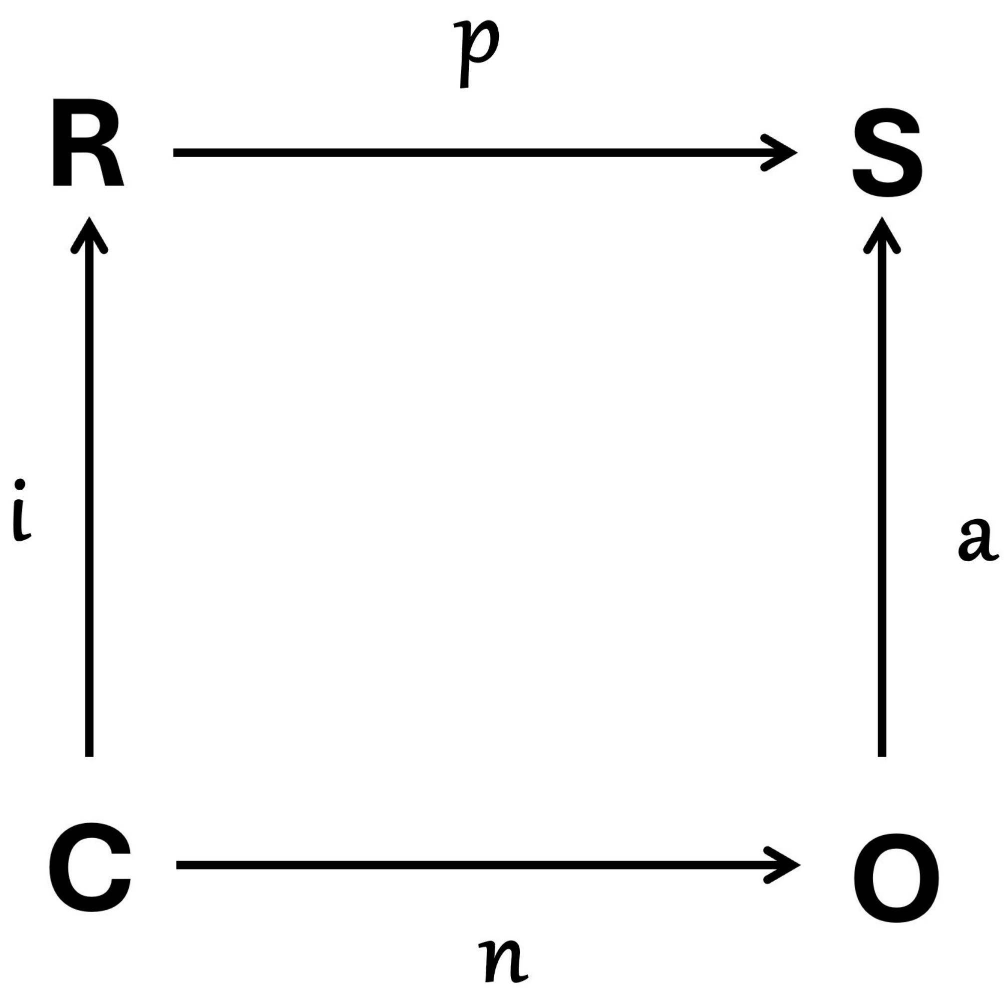

Fig. 3. The graphical representation of the model of the collective knowledge quanta.

QTK, the structure of a knowledge system comprises *quantum bricks* and *quantum blocks*, which serve as the primary components—referred to as quantum elements—at the quantum level of knowledge analysis. These systems are constructed from quantum elements such as propositions and predicates (Burgin, 2017).

For example, a cognitive unit or knowledge system concerning a book may include quantum elements such as the author's name, book title, and publication date. Burgin (2017) identifies *descriptive knowledge* as the most representative category for recognizing quantum elements. The graphical representation of these elements—particularly in the context of descriptive knowledge about concepts or classes of individual objects—is referred to as *collective knowledge quanta*, as illustrated in the following figure:

As shown in Fig. 3, the model includes several quantum elements. For instance, C denotes a class of objects (e.g., a class of cats). Knowledge about objects in C includes:

- The domain C (e.g., house cat).
- An intrinsic property i of objects in C (e.g., domestic cat, measured by scale R).
- A class O of names for objects in C (e.g., Persian cats).
- An ascribed property a of objects in C (e.g., long-haired breed, round face, and short muzzle, measured by scale S).

Fig. 3 displays several quantum elements of a knowledge system, such as C, which comprises a class of objects, for instance, a class of cats. The knowledge about objects from C includes; The domain C (house cat), an intrinsic property i of objects from C (domestic cat with the scale W), a class O of names for objects from C (Persian Cats), and an ascribed property a of objects from C (a long-haired breed, round face and short muzzle with the scale S). The ascribed property of the objects plays the role of the cognitive or symbolic component of the knowledge in the analysis of the quantum level of knowledge. Moreover, p relates values of the intrinsic property (domestic cat or i values) to values of the ascribed property (a long-haired breed, round face, and short muzzle or a values). The relation-making between intrinsic and ascribed properties becomes a factor in creating knowledge or cognition at a higher level. Using knowledge quanta of these types and their components

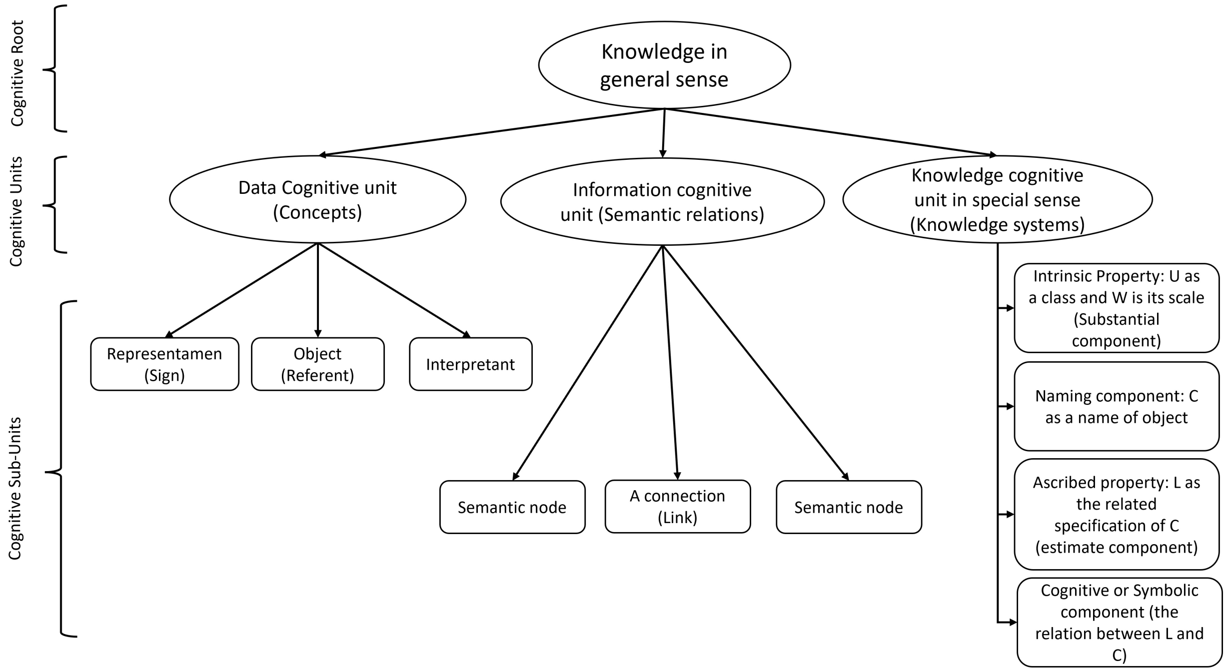

Fig. 4. Hierarchical relationships among cognitive roots, cognitive units, and sub-units within the cognitive structure of Knowledge Organization Systems (KOSs) (Amirhosseini, 2024).

makes it possible to aggregate all knowledge systems from such units (Amirhosseini, 2024; Burgin, 2017).

By employing such knowledge quanta and their constituent components, it becomes possible to construct comprehensive knowledge systems from these foundational units (Burgin, 2017). Consequently, the cognitive unit of *knowledge*, as conceptualized in QTK, comprises core elements—*quantum bricks* and *quantum blocks*—that integrate *concepts* (as data) and *semantic links* (as information) into a coherent and systematic structure. These integrated elements are fundamental to the formation of knowledge systems within the cognitive framework of KOSs. Fig. 4 illustrates the hierarchical relationships among cognitive roots, cognitive units, and sub-units within the cognitive structure ofKOSs.

3.2.4 The Dynamic Nature of the Cognitive Units of the KOSs

Within cognitive analysis, the identification and explanation of cognitive units represent a foundational step in understanding the structure and function of KOSs. Recent epistemological developments in cognitive science have introduced alternative theoretical frameworks that reconceptualize the nature of cognitive units and their relationship to contextual environments. These contemporary perspectives distinguish modern cognitive units from traditional ones by emphasizing their contextual dependency—referred to as *dynamic cognitive units*—across various levels of scientific inquiry, particularly in linguistic and conceptual organization.

A dynamic cognitive unit is defined as a "tightly integrated scene" that can be cognitively manipulated as a unified entity (Mandelblit and Zachar, 1998). To differentiate dynamic cognitive units from their traditional counterparts, Mandelblit and Zachar (1998) propose four defining characteristics that facilitate the recognition of unity within these structures:

Characteristic 1: Stable Correlation Patterns within Contextual Activity. Dynamic cognitive units are identified by the presence of stable patterns of correlation among their constituent elements and their functional role within a specific context of activity. In KOSs, the cognitive elements of *data*, *information*, and *knowledge*—all situated under the cognitive root of *knowledge*—exhibit interdependent relationships. A change in the value or quantity of one element influences the others. Moreover, these elements derive meaning not only through their mutual correlations but also through their embeddedness in a specific contextual domain.

Characteristic 2: Context-Dependent Definition. The definition of a dynamic cognitive unit is inseparable from the context in which it is observed (Mandelblit and Zachar, 1998). Each unit comprises correlated elements that yield distinct informational value based on their contextual setting. This principle is evident in the cognitive units of KOSs, where the nature and definition of *data*, *information*, and *knowledge* must be interpreted in relation to the specific domain or disciplinary context of the system.

Characteristic 3: Holistic Integration Beyond Componential Sum. Dynamic cognitive units are characterized by a structural integrity that transcends the mere aggregation of their parts (Mandelblit and Zachar, 1998). The integration of internal elements within a cognitive unit—such as semantic links between concepts—produces emergent properties that exceed the informational value of the individual components. For instance, a semantic link between two nodes conveys meaning that is not reducible to the isolated concepts it connects.

Characteristic 4: Systemic Interaction with the Environment. A dynamic cognitive unit interacts with its environment as a coherent whole, rather than through the isolated properties of its constituents (Mandelblit and Zachar, 1998). This systemic interaction is exemplified in knowledge systems, which engage with external contexts as unified entities. For example, while a book may contain discrete attributes such as the author's name and publication date, its integration into a knowledge system occurs holistically, not through individual metadata alone.

In summary, the core elements of cognitive units in KOSs—*data*, *information*, and *knowledge*—are interrelated in ways that form an integrated structure whose meaning is contextually situated. These units, when analyzed through the lens of dynamic correlation and contextual embeddedness, exemplify the characteristics of *dynamic cognitive units*. Their recognition is essential for understanding the evolving cognitive architecture of KOSs.

4. The Analysis of Unity in the Cognitive Structure of KOSs

The evolving interpretation of *dynamic cognitive units* has given rise to a redefinition of the concept of *unity*, particularly within the domain of conceptual organization (Mandelblit and Zachar, 1998). In this context, *dynamic unity* refers to a form of integration wherein cognitive units are not merely aggregated but are contextually interrelated in a manner that reflects their embeddedness within specific cognitive or conceptual environments. This reconceptualization marks a departure from traditional notions of unity, emphasizing the role of context-sensitive, flexible, and functionally integrated cognitive units.

From the perspective of cognitive science, various forms of unity can be identified based on the structural and functional characteristics of cognitive units. These forms range from classical, spatially bound configurations to highly dynamic, context-dependent structures. Mandelblit and Zachar (1998) illustrate this continuum through four distinct graphical representations:

Type 1: Traditional Unity In this model, a unit is defined by the spatial integration of its constituent elements. The elements are physically or structurally bound, forming a cohesive whole that presents in Fig. 5.

Type 2: Channel-Based Unity. Here, elements are not necessarily spatially integrated but are connected through "channels" that transmit "forces" or interactions among them. This model introduces a more flexible notion of connectivity (see Fig. 6).

Type 3: Control-Unit-Based Unity. In this configuration, elements are indirectly connected via a *control unit*, which exerts influence or coordination over each element without being an intrinsic part of the unit itself. This type of unity is represented in Fig. 7.

Type 4: Correlational or Dynamic Unity. This most advanced form of unity is characterized by elements that are not spatially or structurally connected but exhibit correlated behavior within a specific context or environment. The coherence of the unit arises from the contextual interdependence of its elements, forming what is termed *dynamic unity* (see Fig. 8).

This typology of unity, grounded in cognitive science, provides a framework for distinguishing between static and dynamic forms of integration. It is particularly relevant for analyzing the cognitive structure of KOSs, where *data*, *information*, and *knowledge*—as cognitive units under the overarching cognitive root of *knowledge*—interact in complex, context-sensitive ways.

The subsequent sections will explore how dynamic unity manifests among these cognitive units within KOSs. Specifically, it will examine the types of unity that emerge between the core elements of dynamic cognitive units—*data*, *information*, and *knowledge*—and how these relationships contribute to the overall cognitive coherence of KOSs.

4.1 The Dynamic Unity Among Dynamic Cognitive Units

As previously discussed, the dynamic cognitive units—*data*, *information*, and *knowledge*—are situated under the overarching cognitive root of *knowledge*, which serves as the central organizing principle of KOSs. The unity among these dynamic cognitive units (i.e., subdynamic cognitive units) does not conform to the principles of classical unity. Rather than being statically integrated, these units are interrelated through dynamic correlations that reflect their mutual contribution to the formation of the cognitive root.

This interdependence implies that any quantitative or qualitative change in one cognitive unit directly influences the others. For instance, an increase in the quantity and diversity of monetary items—such as nickels, silver, and gold coins (representing *data*)—may signify an enhanced financial status (*information*), which in turn enables broader purchasing power and decision-making capacity (*knowledge*). This example illustrates how the transformation of data into information and subsequently into knowledge is governed by a dynamic and reciprocal relationship.

As depicted in Fig. 9, an increase in the volume or quality of one cognitive unit (e.g., data) leads to corresponding increases in the other units (e.g., information and knowledge). This mutual reinforcement exemplifies the *correlational* nature of their interaction. Consequently, the unity among these cognitive units aligns with the fourth type of unity described by Mandelblit and Zachar (1998)—*dynamic unity*—which is characterized by context-sensitive

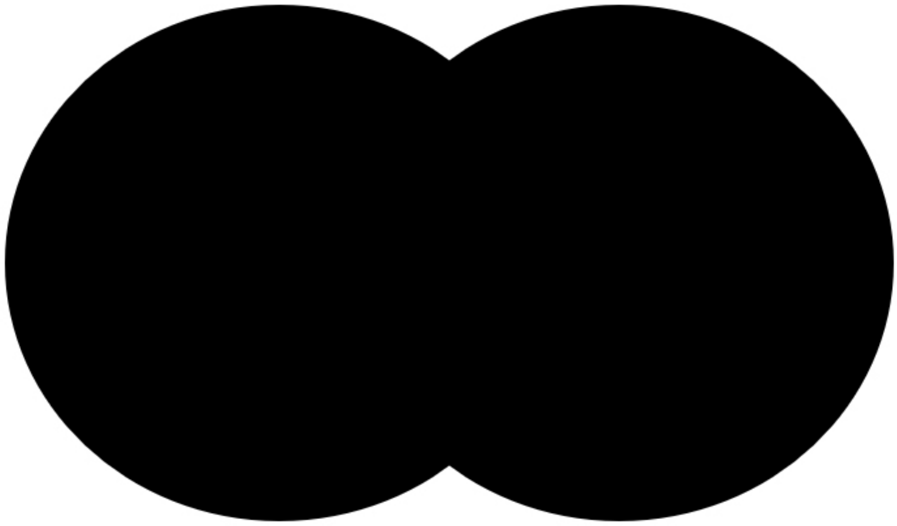

Fig. 5. Graphical representation of classical unity (Mandelblit and Zachar, 1998).

Fig. 6. The graphical representation of the second type of unity (Mandelblit and Zachar, 1998).

correlations rather than fixed structural integration. This form of unity underpins the emergence of *knowledge* as a shared cognitive root within the architecture of KOSs.

4.2 Internal Unity Within Dynamic Cognitive Units

This section explores the internal unity that exists among the constituent elements of each dynamic cognitive unit—*data*, *information*, and *knowledge*—which collectively form the cognitive subset of the overarching concept of *knowledge* in KOSs. Internal unity refers to the coherence and interrelation among the core components that constitute a single cognitive unit.

To analyze the dynamic nature of this internal unity, it is essential to distinguish between two complementary perspectives:

• **Graphical Perspective**: This approach focuses on the structural representation of internal relationships, often visualized through nodes and links that illustrate how elements such as concepts, referents, and signs are interconnected within a cognitive unit.

• **Substantive Perspective**: This dimension emphasizes the semantic and functional coherence among the elements, examining how interpretants, referents, and representations collectively contribute to the meaning and function of the cognitive unit within a specific context.

Together, these perspectives provide a comprehensive framework for understanding the internal dynamics of cognitive units in KOSs. By examining both the structural and semantic dimensions of unity, it becomes possible to assess how data, information, and knowledge function not only as discrete units but also as internally coherent and contextually meaningful entities within the broader cognitive system.

4.2.1 Types of Unity Among the Main Constituent Elements of Data

The constituent elements of *data*—or *concepts* functioning as dynamic cognitive units within KOSs—exhibit a form of internal unity that warrants detailed examination. As previously established, concepts in the role of data serve as foundational building blocks, units of knowledge, and the smallest semantic components within the structure of KOSs. These concepts possess an internal cognitive architecture that can be analyzed through the lens of semiotic theory in linguistics.

From a semiotic perspective, a concept comprises three interrelated elements: the *interpretant* (sense), the

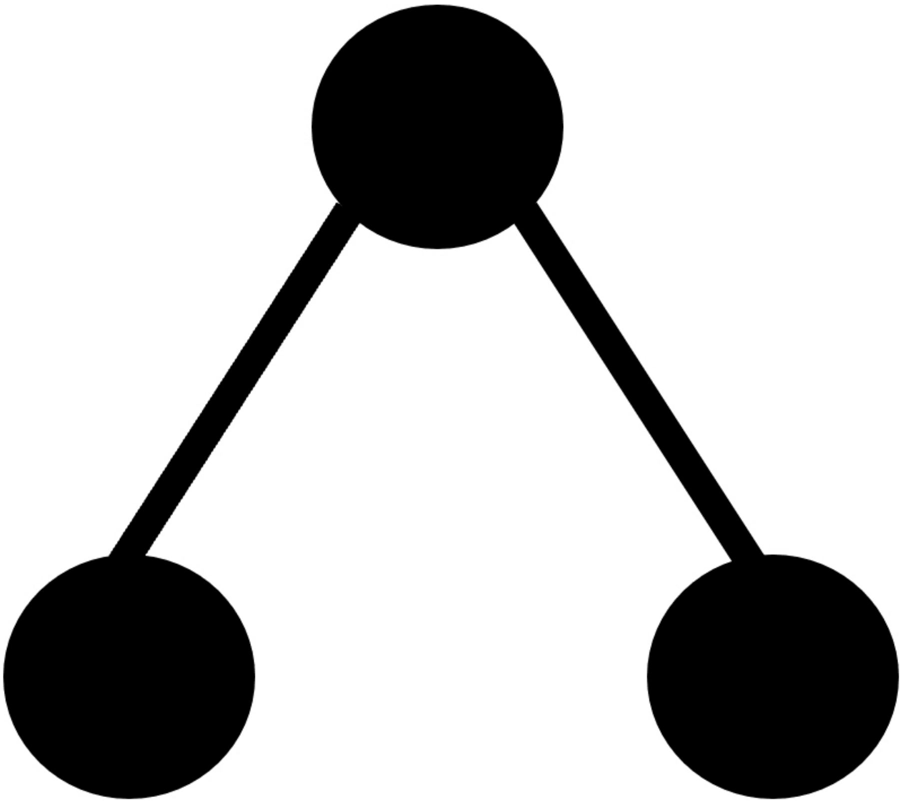

Fig. 7. The graphical representation of the third type of unity (Mandelblit and Zachar, 1998).

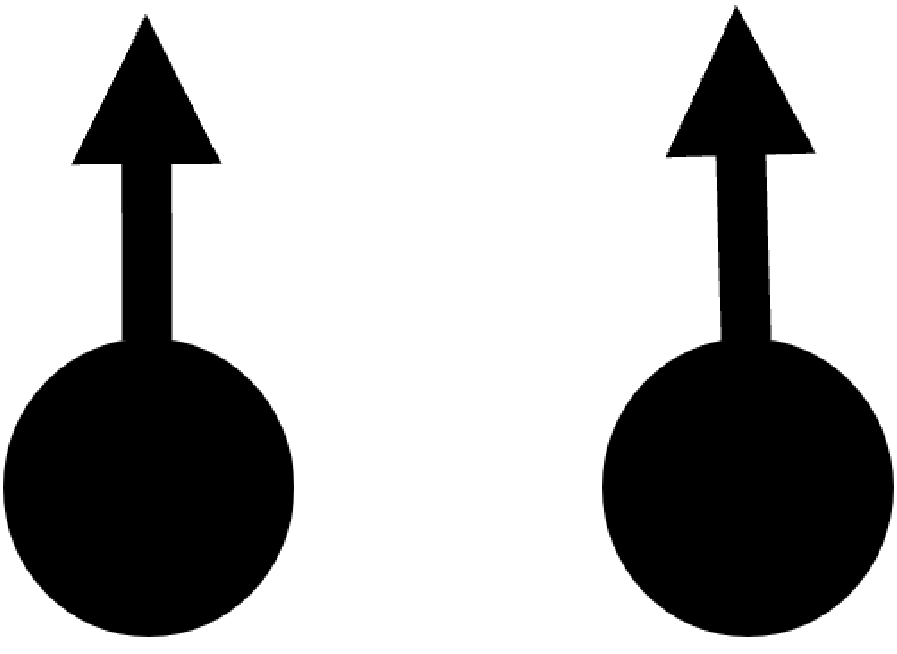

Fig. 8. The graphical representation of the fourth type of unity or dynamic Unity (Mandelblit and Zachar, 1998).

referent (object), and the *representation* (sign). These elements collectively function as data within the cognitive framework of KOSs. The internal unity of a concept arises from the relational dynamics among these elements—specifically, the process by which a referent is represented through a sign, thereby generating meaning via the interpretant. This triadic relationship forms the basis of internal coherence within the concept.

As illustrated in Fig. 10, the three core elements of a concept are interconnected through channels, forming a

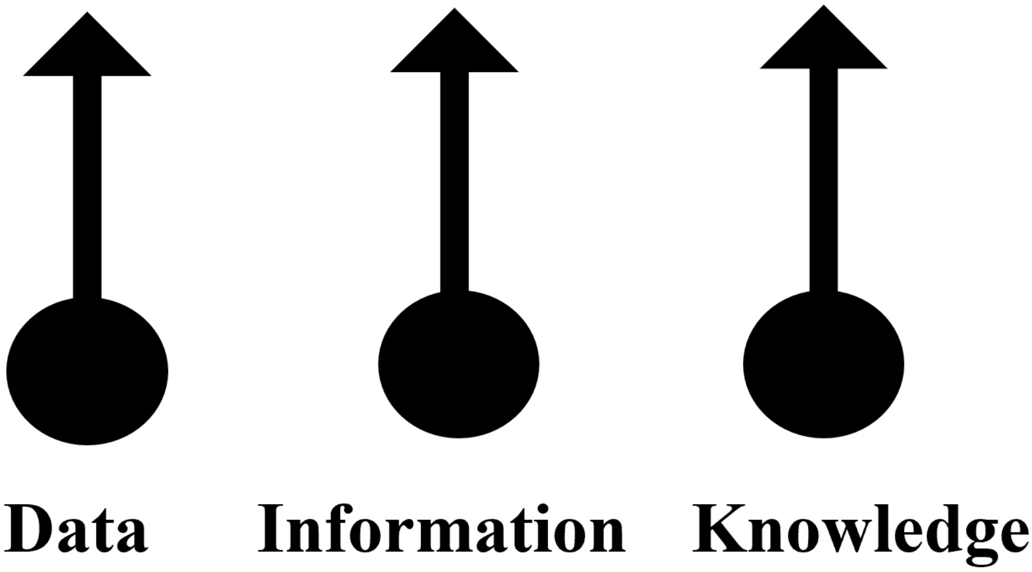

Fig. 9. Relationships among dynamic cognitive units (i.e., data, information, and knowledge) in establishing dynamic unity.

network of relational nodes. These elements are not necessarily spatially or structurally bound but are linked via three distinct channels. This configuration corresponds to the *second type of unity* as defined by Mandelblit and Zachar (1998), which emphasizes connectivity through mediated channels rather than direct integration. This form of internal unity—termed *unity from a graphical perspective*—is neither classical unity nor fully dynamic (i.e., the fourth type of unity), but represents an intermediate structural form.

However, the internal unity among the interpretant, referent, and representation does not exist in isolation. The conceptual structure is inherently dynamic, allowing for multiple instantiations and variations even within a single moment. Concepts may convey diverse meanings depending on the signs used, and conversely, multiple signs may represent a single concept. This variability implies that any quantitative or qualitative enhancement of one element (e.g., a richer interpretant or more precise representation) contributes to the enrichment of the others, thereby facilitating the generation of new concepts and data.

Consequently, from a *substantive perspective*, the internal relationships among the main elements of data or concepts reflect the characteristics of *dynamic unity*—the fourth type of unity—wherein the elements behave in a correlated and context-sensitive manner. Thus, while the graphical structure of these relationships aligns with the second type of unity, their interaction within broader conceptual systems (i.e., among other concepts and data in a KOS) exemplifies dynamic unity in its substantive form.

In summary, the internal unity of data or concepts in KOSs can be understood through two complementary lenses:

- **Graphical Unity (Type 2)**: Based on structural connectivity via channels among interpretant, referent, and representation.
- **Substantive Unity (Type 4)**: Based on dynamic, context-dependent correlations among these elements within broader conceptual systems.

Together, these perspectives offer a nuanced understanding of how data functions as a dynamic cognitive unit within the cognitive architecture of KOSs.

4.2.2 Types of Unity Among the Main Constituent Elements of Information

Information, as a dynamic cognitive unit situated under the cognitive root of *knowledge* within KOSs, comprises core elements that exhibit a distinct form of internal unity. As previously discussed in relation to *concepts* functioning as *data*, a similar structural coherence exists among the constituent elements of *information*.

A key observation is that one of the foundational building blocks of information is the concept itself—or *data*. Information, in its semantic dimension, consists of concepts and the relationships among them within a specific context. These relationships are typically expressed through propositions or statements, which include a subject, predicate, and relational component. In the framework of KOSs, such propositions function analogously to *semantic links* within a semantic relations network. That is, a proposition may be represented as a semantic link connecting two concepts within a defined domain.

As previously noted, the minimal structural components of a semantic link—when understood as a unit of information—include two *nodes* (representing concepts) and one *link* (representing the relationship). This triadic configuration establishes an internal unity among the elements that constitute the semantic link, and by extension, the cognitive unit of information. This form of internal unity is illustrated in the figure below:

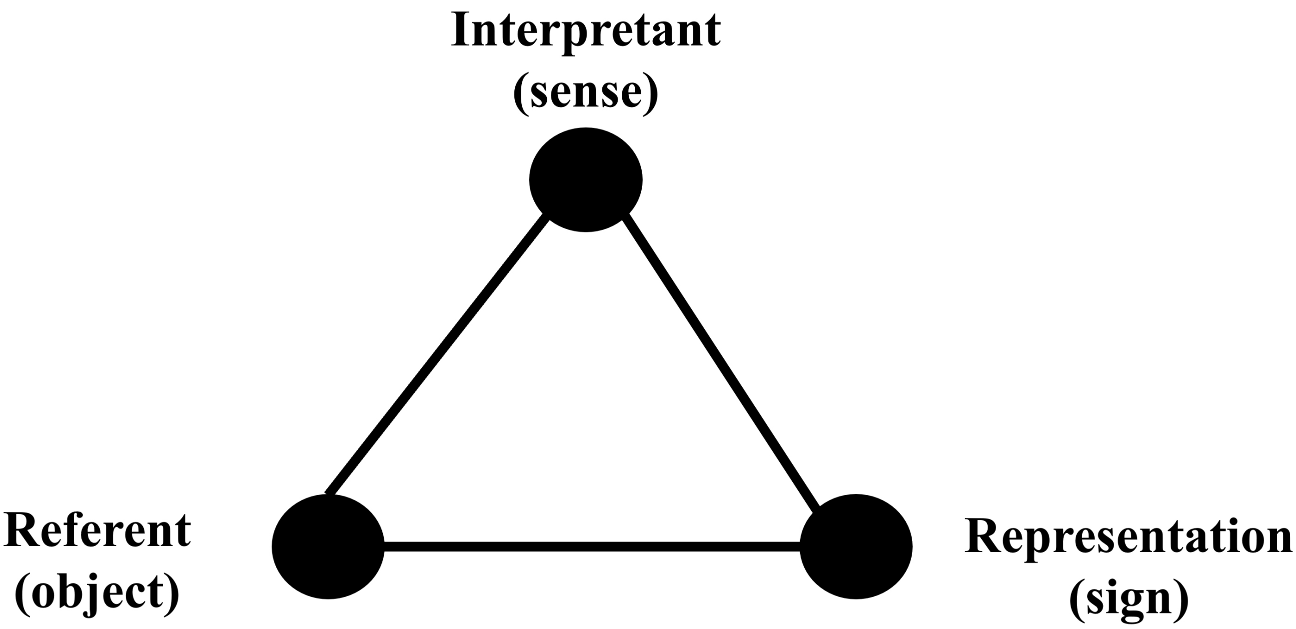

Fig. 10. Relationships among the main elements in creating concept or data from a graphical perspective.

Fig. 11. Relationships among the main elements in the formation of a semantic link or unit of information from a graphical perspective.

Fig. 11 depicts the basic structure of a semantic link, comprising two conceptual nodes and a relational channel. These nodes are not necessarily bound in a fixed spatial arrangement but are connected through a single channel that mediates their interaction. This configuration corresponds to the *second type of unity* as defined by Mandelblit and Zachar (1998), referred to as *unity from a graphical perspective*. This form of unity is neither classical nor fully dynamic, but rather represents a transitional and structurally mediated form of integration.

However, the constituent elements of information—like those of data—do not exist in isolation. Semantic links derive their meaning from their interaction within the broader semantic relations network. The coherence and interpretive value of information emerge through the dynamic interplay among semantic links and their components. Any quantitative or qualitative enhancement of these links and their elements contributes to increased coherence and complexity within the semantic network.

From this perspective, the internal unity among semantic links—when viewed in terms of their contextual correlations—reflects the characteristics of *dynamic unity*, or the *fourth type of unity*. This form of unity is substantive rather than merely structural, arising from the correlated behavior of elements within a specific semantic environment.

In summary, the internal unity of *information* in KOSs—represented through semantic links—can be understood through two complementary lenses:

- **Graphical Unity (Type 2)**: Based on structural connectivity via channels among two conceptual nodes and one relational link, forming the minimal building block of a semantic link.
- **Substantive Unity (Type 4)**: Based on dynamic, context-dependent correlations among semantic links and their constituent elements within the broader semantic relations network of KOSs.

In conclusion, the graphical configuration of semantic links—comprising two nodes and one relational channel—exemplifies the second type of unity. Yet, the deeper semantic correlations among these elements within the network of relations in KOSs give rise to *dynamic unity*. Thus, information, as a dynamic cognitive unit, embodies both structural and substantive forms of unity, reinforcing its integral role in the cognitive architecture of KOSs.

4.2.3 Types of Unity Among the Main Constituent Elements of Knowledge

Knowledge, as a cognitive unit, represents the highest level of cognitive states within the architecture of KOSs. The term *knowledge organization* itself implies that what is being structured and systematized is *knowledge*, which in-

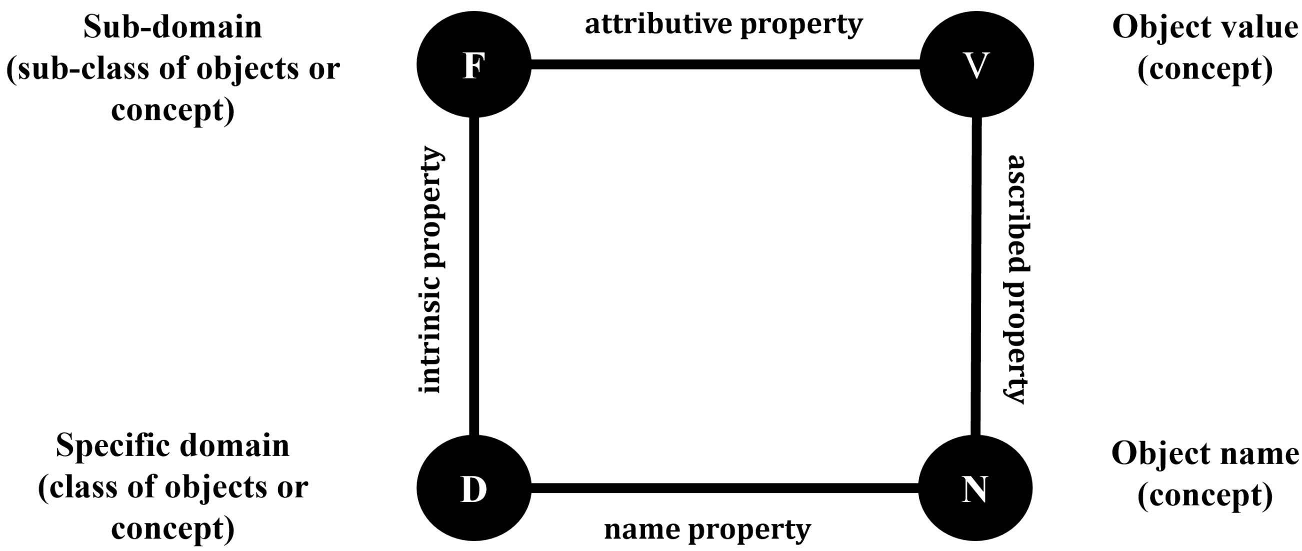

Fig. 12. Relationships among the main elements in the formation of a knowledge unit or cognitive unit of knowledge from a graphical perspective. The letters N, V, F, and D represent object name, value, sub-domain, and domain, respectively.

herently encompasses the cognitive units of *data* and *information*. Therefore, any analysis of the constituent elements of the dynamic cognitive unit of knowledge must account for both the structural components of data and information and their respective internal relationships.

Specifically, the constituent elements of *data*—including the interpretant, object, and sign—and the structural components of *information*—comprising two nodes and a semantic link—play a foundational role in the systematic construction of knowledge. In this context, *knowledge* as a cognitive unit may be conceptualized as a *knowledge unit*, representing multiple dimensions of a single entity and contributing to the development of a *knowledge system* that reflects cognitive, social, and sociocognitive dimensions.

A dynamic cognitive unit of knowledge that contributes to the formation of a knowledge system typically consists of at least four interrelated concepts and their corresponding semantic links. These four concepts, connected through four distinct relational properties, form the basis of internal unity within the knowledge system. This structure is illustrated in the figure below:

As shown in Fig. 12, the knowledge system comprises four nodes—each representing a concept—linked through four channels that denote different types of properties. For example, N represents a *name property* for a domain or object D, F denotes an *intrinsic feature* of D, and V serves as a *cognitive representation* of D, linked to F through an attributive property. The name N is associated with the value V via an *ascribed property*. If D is a book, N may be its title, F the year of publication, and V a specific value such as "2022".

This configuration demonstrates that the internal unity among the constituent elements of a knowledge system is achieved through structured relational channels. The four nodes are not spatially bound but are interconnected via four distinct links, exemplifying *graphical unity* of the second type (Mandelblit and Zachar, 1998). This form of unity is more dynamic than classical unity, yet not fully representative of dynamic unity in its substantive form.

Importantly, the constituent elements of a knowledge system can interact with other cognitive units of knowledge, particularly through their shared components, to form more complex and expansive knowledge systems. Any quantitative or qualitative enhancement of these elements contributes to the emergence of new or more sophisticated knowledge structures. This correlational behavior among the elements reflects *dynamic unity*—the fourth type of unity—characterized by context-sensitive integration and emergent coherence.

Thus, the internal unity among the constituent elements of knowledge systems in KOSs can be understood through both structural and substantive lenses. While the graphical configuration aligns with the second type of unity, the dynamic correlations among elements in the development of larger systems exemplify the fourth type of unity.

The structure presented in Fig. 12 demonstrates the applied cognitive architecture of a knowledge unit. It is important to distinguish this from the theoretical model of knowledge components provided by the Quantum Theory of Knowledge in Fig. 3. While both model entities and relations, they serve complementary functions: Fig. 3 defines the fundamental types of elements (e.g., object classes, intrinsic/ascribed properties) and their ontological relations at a quantum level. Figs. 11,12 instantiates these principles, showing how such elements are configured through specific relational channels (e.g., naming, featuring) to form a single, coherent cognitive unit within a KOS. This approach extends beyond static entity-relationship modeling by emphasizing the types of unity, particularly the channel-based graphical unity (Type 2) shown here and the potential for dynamic, correlational unity (Type 4), that enable this structure to function as a manipulable whole within a knowledge system.

In summary, the internal unity of *knowledge* as a cognitive unit in KOSs can be understood through two complementary lenses:

• **Graphical Unity (Type 2)**: Based on structural connectivity among at least four conceptual nodes and four relational channels, forming the minimal building block of a knowledge system.

• **Substantive Unity (Type 4)**: Based on dynamic, context-dependent correlations among knowledge elements that contribute to the formation of more complex and integrated knowledge systems.

In conclusion, the internal unity of knowledge as a cognitive unit in KOSs arises from the integration of concepts and semantic links into structured knowledge systems. Graphically, this reflects Type 2 unity, where multiple nodes are connected through relational channels. Substantively, the correlated behavior of these elements across domains exemplifies Type 4 dynamic unity, enabling the emergence of complex and scalable knowledge structures.

4.3 Case Study Analysis: Applying the Framework to the Gene Ontology (GO)

To move from abstract typology to concrete analysis and demonstrate the applicability of the cognitive unity framework, it is instructive to apply it to a specific, complex KOS. The GGO provides an ideal case study. GO is a widely used, large-scale biomedical ontology that provides a structured, controlled vocabulary for describing gene and gene product attributes across species (Aleksander et al., 2023). Its structure and use illuminate the interaction of cognitive units and forms of unity.

4.3.1 Cognitive Roots and Units in GO

The GO system explicitly embodies the cognitive roots of knowledge (biological knowledge), organization (systematic curation of terms and relations), and system (a formal, computationally tractable structure). Within this, its components align with the proposed dynamic cognitive units:

(1) Data/Concepts: The foundational unit consists of over 40,000 defined GO terms (e.g., "DNA repair", "mitochondrial membrane"). Each term functions as a conceptual sign, with an interpretant (the biological definition), a referent (the class of biological phenomena), and a representation (the term label) (Ashburner et al., 2000), fitting Peirce's triadic model.

(2) Information: GO terms are not isolated but are interconnected via a rich set of semantic relationships, primarily is_a (subclass) and part_of. These relationships form a massive Semantic Link Network (Zhuge, 2012), where each link (e.g., "nucleus part_of cell") constitutes a unit of information, i.e., a proposition about biological reality.

(3) Knowledge: The network of terms and relations forms a coherent knowledge system. It supports complex queries and automated reasoning, such as inferring gene function based on ancestral term annotations. This systemic, inferential capability reflects the integration of data and information into a pragmatic knowledge structure, analyzable through its capacity for conceptual compression and its role in hypothesis generation (Burgin, 2017).

4.3.2 Analysis of Unity Within GO

(1) Internal Unity (Type 2) within Units: Within the data unit, the definition, label, and database identifier for a single GO term are linked in a stable, channel-like unity, essential for unambiguous reference. Within the information unit, the triad of two GO terms and the relationship linking them (e.g., Term A is_a Term B) forms the basic, channel-connected semantic link.

(2) Dynamic Unity (Type 4) between Units: The cognitive units in GO exhibit strong dynamic correlation. An increase in the number of precisely defined terms (data) enriches the potential semantic connections (information), which in turn expands the scope and power of functional predictions and analyses (knowledge). This is not a linear sequence but a correlated, reinforcing dynamic. For example, the annotation of a gene product to multiple specific terms (data) creates a unique pattern of links (information) that collectively define a functional profile (knowledge), a profile that changes dynamically as new annotations are added.

(3) Resilience and Pragmatic Unity: GO demonstrates resilience under contextual change—a key metric for dynamic unity. Its structure can assimilate new biological discoveries by adding new terms or relationships without collapsing, showing robust correlational patterns. Its unity is ultimately pragmatic, serving the goal of unifying biological data across databases (Aleksander et al., 2023). The dialectical synthesis between computable formalism (a system root) and evolving biological understanding (a knowledge root) is a driving force in its development.

This brief analysis demonstrates how the framework of cognitive roots, dynamic units, and forms of unity provides a structured lens to dissect and understand the architecture of a real-world KOS. It moves the discussion of "dynamic unity" from typology to an observable characteristic of GO's evolving, interdependent structure, thereby grounding the theoretical principle in pragmatic constraints and utility.

5. Ranking KOSs Based on Dynamic Cognitive Units via Related Unity

Building upon the preceding discussions, this section introduces a conceptual framework for ranking KOSs based on their alignment with dynamic cognitive units—namely *data*, *information*, and *knowledge*—and the degree of internal unity among their constituent elements. This approach is grounded in the principle of *cognitive unity* as a foundational criterion for evaluating and classifying KOSs. A comprehensive analysis of the mechanisms underlying this principle will be addressed in a subsequent, dedicated study.

The theoretical basis for this ranking framework draws on the concept of *compression*, particularly as articulated in Skemp's *varifocal theory* (1979), which offers valuable insights into the formation and recognition of cognitive units. According to Barnard and Tall (2001), "the building of cognitive links in such a way that one item in the focus of attention can refer at will to a variety of closely connected pieces of knowledge will be termed compression". This process—also referred to as *conceptual compression* (Gray and Tall, 1994; Thurston, 1990)—involves the integration of separate ideas into a unified conceptual whole, akin to cognitive processes in the human brain (Carter, 1998).

Compression enables a collection of related ideas or products to be cognitively apprehended as a single, coherent unit—*small enough* to be consciously grasped in its entirety (Tall and Crowley, 1999). At the same time, such a unit may exhibit properties that are *greater than the sum of its parts*, reflecting both its compactness (in terms of short-term cognitive focus) and its holistic conceptual richness (Barnard, 1998). In Skemp's varifocal theory, the resulting entity is a *conceptual schema*—a cognitive structure characterized by internal links and functional coherence (Tall and Crowley, 1999).

This theoretical lens can be applied to the cognitive structure of KOSs. For example, the development of cognitive units of *information* can be modeled through *semantic links*, which consist of two nodes and one relation. These links, when situated within a specific context, form clusters of semantic relations that function as cognitive units within a semantic network. A network comprising multiple such clusters within a domain may itself be regarded as a higher-order cognitive unit. Through successive layers of compression, these networks can be integrated into a comprehensive KOS—representing a macro-level cognitive unit or *single structure*.

Furthermore, distinct KOSs—each with unique structural and functional characteristics—can be conceptually compressed and unified under broader cognitive categories such as *data*, *information*, and *knowledge*. This enables the construction of a hierarchical schema for ranking KOSs based on the extent to which their cognitive structures align with these foundational units.

In essence, the formation of cognitive units in KOSs—from micro-level clusters of concepts to macro-level conceptual systems—relies on the articulation of internal relationships among their core elements. Compression techniques serve as the methodological basis for identifying and organizing these relationships. As a result, KOSs can be ranked as sub-units or integral components of broader cognitive categories—*data*, *information*, and *knowledge*—according to the degree of structural and functional adaptation they exhibit in relation to each dynamic cognitive unit.

5.1 The Unity of KOSs Under the Cognitive Unit of Data

This section examines the convergence of KOSs through the lens of their structural alignment with the *data* cognitive unit, particularly as represented in graphical display platforms. As previously discussed, signs or symbols (i.e., terms) that originate from concepts grounded in referents (objects) serve as the foundational building blocks—or *knowledge units*—of KOSs. The triadic structure of the sign, comprising the term, concept, and referent, constitutes what may be referred to as *data* within the cognitive framework of KOSs.

A central question arises: *How does the sign (or data) signify?* In this context, the sign is reduced to a specific form known as a *signal*—a sign in which the object and the interpretant converge at the syntactic level. As Nake (2002) explains, *syntactics* represents a reduction of semiotics to the material aspects of signs. Accordingly, KOSs that aim to describe or organize the material or structural components of signs are situated within the cognitive unit of *data*.

A key function of such KOSs is to facilitate access to signs. Systems that prioritize access based on formal ordering principles—such as alphabetical or, in some cases, thematic arrangements—are classified under the data cognitive unit. While these systems may also provide semantic information about signs (as in dictionaries), such semantic content is not the organizing principle. Rather, the syntactic dimension—how signs are materially arranged—forms the basis of their internal structure.

As illustrated in Fig. 13, KOSs that list terms or data (as *representamens*) according to a specific order—typically alphabetical—are aligned with the cognitive unit of *data*. In this representation, *data* functions as the central cognitive unit, and the associated KOSs (e.g., dictionaries, gazetteers, Roget's Thesaurus) are treated as its constituent elements. These systems are not directly interconnected but are coordinated through a *control unit*—namely, *data*—which mediates their internal unity.

This structural configuration corresponds to the *third type of unity* (Mandelblit and Zachar, 1998), wherein elements are linked through a control unit rather than being directly wired to one another. This form of internal unity, while not fully dynamic, exhibits a significant degree of flexibility and coordination, reflecting a transitional stage toward dynamic unity.

In conclusion, KOSs whose cognitive architecture is organized around the syntactic representation of concepts—typically through fixed ordering mechanisms such as alphabetical arrangement—are classified under the cognitive unit of *data*. These systems demonstrate a notable form of in-

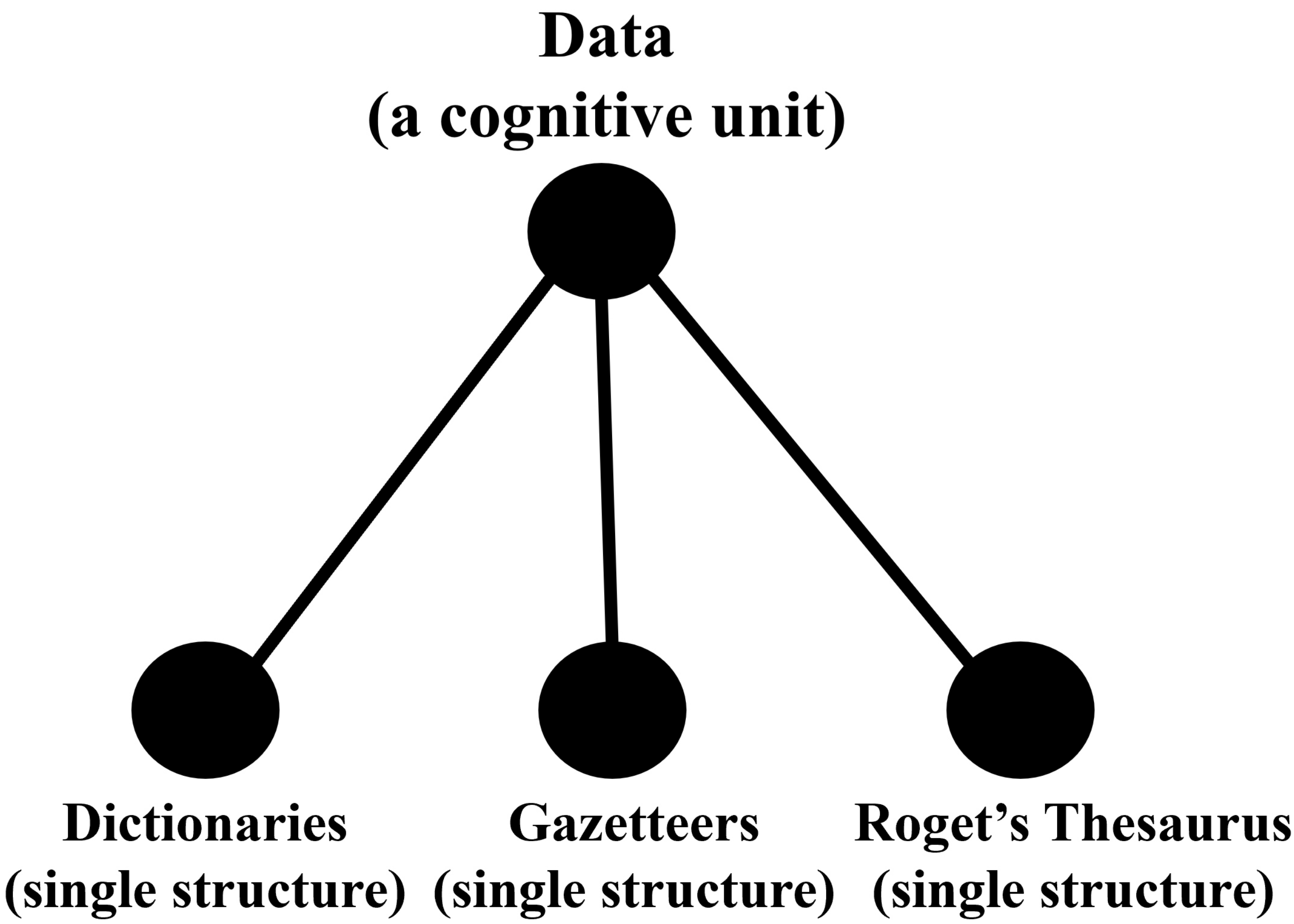

Fig. 13. Categorization and convergence of some types of KOSs under the cognitive unit of data from a graphic perspective.

ternal unity, both structurally and functionally, through a graphical approach that aligns with the third type of unity. This structure supports the extraction and organization of information from signs, concepts, and referents, reinforcing the foundational role of *data* in the cognitive structure of KOSs.

Summary: The unity of KOSs under the cognitive unit of *data* can be understood through:

• **Graphical Unity (Type 3)**: Based on indirect connectivity among KOSs via a control unit (*data*), where systems like dictionaries, gazetteers, and Roget's thesaurus are organized through syntactic ordering (e.g., alphabetical and in some cases thematic order).

• **Syntactic Dimension**: Signs are treated as signals, and meaning is derived from their material arrangement rather than semantic relations, emphasizing access and representation over interpretation.

5.2 The Unity of KOSs Under the Cognitive Unit of Information

This section explores the categorization and convergence of KOSs that align with the *cognitive unit of information*, particularly through a graphical modeling approach. As previously established, the foundational components of semantic relations are *semantic links*, each comprising at least two nodes and one relational connector. These links serve as graphical representations of informational propositions contextualized within specific domains.

In this framework, *information* and its associated meaning are derived from the semantic links embedded within the semantic relations network of KOSs. From a semantic perspective, the central question becomes: *What does the sign signify?* According to Nake (2002), the semantics of a sign reflect meanings that are socially constructed and commonly accepted within a community, culture, or discourse group. Thus, the meaning of a sign or term emerges from its semantic relationships with other terms in a given context.

The acquisition of meaning in KOSs is therefore contingent upon the semantic interconnections among terms within a complex relational network. KOSs that utilize semantic links to extract and represent information within specific domains are classified under the cognitive unit of *information*. These systems operationalize meaning through structured semantic relations and are exemplified in the figure below:

Fig. 14 illustrates the convergence of various KOSs—such as subject headings, taxonomies, and thesauri—that

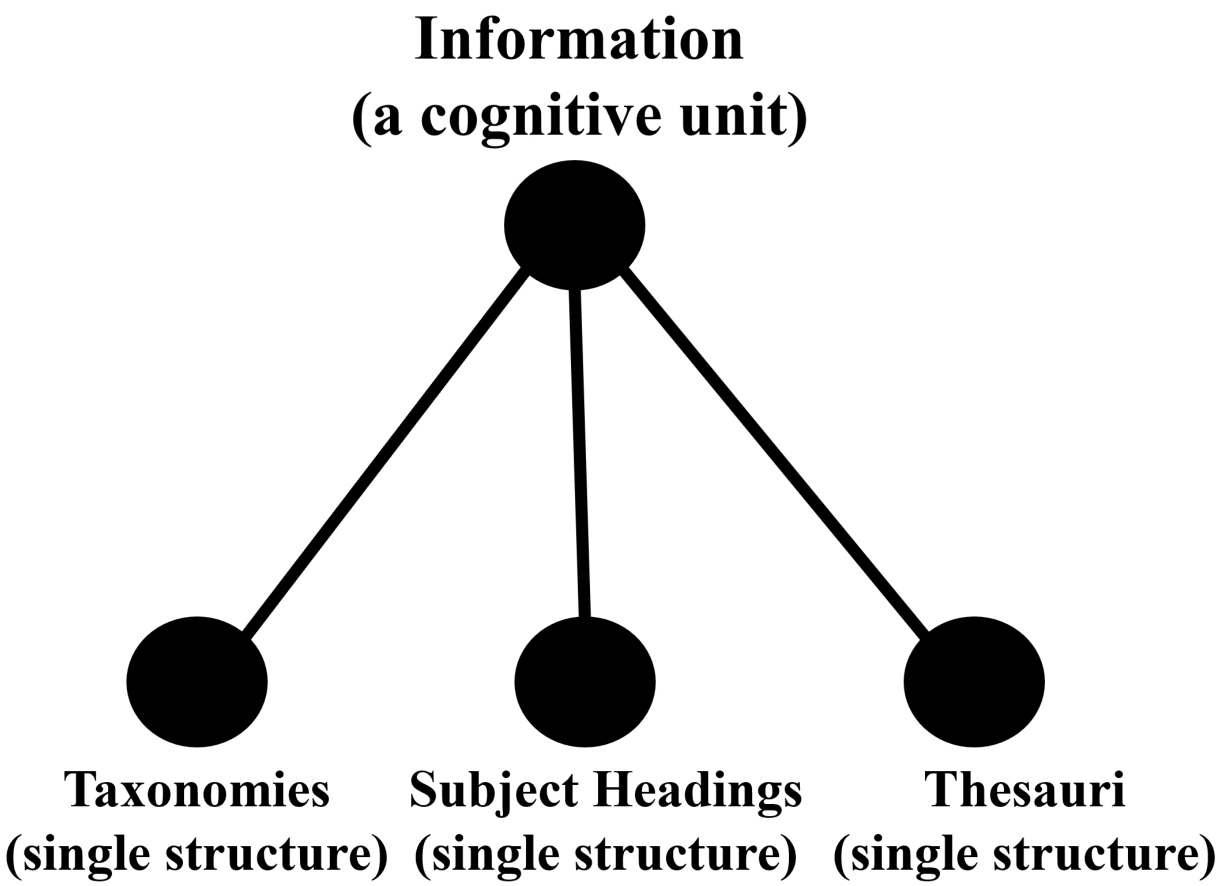

Fig. 14. Categorization and convergence of selected KOSs under the cognitive unit of information from a graphical perspective.

extract information from terms via semantic links. These systems function as constituent elements (i.e., single structures) within the broader cognitive unit of *information*. Similar to KOSs categorized under the cognitive unit of *data*, these systems are interconnected through a *control unit*, which in this case is *information*. This control unit facilitates internal unity among the KOSs, enabling coordinated functionality and structural coherence.

The form of unity exhibited by these systems corresponds to the *third type of unity* (Mandelblit and Zachar, 1998), wherein elements are connected via a control unit rather than being directly bound. This type of unity is notably more dynamic than classical unity (Type 1) and channel-based unity (Type 2), reflecting a higher degree of structural flexibility and semantic integration.

In conclusion, KOSs that are constructed around semantic links for the purpose of representing and extracting information are situated within the cognitive unit of *information*. Their internal unity—both in terms of structure and function—demonstrates a dynamic nature that aligns with the third type of unity, offering a more sophisticated and context-sensitive model of convergence than earlier forms.

Summary: The unity of KOSs under the cognitive unit of *information* can be understood through:

- **Graphical Unity (Type 3)**: Based on indirect connectivity among KOSs via a control unit (*information*), enabling coordinated semantic extraction.
- **Semantic Dimension**: Meaning is derived from relational links among terms within a domain-specific semantic network, reinforcing dynamic internal unity.

5.3 The Unity of KOSs Under the Cognitive Unit of Knowledge

KOSs can converge and be unified under the *cognitive unit of knowledge* through graphical representation. The minimal structural unit of any knowledge system comprises *concepts* and the *semantic relations* among them—typically involving at least four concepts and four relational links. These elements constitute the foundational components of a *cognitive unit of knowledge*, which is formed through the internal connectivity of its constituent concepts and semantic relations.

Establishing links among these minimal knowledge units facilitates the emergence of more complex and context-sensitive knowledge systems, which manifest as KOSs. While both *information* and *knowledge* as cognitive units are grounded in semantic relations, they differ in their organizing principles. In knowledge systems, semantic relations are primarily established through *concepts*, rather than through the meanings conveyed by terms. This conceptual grounding results in a higher degree of semantic granularity and coherence, distinguishing knowledge systems from traditional KOSs such as thesauri.

Modern KOSs—particularly *ontologies* and *folksonomies*—further emphasize real-world entities and are structured around a *pragmatic dimension*. This raises a critical interpretive question: *Why (and for what purpose) does the sign signify?* As Nake (2002) notes, while syntactic and semantic dimensions are essential for analyzing signs, a complete understanding requires consideration of their *pragmatic context*. In other words, the full meaning of a sign emerges only through its intended use and practical application.

Accordingly, KOSs that establish semantic relations through concepts grounded in real-world entities and guided by pragmatic considerations are classified under the cognitive unit of *knowledge*. These systems leverage the full potential of semantic relations to support purposeful, context-driven knowledge representation.

Fig. 15 illustrates how modern KOSs—such as ontologies and folksonomies—converge under the cognitive unit of *knowledge* due to their pragmatic orientation. These systems function as constituent elements (i.e., single structures) within the broader knowledge unit and are interconnected through a *control unit*, namely *knowledge*. This control unit facilitates internal unity among the KOSs, enabling coordinated integration based on shared conceptual and pragmatic foundations.

The resulting internal unity corresponds to the *third type of unity* (Mandelblit and Zachar, 1998), wherein elements are connected via a control unit rather than direct binding. This form of unity departs from classical models and approaches *dynamic unity*, reflecting a more flexible and context-sensitive mode of integration.

Summary: The unity of KOSs under the cognitive unit of *knowledge* can be understood through:

• **Graphical Unity (Type 3)**: Based on indirect connectivity among KOSs via a control unit (*knowledge*), emphasizing conceptual and pragmatic coherence.

• **Pragmatic Dimension**: Meaning arises from the purposeful use of signs and the semantic relations among real-world entities, enabling dynamic and context-sensitive knowledge representation.

5.4 Dynamic Unity Between KOSs Under the Dynamic Cognitive Units

This section examines the *substantive unity* among KOSs categorized under the dynamic cognitive units of *data*, *information*, and *knowledge*. As previously discussed, KOSs are grouped according to their cognitive orientation toward *concepts*—the foundational elements of KOS structures—analyzed through graphical representation. The central question addressed here is: *Is there a form of correlation among KOSs that are subsets of these cognitive units?*

This question is explored in depth in an independent study published in *Knowledge Organization* (Amirhosseini, 2021), which identifies a *dynamic dialectical movement*—or *dynamic unity*—among KOSs from a substantive perspective. This movement reflects an evolutionary trajectory in which the development of simpler KOSs contributes to the emergence of more complex systems. The dialectical process, characterized by the interplay of *thesis*, *antithesis*, and *synthesis*, serves as a conceptual framework for understanding this progression.

For instance, the creation of dictionaries based on alphabetical ordering (thesis) stands in contrast to the semantic structuring of Roget's Thesaurus (antithesis). This tension has led to the synthesis of *semantic relations networks*, which underpin the construction of modern thesauri. Such examples illustrate how conceptual contradictions between KOS models generate new organizational paradigms, reinforcing the dynamic nature of their interrelations.

Therefore, beyond the internal unity exhibited within each cognitive unit—graphically represented through types of structural integration—there exists a *dynamic unity* among KOSs across cognitive categories. This unity is driven by dialectical transformation, wherein the conceptual and structural evolution of one KOS informs and reshapes the development of others. The result is a layered and interconnected ecosystem of KOSs, each contributing to the broader cognitive architecture through substantive correlation and synthesis.

Summary: The dynamic unity between KOSs across the cognitive units of *data*, *information*, and *knowledge* can be understood through:

• **Substantive Unity**: Based on dialectical movement, where conceptual contradictions (e.g., alphabetical vs. semantic order) lead to synthesis and the emergence of new KOS models.

• **Evolutionary Interdependence**: Simpler KOSs serve as precursors to more complex systems, forming a correlated and progressive cognitive structure.

5.5 Towards an Evaluative Framework: Observable Properties of Cognitive Unity

The preceding analysis categorizes KOSs based on their primary alignment with the syntactic, semantic, or pragmatic dimensions of cognitive units, establishing a foundational taxonomy. For the principle of cognitive unity to function as a genuine ranking mechanism, moving beyond classification to evaluation, it is necessary to define the specific, observable properties that indicate a "higher" or more cohesive state of cognitive unity within and across these categories. A KOS demonstrating a greater degree of cognitive unity will exhibit enhanced integration, coherence, and dynamic adaptability across the levels of data, information, and knowledge. Drawing from the theoretical synthesis of conceptual compression, dynamic correlation (Mandelblit and Zachar, 1998), and the pragmatic-

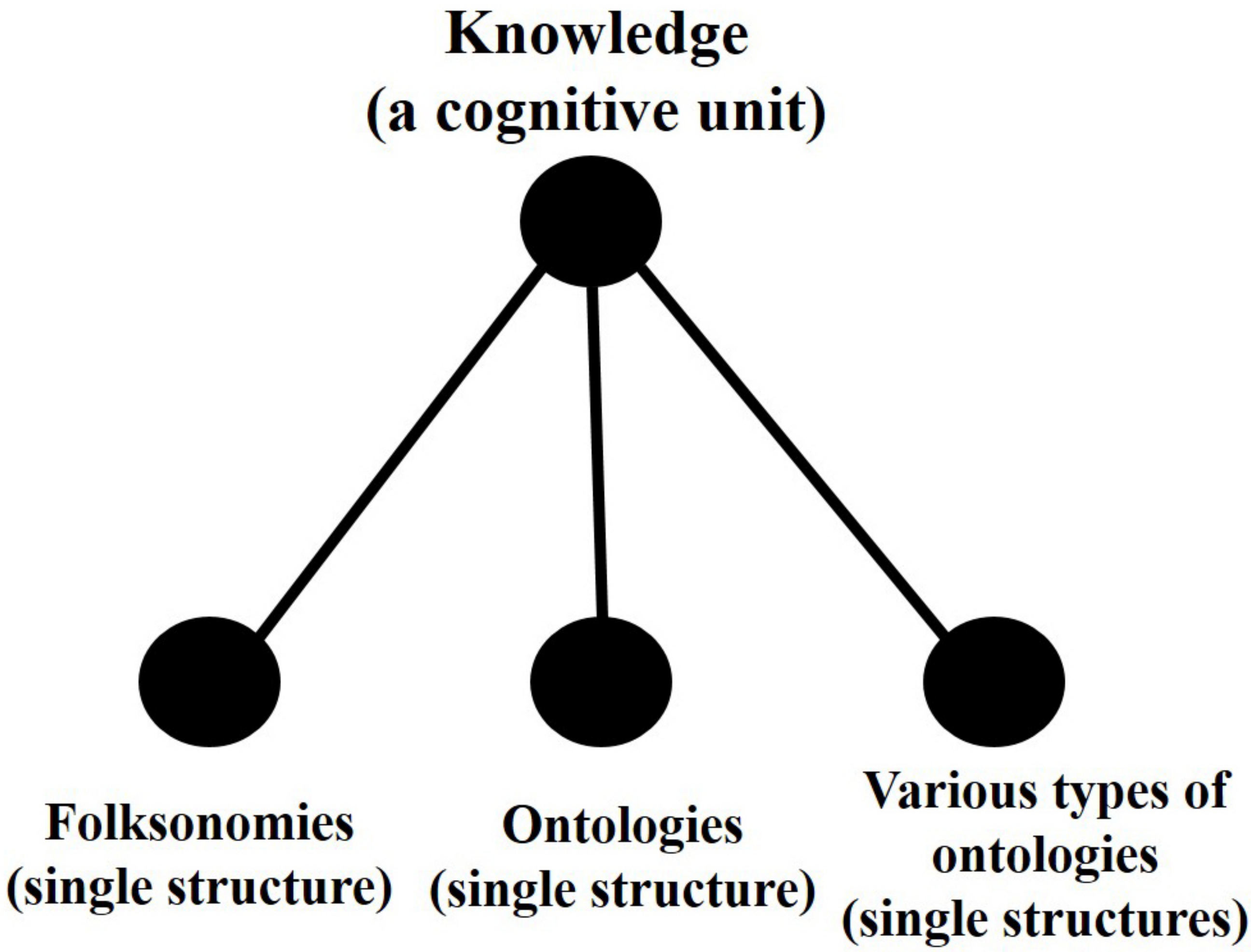

Fig. 15. Categorization and convergence of selected KOSs under the cognitive unit of knowledge from a graphical perspective.

semiotic continuum (Nake, 2002), the following interdependent properties are proposed as normative dimensions for assessment:

(1) Density and Coherence of Semantic Links: A higher degree of cognitive unity is marked not merely by the quantity of semantic links (as in a simple network density measure) but by their coherence, the extent to which links form meaningful, contextually appropriate, and non-contradictory pathways between concepts (Zhuge, 2012). A high coherence density is indicative of strong internal unity (Type 2 evolving toward Type 4) and is a hallmark of advanced KOSs in the information and knowledge categories. A thesaurus (information unit) with richly defined, hierarchically and associatively related terms exhibits greater internal unity than a mere glossary of terms (data unit).

(2) Degree of Conceptual Compression Achieved: Efficiency of Conceptual Compression operationalizes Skemp's (1979) varifocal theory and Tall's (1992) cognitive root concept by evaluating how effectively a KOS encapsulates complex, lower-level details into higher-order, manipulable knowledge units. An efficient KOS provides clear pathways through hierarchical relationships or defined axioms, allowing users to "chunk" detailed information into meaningful wholes. This efficiency can be measured by the ratio of core concepts to total terms or the intuitiveness of pathways to general principles (Tall and Crowley, 1999). The Degree of Conceptual Compression achieved assesses a KOS's (i.e., ontology as a knowledge unit) ability to organize relationships into manageable units, indicating cognitive unity compared to a flat taxonomy (information unit). Metrics include compression efficiency and cognitive manageability.

(3) Pragmatic Alignment and Contextual Flexibility: A KOS with high cognitive unity will show strong alignment with the pragmatic needs and real-world use within its domain (Hjørland, 2009). Its structure should facilitate not just retrieval, but reasoning, decision-making, and knowledge discovery. Furthermore, it should exhibit dynamic unity (Type 4), meaning its elements remain correlated and meaningful under varying contextual interpretations or within evolving knowledge landscapes (Mandelblit and Zachar, 1998).

(4) Integration Across Cognitive Unit Boundaries: A superior KOS will facilitate, rather than hinder, the dialectical movement between data, information, and knowledge. This can be observed in its capacity to link granular concepts (data) to propositional statements (information) and further to systemic rules or theories (knowledge) in a traceable and functionally supportive manner. The dynamic unity between units, as shown in Fig. 8, becomes an operational feature.

(5) Evolutionary Advancement via Dialectical Synthesis: Following the dialectical perspective (Amirhosseini, 2021), a KOS that embodies a synthesis resolving contradictions in earlier forms (e.g., integrating alphabetical access with semantic relationships, or combining formal structure with social tagging) demonstrates a more advanced evolutionary state. This synthesis manifests as a more complex and adaptive internal unity.

(6) Strength and Pattern of Dynamic Correlations: This criterion evaluates the nature of interdependence among a KOS's constituent elements (concepts, semantic links, quantum blocks). Beyond mere connectivity, it assesses the strength (i.e., the consistency and predictability of co-variation), and the pattern of correlations in response to contextual shifts. A KOS with strong, stable correlations among its elements under defined domain constraints exhibits higher dynamic unity (Type 4). This could be approximated by analyzing the stability of semantic link patterns across different subsets of the system or in response to simulated queries (Zhuge, 2012). For instance, a robust thesaurus should maintain coherent relational patterns (e.g., hierarchical consistency) across its various facets.

(7) Resilience of Internal Structure Under Contextual Change: Closely related to dynamic correlation, this metric measures a KOS's ability to maintain its functional coherence and interpretative validity when the context of use or the underlying knowledge domain evolves (Hjørland, 2009). A resilient KOS, often one operating at the knowledge unit level, possesses an internal structure (its configuration of concepts and relations) that can absorb new elements or accommodate novel interpretations without fundamental breakdown. Its unity is not brittle but adaptive. Assessing resilience might involve analyzing how well a classification schema or ontology can integrate new, emerging topics without requiring extensive structural reorganization.

Therefore, ranking KOSs based on cognitive unity involves evaluating their structural and functional manifestation of these properties. A KOS primarily operating at the data level (e.g., an alphabetical index) would score low on semantic coherence and compression but high on syntactic order. A knowledge-level KOS (e.g., a well-designed ontology) would be expected to score highly on all dimensions, particularly compression, pragmatic alignment, and cross-unit integration. This multi-dimensional assessment transforms the static taxonomy into a dynamic evaluative framework, providing the normative dimension necessary for true ranking and establishing a research agenda for developing specific quantitative and qualitative metrics.

6. From Descriptive Framework to Evaluative Theory: Synthesizing the Principle of Cognitive Unity

The preceding sections have developed a descriptive taxonomy of KOSs based on cognitive roots and dynamic units, and proposed metrics for assessing unity. To elevate this into a coherent evaluative theory, this section synthesizes these components into an actionable principle of cognitive unity. This principle posits that: The efficacy and evolutionary sophistication of a KOS can be evaluated by the degree to which it exhibits coherent integration (unity) within and between the dynamic cognitive units of data, information, and knowledge, as manifested through strong dynamic correlations, resilient structure, and efficient conceptual compression.

6.1 Operationalizing the Principle: A Tripartite Evaluative Lens

The principle moves beyond classification by providing a tripartite lens for evaluation, integrating the proposed metrics:

6.1.1 Structural-Cohesive Dimension

Assesses the formal integrity within units (internal unity, Types 2 & 3) and the strength of correlational patterns between units (dynamic unity, Type 4). This involves analyzing semantic link coherence, relational density, and the stability of these patterns under contextual perturbation.

6.1.2 Cognitive-Compressive Dimension

Evaluates the KOS's capacity to serve as a cognitive tool that compresses complexity. This is measured by the efficiency with which the system allows users or agents to navigate from granular data to informational patterns and synthesized knowledge, reducing cognitive load while preserving inferential power (Tall and Crowley, 1999).

6.1.3 Pragmatic-Adaptive Dimension

Judges the KOS's success in fulfilling real-world epistemic functions within its domain. This dimension tests resilience and pragmatic alignment, asking whether the system's unity supports tasks like discovery, reasoning, and knowledge evolution (Hjørland, 2009).

6.2 The Utility of the Principle: From Classification to Evaluative Analysis

The principle of cognitive unity is not merely a descriptive label but an analytical tool designed to address a specific gap in KOS evaluation. Its utility lies in transforming the analysis of KOSs from a focus on formal properties (e.g., "this is a faceted classification") to an evaluation of cognitive efficacy ("how coherently does this system structure knowledge for understanding?"). This is achieved by providing a common, multidimensional framework for comparative assessment.

• For Classification: Traditional classifications are typological (e.g., list, hierarchy, network). The principle of cognitive unity enables a gradient classification based on qualitative depth. It allows us to rank KOSs on a continuum of cognitive sophistication, where a folksonomy (low compression, weaker dynamic correlations) and a formal ontology (high compression, strong resilience) occupy different positions. This reveals an evolutionary and functional hierarchy more informative than a flat taxonomy of system types.

• For Analysis: The principle directs analysis toward specific, diagnostically valuable features:

➢ Does the system's relational network (information unit) exhibit stable patterns or fragment under query?

➢ Can users easily navigate from specific instances to general principles (effective compression)?

➢ How does the system accommodate new knowledge without structural collapse (resilience)?

Answering these questions through the lens of cognitive unity yields insights into the KOS's long-term viability and domain-modeling power, which conventional analysis of link counts or term coverage cannot provide.

Therefore, the principle's usefulness is precisely in offering a theory-grounded rationale for why some KOSs are more fit for purpose than others, moving classification from a static exercise to a dynamic assessment of architectural quality. This makes it a vital tool for designers, evaluators, and scholars aiming to understand and improve the foundational tools of knowledge organization.

6.3 Theoretical Synthesis as the Foundation for Evaluation

The operationalization above is made possible by the deliberate complementarity of the integrated theoretical framework. The theory is not a collage but a stratified model where each component addresses a specific layer essential for evaluation:

6.3.1 Meta-Theories

Tall/Skemp's Cognitive Models provide the meta-theory of hierarchical organization and compression, defining what a "unit" is and how complexity is managed.

6.3.2 Peircean Semiotics

This theory offers the evaluative foundation for the data unit, providing criteria (clarity of interpretant, sign-object relation) to assess the quality of basic conceptual building blocks.

6.3.3 Semantic Link Network Theory (SLNT)

SLNT furnishes the analytical toolkit for the information unit, supplying the relational grammar and network metrics needed to evaluate structural cohesion.

6.3.4 Quantum Theory of Knowledge (QTK)

QTK contributes the systemic logic for the knowledge unit, modeling how integrated components yield emergent, evaluable properties like inferential capacity.

Thus, the synthesis itself is evaluative: a KOS is analyzed by how well its structure at each level (concept, link, system) can be meaningfully modeled by the corresponding theory, and how seamlessly these levels interact.

6.4 Applied Evaluation: Revisiting the Gene Ontology (GO) Through the Unified Principle

Applying the unified principle transforms the earlier case study from description to evaluation:

6.4.1 Evaluation via Structural-Cohesive Lens

GO scores highly. Its is_a and part_of relations create a massive, coherent network. The strength of dynamic correlations is evident; changes in term annotations propagate consistently through the relational structure, maintaining logical coherence.

6.4.2 Evaluation via Cognitive-Compressive Lens

GO is highly efficient. A researcher can operate on the compressed concept "mitochondrial translation" (a knowledge-level unit) while the system manages thousands of underlying gene annotations (data) and their relational pathways (information). This enables complex functional enrichment analyses, a direct measure of successful compression.

6.4.3 Evaluation via Pragmatic-Adaptive Lens:

GO demonstrates robust resilience and alignment. It successfully unifies data across thousands of independent biological databases (Aleksander et al., 2023), proving its pragmatic unity. Its governance model allows for the controlled addition of new terms, showing adaptive resilience.

This applied analysis demonstrates the principle in action. It moves from stating "GO is a knowledge-level KOS" (description) to assessing "GO exhibits a high degree of cognitive unity due to its strong scores across structural, cognitive, and pragmatic dimensions, which explains its widespread utility and adaptability" (evaluation).

Therefore, the principle of cognitive unity, operationalized through this tripartite lens and grounded in a coherent theoretical synthesis, provides a concrete, multidimensional framework for the comparative evaluation and ranking of KOSs based on the robustness of their cognitive architecture.

6.5 Theoretical and Practical Contributions of the Principle of Cognitive Unity

This study makes several substantive contributions to the conceptual understanding of knowledge organization and provides actionable directions for improving KOSs and their applications. By formulating and operationalizing the principle of cognitive unity, the research advances the field in the following distinct ways:

6.5.1 Advancing KO Theory: A New, Cognitively-Grounded Evaluative Principle

The primary theoretical contribution is the introduction of cognitive unity as a foundational principle for KOS analysis. While existing literature offers classification schemas and functional criteria (e.g., Broughton et al., 2005), this principle provides a novel, integrated lens rooted in the dynamics of human cognition. It posits that the quality of a KOS is intrinsically linked to the coherence and adaptability of its internal cognitive architecture, a perspective that bridges the gap between descriptive KO theory and the cognitive sciences (Mandelblit and Zachar, 1998). This moves beyond traditional, often static, descriptions of KOSs (e.g., as mere lists or hierarchies) to a dynamic model where unity becomes a key variable for understanding a system's sophistication and potential efficacy.

6.5.2 Providing a Novel Methodological Framework for KOS Analysis

The research offers a concrete, structured methodology for dissecting and evaluating KOSs. By integrating Tall's cognitive structures, Peircean semiotics, SLNT, and QTK into a coherent analytical progression (see Section 1.1), it provides scholars and practitioners with a replicable toolkit. This framework enables a systematic analysis of any KOS by deconstructing it into its constituent dynamic cognitive units (data, information, knowledge) and assessing the forms of unity (internal, dynamic) that bind them. This methodological contribution fills a gap, offering a more granular and theoretically robust alternative to ad-hoc or purely bibliometric evaluations.

6.5.3 Offering Actionable Pathways for KOS Design, Evaluation, and Interoperability

The principle has direct practical implications for improving KOSs:

(a) **For Design**: It provides clear design heuristics. Developers should aim to build systems that foster strong dynamic correlations between concepts and relationships, ensure internal consistency within units, and achieve efficient conceptual compression. For example, ontology engineers can use the criteria of resilience and pragmatic alignment as explicit design goals to create more adaptable and useful systems (Amirhosseini, 2022).

(b) **For Evaluation**: The operational definition and tripartite evaluative lens (Section 6.1) transform cognitive unity from an abstract idea into a set of assessable dimensions. This offers a new, comprehensive basis for comparative KOS evaluation and ranking, moving beyond measures of recall/precision or node-count to assess cognitive coherence and adaptability.

(c) **For Interoperability and Evolution**: By framing KOS development as a dialectical process driven by synthesizing contradictions (Amirhosseini, 2021), the framework provides a model for understanding how KOSs evolve and how interoperability might be achieved by seeking higher-order unities between systems. It suggests that successful integration requires aligning not just terms, but the underlying cognitive architectures and patterns of unity.

In summary, this work contributes a new theoretical principle to KO, a novel methodological framework for analysis, and a set of actionable criteria for the design, critical evaluation, and future development of more robust, cognitively coherent, and pragmatically effective Knowledge Organization Systems.

7. Conclusion

This study has examined the cognitive architecture of KOSsthrough the lens of *knowledge* as both a cognitive root and a high-level cognition state. As reflected in the title of KOSs, *knowledge* functions dually: first, as the foundational cognitive root encompassing the dynamic cognitive units of *data*, *information*, and *knowledge*; and second, as an advanced cognitive level that integrates and governs these units. Each of these cognitive units exhibits dynamic properties and is composed of minimal structural elements—such as signs, concepts, and semantic links—that contribute to internal coherence and system-wide integration.

A key finding is the existence of *dynamic unity* (Type 4) among the cognitive units of data, information, and knowledge. This unity is characterized by substantive correlations, whereby the quantitative and qualitative enhancement of one unit leads to the enrichment of others. Additionally, each cognitive unit demonstrates *internal unity* (Type 2) among its constituent elements, which—although not classical in form—supports the emergence of dynamic coherence within and across KOSs.

From a structural perspective, KOSs can be classified according to the cognitive dimension they emphasize:

• Systems grounded in the *syntactic* dimension (e.g., alphabetical ordering of signs) align with the cognitive unit of *data*.

• Systems based on *semantic* relations (e.g., term-based semantic links) correspond to the cognitive unit of *information*.

• Systems that prioritize *pragmatic* meaning-making through real-world entities and concept systems fall under the cognitive unit of *knowledge*.

This tripartite classification enables the grouping of KOSs into cognitive platforms based on their approach to concept identification, representation, and interpretation. Furthermore, graphical modeling reveals significant internal unity within each cognitive unit.

In summary, *knowledge* serves as the cognitive root from which the dynamic cognitive units of *data*, *informa-*

tion, and *knowledge* emerge. KOSs can be ranked and classified based on the type of cognition they provide, and their structural and functional alignment with these units. The identification of cognitive roots, dynamic units, and internal unity offers a robust framework for proposing a *theory of cognitive unity in ranking KOSs*.

The theory of cognitive unity or the principle of cognitive unity—introduced here as a foundational model for ranking and evaluating KOSs—will be elaborated in a forthcoming independent publication. Future studies should further explore:

• Identifying the most important factors and features in the evolution of KOSs.

• Drawing the knowledge map of the development, transformation and evolution of KOSs.

• Clarifying the relations between the cognition states in the cognitive structure of KOSs.

• Proposing operational criteria for measuring cognitive adaptation in KOSs.

• Creating a research platform to mathematically calculate the connections and relations between KOSs.

• Comparative analysis of KOSs across disciplines and cultural contexts.

Such investigations will deepen our understanding of how dynamic cognitive structures shape the design, evaluation, and interoperability of KOSs in contemporary knowledge environments.

Availability of Data and Materials

This study is a theoretical and conceptual analysis. There are no data or materials to be shared beyond what is already included in the manuscript and its references.

Author Contributions

The author (MA) designed the study, conducted the conceptual development, drafted the manuscript, and critically revised it for intellectual content. The author read and approved the final version and agrees to be accountable for all aspects of the work.

Acknowledgment

I extend my deepest gratitude to Professor Dr. Birger Hjørland for his generous and insightful guidance. His beneficent comments and intellectual encouragement have been instrumental in leading me toward a deeper understanding of cognitive units in Knowledge Organization Systems (KOSs). His scholarly contributions continue to inspire and shape the theoretical foundations of this research.

Funding

This research received no external funding.

Conflict of Interest

Given MA as Editorial Board member, the author (MA) had no involvement in the peer review of this article and has no access to information regarding its peer review. Full responsibility for the editorial process for this article was delegated to Dr. Natália Tognoli.

Declaration of AI and AI-Assisted Technologies in the Writing Process

During the preparation of this manuscript, artificial intelligence (AI)-assisted technologies (e.g., ChatGPT and Perplexity) were used solely for language enhancement and grammatical refinement. These were employed to improve clarity, coherence, and stylistic precision in the initial drafting and revision phases. All content, conceptual development, theoretical framework, and critical analysis were conceived, developed, and authored entirely by the author (MA). Following peer review, AI was used to support a targeted literature search to identify relevant scholarly sources. In each case, MA personally reviewed, evaluated, and verified the relevance and accuracy of every retrieved reference before incorporating it into the manuscript. All revisions were conducted by the author, and MA has personally read, validated, and taken full responsibility for the final version of the manuscript.

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