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Interdisciplinary Approaches to Semiotics

Edited by Asuncion Lopez-Varela Azcarate

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Contributors

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Meet the editor

Prof. Asunción López-Varela Azcárate's research interests involve cognitive and intermedial semiotics and InterArt and cultural studies. Since 2007, she has been coordinating the research programme Studies on Intermediality and Intercultural Mediation (SIIM) at Complutense University of Madrid. She has been visiting scholar in universities in Europe, North America and Asia. A proactive member of the profession, she is honorary member of the Poetry Award Committee of Beijing Literature and ArtNetwork, the Executive Committee of Alumni RCC-Harvard and the European Network of Comparative Literary Studies. In order to strengthen relations between Europe and Asia, López-Varela coordinates with the One Asia Foundation Seminar Series on cross-cultural dialogue. She is external evaluator for the European Union research programmes (Horizon 2020) and postgraduate programmes at Dublin City University, Trinity College Dublin and the Institute for Intermedial Studies at Linnaeus University and has collaborated with the Department of Romance Studies at Harvard University.

Contents

Preface

Semiotics has a long tradition as the science of signs, signification and meaning-making. Four traditions have contributed to Western semiotics: semantics (including the philosophy of language), logic, rhetoric and hermeneutics. However, as this volume will show, there are many other fields contributing to make semiotics an interdisciplinary arena and an ever-growing field of interest.

The volume opens with a paper entitled 'Semiotics of Conscience' by **Dr. Rufus Duits**, which offers a fundamental introduction to the semiotic analysis of conscience. The paper starts from Martin Heidegger's phenomenological analysis and moves towards a Peircean perspective where the author discusses the concept of conscience as a fundamental semiotic operation beyond deconstructive scepticism. Positing conscience as a psychical component of semiosis, based on Heidegger's insights on the notion of 'care' and on how human horizons are mapped out by concern, Dr. Duits stresses that it is not only that humans seek to create meanings, but that humans' perceived needs and desires give rise to such meanings. Objects around us become part of our perceptual experience only when they acquire meaning for our task-oriented actions. Organised around goals to be accomplished, they only take significance from the projects we envision to perform with them. Thus, in Heidegger's view, conscience is a sort of inner moral 'voice', the result of the phenomenological structure of 'care' and the notion of responsibility attached to it, defined ontologically around three social moments: the call (i.e. the message), the caller and the one summoned by the call. The author sees the three Peircean semiotic moments—*representamen* (the sign vehicle, or form that the sign takes), *object* (the referent that the sign stands for) and *interpretant* (the sense conveyed by the sign)—as part of a liminal conscience sign, 'at the boundary of semiosis'; a 'sign of signs' where 'the sign vehicle, the sense and the referent of the sign are all the same thing', 'the point at which semiosis begins or ends', writes the author. In the last part of the paper, the analysis moves towards ethical implications of the theory of signs based on the notion of 'concern' for the self. To the author, this is an essentially normative dimension that compels a way of thinking about semiotics that is inherently critical.

The paper by **Dr. Miguel López-Astorga** 'Mental Models Are Compatible with Logical Forms' addresses the continuing debate as to whether human reasoning is based on mental models versus formal rules of inference, domain-specific rules of inference or probabilities. Thus, the paper traces the relationships between MMT (which focuses on the semantic aspects of content, drawing on inference reasoning rather than on syntax or formal structure) and standard logic. López-Astorga's research includes correspondences between the combinations of possibilities that MMT assigns to some of the traditional connectives in standard logic (e.g. the conditional conjunction and the inclusive disjunction), the truth value and the definitions that standard logic attributes to the same connectives. The paper also shows that the possibilities or models that, following MMT, correspond to those connectives and their negations are evidently compatible with the truth tables in standard logic for those very connectives and their negations. The author proposes that the models that MMT assigns to such connectives are consistent with their definitions by means of other connectives valid in standard logic.

Dr. Fionn Bennett deals with 'The Art of "Scoring" Cosmopoiesis in Archaic Melic Verse'. This chapter sheds light on the semiotic correspondence between the arithmetic of music for the Hellenes and the blends of cosmic energies behind sacred melodies and subject matter. Delving into Plato's works, the author explores the experience of the divine and how this experience was enacted in musical melic verse and conveyed effectively to the audiences at the time, thus contributing through the values, norms and aspirations encoded to create a sense of community. Dr. Bennett also points out how melic verse had the power to 'epi-*phon*-ise', that is, to re-enact the 'astrocentric paradigm of cosmopoiesis' or the 'harmony of the spheres', exerting a sort of cosmic agency upon being-in-the-world. The paper explores the semiotic relational behind these sacred songs, which voiced the divine because the melodies and rhythms that accompanied the words mimed cosmic powers and encoded immortal intelligences.

The paper by **Dr. Mark Reybrouck**, 'Music and Semiotics: An Experiential Approach to Musical Sense-Making', explores recent cognitive bio-semiotic theory, ecological psychology and the transition from a disembodied to an embodied approach as applied to music. Reybrouck brings to the fore three dimensions of musical sense-making: the syntactic, the semantic and the pragmatic levels. Within the syntactic, the author notes the conceptual tools of deixis and indexical devices, which anchor referential exchanges, systematised in terms of personal, spatial and temporal axes, defined with reference to the sound event. However, Reybrouck argues that the deictic approach, as applied to music, favours an experientialist as against a merely conceptual-symbolic, stressing first-hand information in perception rather than relying on second-order stimuli. Such approach might disregard the centripetal tendency in music, where attention is directed from external references to the semantic self-reflection of elements that trigger internal processes of sense-making (bodily resonance) along the lines of the cognitive embodiment hypothesis, which understands perception as perceptually guided enactment. The listener conceives the sounds of music at a symbolic level or representation, beyond their experiential qualities. Cognitive neuroscience has also noted this inductive power of music on the human brain and the reactions within the internal environment of the body. With regard to the pragmatic level, the concept of 'musical affordances' is of particular importance and deals with the extensions of the possibilities of sound production at several levels (i.e. musical instruments, the shaping of sound through playing and modulatory techniques and motor induction, including the possibility of moving in reaction to music). These affordances make possible the conception of music in terms of 'activity signatures', writes Reybrouck, including the mental simulation of movement in terms of bodily based schemata induced by music.

Dr. Vladimir L. Averbukh's contribution to the present volume, entitled 'Semiotic Analysis of Computer Visualisation', discusses the foundation of design, development and evaluation of visualisation systems from a semiotic perspective. Computer visualisation involves three interrelated areas: computer graphics (hardware and software including mathematical and algorithm components), software engineering and human factors. This chapter connects the author's previous research on the human factor subdomain on the transformation of the symbolic into figurative geometric visualisation, involving three aspects: perception, cognition and interpretation. Averbukh describes human-computer interaction as a semiotic process (a unity of lexicon, syntax, semantics and pragmatics), where visualisation is also a sign process and language is understood as a base sign system, which involves the systematic description of entities under consideration, methods of their representation, modes of changes of visual display, as well as techniques of manipulations and interaction with them. Displays are explored as elements of visualisation lexicons, whereas syntax is the set of rules describing (a) relationships of visual objects, (b) possible dynamics of visual objects and (c) techniques and results of interaction with visual objects. Semantics specifies the goals and tasks of computer modelling. Finally, pragmatics determines meaning drawn by users. The paper includes concrete examples of 2D and 3D graphs and their semiotic interpretation.

The chapter 'Developing Building Information Modelling for Facility Services with Organisational Semiotics' co-authored by **Dr. Bohan Tian** and **Dr. Haomin Jiang** explores space and habitat facilities where services are provided. The research uses organisational semiotics (OS) to explore Building Information Modelling (BIM) and employs an object-oriented modelling technology that integrates information from building projects in order to enhance BIM and target facility service activities. BIM has advantages in facilitating design and construction because it can provide specific object description by means of 3D, 4D (which includes time scheduling) and 5D (with integrated cost estimating). The integration of FM (facility management) and BIM is an emerging area. Facility services are generally operated and delivered according to personal preference and organisational policies. Their integration into technical engineering knowledge and the semantic and knowledge-based building information, which includes social and organisational aspects, is the aim of the FM-BIM model in order to connect it to D&B (Design and Build) and O&M (Operation and Maintenance), which enables FM managers to better understand how a building is operated and optimised. In this sense, organisational semiotics (OS) provides a framework that integrates six semiotic levels: social, pragmatic, semantic, syntactic, empirical and physical. Thus, the paper considers buildings as sociotechnical environments whose virtual representations as BIM can be contemplated as complex sign systems that allow stakeholders' interaction. The paper also explores how OS can bridge Building Information Modelling (BIM) by focusing on building fabrics and on facility management activities that concern service management.

Similarly, **Dr. Richa Sharma's** paper 'Grounding Functional Requirements Classification in Organisational Semiotics' uses organisational semiotics (OS) in order to analyse functional requirements in software engineering regarding three defining parameters to ensure consistent, correct, complete and unambiguous requirements: repeatability, quantifiability and systematic thought processes. The paper tries to define these parameters more clearly and put them in relation to activities in requirements engineering (RE) regarding the type of software system concerned, its applicability to other systems and, more specifically, the validity of the proposed solutions with regard to RE activities. The chapter is concerned with information systems that are database driven and have applications in retail, financing, ERP systems, etc. These information systems need to embed organisation structure, hierarchy, policies, processes and behaviour in the form of software requirements. The paper argues that OS presents a feasible solution towards understanding the requirements of such information systems. The experimental study presents two separate approaches: one semiautomated using lexical heuristics and word-tagging and the second of ML classification. Observations drawn from both approaches are similar in the goal of searching for an automatised process of identifying and extracting functional requirements from existing documentation using organisational semiotics. Results are encouraging, revealing that one solution towards a classification scheme for wide-spectrum software systems is functional requirements categorisation by grounding the classification scheme in an established theory of organisational semiotics.

Dr. Daniel L. McGee, Jr. discusses 'An Operational Approach to Conceptual Understanding Using Semiotic Theory' in mathematical representations that employ algebraic, geometric, numerical and verbal registers when concepts are synergically presented and discussed. The paper starts from previous theoretical conceptions of 'simultaneous awareness' of the various registers of representations associated with mathematical concepts, for instance, the semiotic chain of two associated conversions each of which is represented by an arrow in the diagram: (1) the geometric register to the numerical register and (2) the numerical register to the symbolic register. It gradually moves to more complex conversions employing six variables and to recent theories that present operational frameworks to map this fluidity of registers. The research summarises data obtained from these studies and provides insight into their implications, applications and methodology in assessing student understanding. In a classroom context, the simultaneous mobilisation of representations can be very difficult, and the vast majority of learning modules and textbooks use an ordered sequence of semiotic registers when presenting a mathematical concept. The paper argues that students are accustomed to starting with a symbolic representation (a formula), performing a conversion to obtain the associated numerical representation (a table) and finally obtaining a graphical representation through ordered pairs on the Cartesian plane, leading to a unique semiotic chain: symbolic register --> numeric register --> geometric register. Being unable to perform conversions not included in this semiotic chain, such as geometric register --> numeric register (graph to table) or numerical register --> symbolic register (table to formula), suggests that awareness of registers occurs sequentially as they appear in the semiotic chain. The author considers this inconsistent with a simultaneous awareness or a synergy of registers, which is achieved only if students are able to pass seamlessly among table, graph and formula.

The last paper in the volume continues to develop the topic of science education, conceptual change and teaching methods and approaches. 'Using Signs for Learning and Teaching Physics: From Semiotic Tools to Situations of Misunderstanding' by **Dr. Alaric Kohler** and **Dr. Bernard Chabloz** investigates a few semiotic objects mediating the communication in physics classroom, in particular the usage of arrows and graphics. The authors explore students' understanding in problem-solving tasks by taking examples drawn from research data at the high school and college level. In the case of the 'arrow' as a semiotic object, the lack of clues or conventions in its use might lead to misunderstandings emerging in the classroom. Challenges addressed include (a) the coordination between various semiotic registers and objects, extending previous research by Duval in order to analyse specific cognitive tasks of interpretation of signs of various kinds within their specific semiotic context; (b) the lack of clues or conventions in the use of semiotic objects that can play different semiotic roles and (c) the communicative counterpart of the use of semiotic tools for mediating knowledge. In order to explain the coordination of semiotic objects and registers, the authors start from Piaget's theoretical framework where the coordination is a higher-order process relating operations on (semiotic) objects (i.e. signs), but in order to avoid the theoretical reductionism inherent to formal logic, they rely on Grize's logic-discursive operations rather than on Piaget's logic. While interpreting physics tasks, the challenge of semiotic co-ordination involving several resisters comes from the establishment of synergic patterns of logic-discursive operations.

To conclude, we can affirm that papers in the collection prove that semiotics continues to provide a framework for varied emerging knowledge traditions.

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Section 1

Introduction

Chapter 1

Introductory Chapter: Semiotic Hauntologies of Ghosts and Machines

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Additional information is available at the end of the chapter

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1. Introduction

Semiotics has a long tradition as the science of signs, signification and meaning-making. Four traditions have contributed to Western semiotics: semantics (including the philosophy of language), logic, rhetoric and hermeneutics. However, both John Deely and Umberto Eco [1, 2] have claimed the need to re-read the history of philosophy, and maybe of other disciplines, from a semiotic point of view. This volume shows that there are many other fields contributing to make semiotics an interdisciplinary arena and an ever-growing field of interest.

In the Western world, the first semiotic incursions can be traced back to the Greeks. Before contemporary semioticians raised the question of the powerful action and "affordances" of signs (see below for this concept), there were phenomena considered "significant" in three main contexts: poetics (and linguistics), logic (and philosophy) and medicine. This introductory paper shows how knowledges from the past haunt the present and future of semiotics in various ways. The reflection functions as a catalyst to connect the diverse papers collected in this volume, contributing to point out the contemporary relevance of semiotics and its interdisciplinary applications.

The subtitle "of ghosts and machines" refers to a phrase used by Oxford professor of philosophy Gilbert Ryle (1900–1976) to capture the Cartesian idea of a soul/mind within the body/machine, which he employed to criticize materialist theories that reduce mental activity to physical reality. The phrase was later popularized by Hungarian-British journalist Arthur Koestler (1905–1983) who borrowed it for his 1967 book *The Ghost in the Machine*, where his central concern was the controversy over auto-replicative forms of intelligence in the human brain. The phrase has acquired new meanings in artificial intelligence. It was used by Arthur

C. Clarke in his (1982) novel *2010: Odyssey Two,* by Stephen King in his 1991 serial novel *The Dark Tower,* and more recently, by Japanese artist Masamune Shirow for his manga *Ghost in the Shell* and its movie adaptations. The evolution of the topic shows concern over the possibility of cyber-brains and the symbiosis of the human and the machine, throwing light on some key aspects of the contemporary debate on semiotics.

Indeed, cybernetic advance is so rapid that there is already software that tracks the electrical activity of human nervous systems, collecting patterns of thoughts and emotions in order to map entire human life experiences, turning them into searchable data (i.e., the British Telecom "Soul Catcher" computer chip). In the move towards "Silicon Souls", research on biomechatronics developed at MIT lab (http://biomech.media.mit.edu/) will allow a new generation of prosthesis by means of a dynamic socket that maps nerve and muscle movements in the amputee's body. These prostheses are extensions of the body as much as of the mind, since they map machine algorithms upon artificial limbs. All these contemporary immersive technologies explore the imbrication of digital simulations with body schemata. Furthermore, in the race to connect the world, the InterPlaNet (IPN) initiative launched by NASA in 1998 offers a computer networking protocol designed to operate at interplanetary distances (http://ipnsig.org/), not just "connecting people", but connecting galaxies.

Let me turn for a minute to the etymology of the word "ghost". According to the Oxford English Dictionary, the term originates in Proto-Germanic *Gaisto-z,* which in Old English became *gāst* and *gáest* (*Exeter Book*) and *Geist* in German, meaning "breath", in the sense of disembodied spirit of a dead person that inhabits a body and might be good or bad. It later acquired religious and psychological overtones as "psyche", "soul" and "vital principle". According to Sir James Frazer, the "ghost" is a sort of creature that animates de body, escaping it temporarily during sleep and permanently in death: death being the permanent absence of the soul, he explains in *The Golden Bough*. The similarities with Proto-Indo-European *ǵ^{h}eysd-, *ǵ^{h}isd- ("anger, agitation"), *ǵ^{h}yis- ("bewildered, frightened") and *ǵ^{h}ey- ("to propel, move, spin") should also to be noted.

Alongside "ghost", the Greek term *phántasma* originally meant to "make visible" or "bring to light", and it is related to contemporary terms such as "appearance" "image", "phantom" or "fantasy", all of which entered Western languages through Latin. As in the case of "ghost", it came to mean "soul" and "spirit", maintaining a religious significance as in the Bible (i.e., "the Holy Ghost"; in Latin *Spiritus Sanctus*).

Continuing our incursion on etymological roots, the origin of the term semiotics shows interesting parallels that make obvious the human desire to transcend death through memory and representation, that is, the use of signs that try to make present that which is absent. In Jacques Derrida's terms, "logocentrism" would be a characteristic pattern of the Western world. He also used the term "hauntology" in his 1993 book *Spectres of Marx,* following a reference to "spectre" made by Marx himself in his *The Communist Manifesto* [3]. Derrida also echoes Shakespeare's *Hamlet* in order to explain that re-presentation is a form of making present an absent past by means of different sets of signs. He argues that the attempt to isolate social (history) or individual identity is always futile because it is "always already" (he uses this term to capture the idea of the past living in the present) dependent of semiotic systems where meaning is deferred, subject to interpreting actions. According to Derrida, the sign/signifier can never capture the object/signified in its totality because we are not talking of essences but of complex processes that encompass many dimensions, as well as various forms of temporality.

Indeed, the haunting figure of the ghost sign, simultaneously absent and present, dead and alive, was always already there in the etymology of the term semiotics. The Greek noun *sêma* appears in ancient texts (i.e., Homer and Hesiod) with the sense "tomb/burial ground" as well as with the meaning of natural or conventional signal. After the sixth century BCE, the term *semeîon,* which originates from *sêma*, was commonly used by Aeschylus, Aesop, Hecataeus of Miletus, Anaxagoras or Cleostratus, and it comes to mean "symbol" and "sign of a god" as well as "indication" and "proof". It coexists with *tékmor*, found in *The Iliad* with the meaning of "proof" and eventually "sign" and "indication" (*Iliad*, I, 526; VII, 30; IX, 48; IX, 418; IX, 685; XIII, 20; cited in Castañares 2012) [4]. According to Detienne and Vernant, these terms were also used in fortune telling, astronomy and navigation, referring to signals coming from the gods and alluding to cunning knowledge associated with the goddess Metis (pp. 168–169) [5].

The term *tékmor* evolved towards *techné* in the context of medicine during the fifth century BCE and the beginning of the fourth, when Hippocrates' disciples compiled the chief treatises of the *Corpus Hippocraticum*. According to these treatises, doctors were able to identify a specific type of signs (*semeîa*) through which they were able to conclude the health or illness of individuals. The medical method of establishing conjectures (*tekmaíresthai*) for diagnosis departed from the analogical deductive procedure used in philosophy and which rested on the notion of *phýsis* as a cosmos (a whole finished reality, arranged by laws that were replicated at the human microcosmic level). Hippocratic medicine described inferential semiotics when it explained how *semeîa* moves beyond mere conjecture to become *semeîon* and gain the sense of proof (*tekmérion*) [4].

Aristotle's contribution to semiotics had already clarified that signs are demonstrative propositions that might (or might not) acquire meaning to someone. Beyond causality relations, statements can constitute the premises of a syllogism and, as such, they can become conventional cultural signs whose paradigm is the "word". However, they may also lack a specific name (*anónimon*) and therefore be refutable (*Rhetoric* I, 2, 1357 a 34 ff.). For instance, the fact that Socrates was wise and just is a (*anonymous*) sign that wise men are just (1357b pp. 11–13) [6]. Although in his *Poetics* (1456 b 20–21), Aristotle's attempts to define various terms related to the field of logic and semiotics, a clearer allusion appears in *Perihermenias or De interpretatione*, where he puts forth the explicit opposition between words and things (*lógos* and *ón*), already prefigured in Plato. One of the fragments presents an early description of triadic semiotics (Deely p. 76) [7].

"Now spoken sounds (*ta en têi phonêi*) are symbols (*sýmbola*) of affections (*pathématon*) in the soul, and written marks (*ta graphómena*) symbols of spoken sounds. And just as written marks are not the same for all men, neither are spoken sounds. But what these are in the first place signs *(semeîa prótos*) of – affections of the soul – are the same for all; and what these affections are likenesses (*omoiómata*) of – actual things (*prágmata*) – are also the same." (*De interpretatione* 16a 3–8) [7].

After the death of Alexander the Great in 323 BCE and the emergence of the Roman Empire, Greek civilization entered the Hellenistic Age, a period marked by battles and territorial shifts which lasted until the Roman conquest of Ptolemaic Egypt in the first century BCE. Many sources were lost during this period, either because of war or because of lack of interest in scribal preservation.

In the second century CE, Claudius Galenus synthetized Hippocratic medicine and the philosophical thoughts of Plato and Aristotle to include the advancement of technology into the inferential process of medical diagnosis (*diagnostikón meros tes technes*), coining the term *semeíosis.*

In the 1750s, a series of excavations that took place at Herculaneum (an ancient Roman town located at the skirts of Mount Vesuvius and covered with debris after the 79 CE eruption) unveiled a great collection papyrus.[1] Among these, there was a treatise by Epicurean philosopher Philodemus of Gadara (c. 100–35 BCE) probably entitled *Perì semeîon kai semeióseon* (*On Signs and Sign Inferences*), known now by its abbreviated title, *De Signis*. The treatise contains a variation of the term *semeióseos,* from which C.S. Peirce would derive *semiosis* [8, 9]. As in Aristotle, for Philodemus, common signs cannot be taken as valid inferential premises, as can particular or necessary signs (*anankastikón*). The treatise preserves the controversy on the validity of sign inference which took place between Epicureans and Stoics in order to establish the type of "proof" to determine the difference between signs. While the Stoics defended deductive inferences established from *a priori* principles, the Epicureans trusted empirical inductive testing.

Greek reflections on the nature and purpose of sign systems and their relations to different types of knowledge has continued to "haunt" Western thought for centuries. Thus, scholasticism and medieval semiotics developed within theology and the trivium of the three liberal arts, concerned primarily with textual exegesis and hermeneutics: grammar, dialectic (logic) and rhetoric. During this period, realist and nominalist positions debated over the existence (or not) of universals. A proponent of nominalism, William of Ockham (1285–1349) considered universals to be signs without an existence of their own, but standing for individual objects. Conceptualism, held by Peter Abelard (1079–1142), Albert the Great (1200–1280) and Thomas Aquinas (1225–1274), was accepted as a synthesis of the two positions, with universals are also mind-dependent but formed by similarities with real things of a common form.

A new era of interest and research on the nature of signs began in the ages of rationalism and British empiricism. The period showed a shift from analogic reasoning towards the expression of knowledge as both analytic and referential practice, where representation stems in the observer's perceiving/thinking mind (subject of enunciation) and gradually shifts to a more abstract mode, where the word/sign and the phenomenon/matter are brought to coincide in the act of mimetic representation. This move was also associated with an epistemological shift: from the perceiving subject to the observed empirical object (experiment) [10]. The use

[1]http://www.herculaneum.ox.ac.uk/http://163.1.169.40/cgi-bin/library?e=d-000-00---0PHerc--00-0-0--0prompt-10---4------0-1l--1-en-50---20-about---00031-001-1-0utfZz-8-00&a=d&c=PHerc&cl=CL5.1

of optic technologies and lenses employed in instruments such as the telescope, developed by Johannes Kepler (1571–1630) and Galileo Galilei (1564–1642), enabled this viewing transition, just as the screens of computers, tablets and smart phones open contemporary worlds to the virtual cyber-sphere.

In spite of Galileo's innovative engineering, his methods were based largely on the theories of analogy, proportion and inverse proportion, passed, on by the Italian mathematician Leonardo Fibonacci of Pisa (1175–1250) as well as the Egyptian-Greek architect known as Euclid (c. 300 BCE). A new translation of his book of *Elements* was published in 1543, only some 20 years before Galileo's birth. It had the advantage of coming from a Latin version based on an earlier Greek source, rather than via Arabic translations. I bring to the fore these issues of translation and the differences in symbolic representation because the late 1500s and early 1600s mark the expansion of Gutenberg printing press as well as the rupture of the ancient unity between calculation, natural philosophy and alphabetic writing [11].

The ensuing separation continued to pose the problem in philosophical debates between demonstrative and dialectical reasoning, as scholars tried to explain how singular items of experience were part of universal knowledge, a problem explored by Gottfried Wilhelm Leibniz (1646–1716). Mathematician and author of *Alice Adventures in Wonderland,* Charles Lutwidge Dodgson, better known as Lewis Carroll, confronted the problem in his *Tangled Tales*. In *Principles of Mathematics* (1901), Bertrand Russell continued to face a similar challenge: Whether the class of all classes [now called 'sets'] is or is not a member of itself [12, 13].

The analytico-referential form of reasoning developed after René Descartes (1596–1650) tried to explain the connection between the physical body, much like a machine, separated from the "spirit" or "soul" that animated the mind. In *The Description of the Human Body,* he argued that the mind regulates the body through the pineal gland, which he considered the "seat of the soul". His idea of innate human knowledge led John Locke (1632–1704) to combat Cartesian deduction with inductive empiricism. Limitations arose in both cases, as knowledge was treated as an object, thus creating a boundary between the liminal being, of which one is conscious, and the ineffable being (the sublime) for which there was no articulation (Reiss p. 39) [10].

The semiotics of George Berkeley (1685–1753) maintained that words do not always stand for ideas and that they have other functions such as referring to passions. Johann Gottfried Herder (1744–1803) sustained that human cognitive capacity only has access to the exterior marks of things (signs) and that these do not express the things themselves, only their names. Immanuel Kant (1724–1804) *Critique of Pure Reason* (1781) postulated basic conceptual categories of human thought as *a priori* tools for making sense of the world. To Kant, these categories exist independently of human experience; the image (*Bild*) was a category of perception, while *a priori* concepts formed part of 'pure reason'. This topic was also explored by Gotthold Ephraim Lessing (1729–1781) in his work *Laocoon*, a prominent example of the study of iconicity in the arts. A precursor of the studies on iconicity was Giambattista Vico (1668–1744), whose philosophy was also influential upon Friedrich Wilhelm Schelling (1775–1854) or Novalis (1772–1801), and Georg Wilhelm Friedrich Hegel (1770–1831) and, more specifically, Bernard Bolzano (1781–1848) continued to develop a pragmatic dimension of semiosis by exploring different types of signs from the point of view of perception (visual and auditory signs, gestural and verbal signs).

In the twentieth century, the study of semiotics takes a definite impulse. Victoria Lady Welby (1837–1912) has been recently acknowledged an important female precursor. In *Philosophical Investigations*, Edmund Husserl (1859–1938) developed a phenomenological theory of signs and meaning which explored the phenomenon of awareness and attention. Husserl argued that some phenomena are not immediately perceived in themselves. Such assertion already implied a gap between the objects as sign (signifier) and as thing (signified). Under the impetus of Ferdinand de Saussure (1857–1913), Louis Trolle Hjelmslev (1899–1965) and Algirdas Julien Greimas (1917–1992), the European structural approach relied on the supremacy of discourse and emphasized the dyadic correspondence between the material sign (signifier) and its referent (signified). It was later criticized under poststructural and deconstructive criticism (i.e., Derrida above). The North-American triadic approach, developed by Harvard pragmatist Charles Sanders Peirce (1839–1914) and Charles William Morris (1901–1979), as well as Italian semiotician Umberto Eco (1932–2016), went beyond the scholastic conception of reference *aliquid stat pro aliquo* and placed attention on the role of the user in the process of sense-making and interpreting, establishing three semiotic moments of reference: the material sign vehicle, the object it refers to, and the decoding "interpretant". Peircean semiotics, as both metaphysics and epistemology, reconfigures any simple binary distinction between phenomena (sensation, perception) and noumena (unmediated referent or event that exists without sense or perception) as an irreducible triadic relationship [14].

In the years of expansion of Claude Shannon's information theory, Eco insisted in distinguishing between a semiotics of communication, multidimensional, always intentional and based on a shared code by transmitter and receiver, and a semiotics of meaning which only required an intelligent consciousness at the reception pole, not requiring a transmitter that would transmit signs and signals willingly. Likewise, the members of the Palo Alto "Invisible College" who came from various fields but mainly from anthropology, sociology and psychology (i.e., Gregory Bateson 1904–1980, Paul Watzlawick 1921–2007 and Erving Goffman 1922–1982, among others) confronted the mathematical theory of information systems and defended the social aspects of human communication as a matrix that encompasses all human activities, a permanent social process that integrates intentional behaviour, with orchestral forms of verbal and non-verbal communication (i.e., kinesthetics, proxemics, etc.; Matterart pp. 51–54) [15]. This interest for the intentional aspects of communication gradually gave way to the theory of affordances [16].

Anthropologist Marcel Danesi, editor of the world's leading journal "*Semiotica*", sees semiotics as an interdisciplinary Web, following his mentor and collaborator Thomas Sebeok (1920–2001). This "Semiotic Web" provides the interconnectivity of sign systems not just in the milieu of cultural representations but also in nature, embracing recent cybernetic theories of embodiment and performance coming from biosemiotics and the neurosciences. In Sebeok's view, the term "semiology" only captured the anthropocentric part of the discipline [17]. Sebeok's ideas coincided with the development of cybernetics, defined by Norbert Wiener in 1948 as the scientific study of control and communication in the animal and the machine. The term "cybernetic" comes from Greek *kybernetike* meaning "governance" as well as "steering" (in navigation). Metaphors of navigation are frequently used when referring to moving within the encrypted codes of the World Wide Web. In contemporary Data Mining, semiotic modelling is used to map concepts into measurable variables through specific diagnostic criteria, and establish their specificity in relation to contextual interpretation. For instance, Sebeok's and Danesi's modelling systems theory (MST) distinguishes representations that include a singularized (sign), a composite (text) or cohesive form (code) [18, 19].

Ronald Stamper, a British pioneer in the field of semiotics as applied to informational systems, also stresses the importance of "signs" as fundamental units in computer science. Stamper incorporated Speech Act theory (i.e., Austin and Searle) in his *Organizational Semiotics methodology*. Methods for Eliciting, Analysing and Specifying Users' Requirements (MEASUR) is used to incorporate technical and social aspects of communication in data mining models corresponding to three fundamental domains: application domain (i.e., medicine), the computational domain (where mathematical codes correspond to concepts in the application domain), and the implementation or "empirical" domain (physical properties of sign and signal transmission and storage). This last aspect was added by Stamper to the traditional semiotic division of syntactic, semantic and pragmatic concerns, including a "social" level for shared understanding above the level of pragmatics [20].

Since the 1990s, with the advent of the digital revolution, the discussion has shifted towards the inclusion of tools and machines in human lives, and how new technologies might impact meaning making and operate as semiotic instruments, embodying the ghost in the machine. Contemporary trends in semiotics explore interactions between living systems, organisms and their environments, following the pioneering work of Jacob Von Uexküll (1864–1944). These approaches have culminated in perception-action (sensory-motor integration-mirror neuron structures) approach, which stresses the role of observers/users around the concept of "affordance" (experience from previous interactions with the world) and the active task-oriented sense-making anticipated by Gibson [16]. Instead of conceiving living systems in terms of their reactions to external stimuli, in these approaches, it is important to pay attention to their constructed internal model of the world and the relation between sensing, desiring and acting. Interestingly, Marx's spectre lucks behind the theory of affordances as it can be seen in the following passage.

"Since the relative form of value of a commodity—the linen, for example— expresses the value of that commodity, as being something wholly different from its substance and properties, as being, for instance, coat-like, we see that this expression itself indicates that some social relation lies at the bottom of it. With the equivalent form it is just the contrary. The very essence of this form is that the material commodity itself—the coat—just as it is, expresses value, and is endowed with the form of value by Nature itself. Of course this holds good only so long as the value relation exists, in which the coat stands in the position of equivalent to the linen. Since, however, the properties of a thing are not the result of its relations to other things, but only manifest themselves in such relations, the coat seems to be endowed with its equivalent form, its property of being directly exchangeable, just as much by Nature as it is endowed with the property of being heavy, or the capacity to keep us warm" (p. 66) [21].

Another spectre is that of Aristotle, who struggled to define the affordances of knowledge, truth and the "soul" in his *Nicomachean Ethics* (Book VI, Ch. 3). He spoke of *epistēmē* (1139 b 18–36) or universal knowledge, shared, circulated and preserved in cultural memory and heritage; *techne* (*Nicomachean Ethics* 1140 a 1–23), skills or capacities to accomplish tasks that operate on variable spheres, and related in chapter 4 to a trained capacity to create through reason (*logos*); and, in other words, knowledge of specific principles and patterns, and frequently translated as "craft" or "art" in its meaning of systematic use of organizational know-how or codified knowledge oriented towards intelligent human action. And finally, he also defined *phronesis* (*Nicomachean Ethics* 1140 a 24–1140 b 12) as a sort of practical wisdom and idiosyncratic knowledge that comes from life experiences as a result of trial and error; to some extent, it is intuitive and cannot be shared. Aristotle distinguished *phronesis* from *sophia* (theoretical wisdom, which involves epistemic reasoning) and held that these types of knowledge corresponded to three basic human activities: *theoria* (thinking), aimed at universal knowledge and truth, *poïesis* (making), whose end goal is production, and *praxis*, the objective of which is doing or action [6].

In recent discussions of Aristotle's *Rhetoric*, such as the collection edited by Alan G. Gross and Arthur E. Walzer (2000), *phronesis* is discussed in relation to an older quality, *metis* or conjectural intelligence, personal mode of knowledge encapsulated in practice, and popular in the Mycenae civilization, and attributed to figures such as Prometheus and Odysseus/Ulysses, the paragon of craftiness and cunning [22]. Drawing on work by Detienne and Vernant, *metis* has been found to exemplify and earlier form of world knowledge prior to the development of the synthesis of Platonist and Aristotelian models [5]. Carolyn R. Miller writes that this "conjectural worldview concerns the individual case, rather than universal knowledge, probability rather than certainty, qualitative rather than cumulative or quantifiable information, and inferential rather than deductive thought" (p. 138) [23].

Thus, rapidly shifting and disconcerting apprehensions of reality require both conjectural knowledge (*metis*) and practical intelligence (*techne*) targeted at concrete decisions. Some scholars (notably Stephen Gaukroger) have noted that when knowledge shifts occur, and a new cluster of concepts emerge. In the case discussed, the notion of *epistēmē* took over *metis* (p. 42) [24]. In the introduction to the thematic issue of the journal *Icono 14*, "Technopoïesis: Transmedia Mythologisation and the Unity of Knowledge" (2017), co-authored with Henry Sussman, we attempted to show, following Foucault's *L'Archéologie du Savoir* or Timothy Reiss among others [25, 26], the co-existence and shifting of different *epistēmēs* as power-knowledge systems, visible for instance in the transition that took place in the late medieval and early Renaissance Europe with the combination of Neo-Platonism and Aristotelianism [27].

In his contribution to the *International Handbook of Semiotics* (2015), Deely traced back to Aristotle the premodern background of the semiotic triangle and explained how translations overlooked certain expressions referring to a kind of collective consciousness (a hauntology?) prior to the development of individual self-awareness:

"In terms of the (lost) terminology, the *passiones animae* or "passions of the soul" are the forms of specification (*species impressae*) for developing thought which have their origin in the action of sensible things upon the senses, as these stimuli are *further* developed or shaped by the active interpretative response of the internal sense of memory, imagination, and estimation that together, or "collectively" constitute, on the side of animal Innenwelt, the foundations or basis (*species expressae*, or "phantasms") for the relations to the environment constituting the animal's objective world, the Umwelt" (p. 67).

As John Derbyshire's contribution to *The Spectator* (June 5, 2014), "Chasing down the Ghost in the Machine" shows the controversy on the seat of consciousness remains [28]. Writing also in 2014, semiotician Paul Cobley emphasizes the role of biosemiotics in challenging the mechanist worldview and placing consciousness in relation to nature and in a continuum with plant-animal existence. To Cobley, biosemiotics also serves to question the role of agency as inherently human and shows that different forms of agency can be found at very lower biological levels in the most rudimentary of organisms [29].

Introduced by Jakob von Uexküll (1936, 1937), the idea of Umwelt is pivotal in biosemiotics. For some scholars, it is the 'world' of signs which an animal *creates/inhabits* according to its sensorium. According to Sebeok, the Umwelt can be understood as a 'model' that allows an organism to survive (avoid predation, seek out comfort and nourishment, reproduce etc.) [30]. The perception-action shift has placed semiotics at the centre of phenomenal apprehension, and meaning making as a subjective mapping-function of (*interpreter*) intentionality and action-oriented survival. The object is also invested with perceptual-effector potentialities that capture interpretive action and reflect human desires [27].

The emphasis on performative models that stress the 'actant/agent/user' is also visible in relation to the tools and machines we use. Since the publication of Philip Johnson-Laird's theory of Mental Models, [31] there has been much discussion and use of the theory of "affordances" and mental models in human-computer interaction and usability, as shown in several paper in this volume, which address the debate between the compatibility of mental models and formal rules of inferential logic. In recent years, software tools capable of capturing and analysing the structural and functional properties of mental models are being designed [32]. The study of semiotics and the concept of "affordance" is relevant to these fields with regards to the semantic and pragmatic possibilities of task-oriented sense-making approaches, conceived in terms of their constructed internal model (*Innenwelt*-eventually *Umwelt* in biosemiotics), as applied to very different fields such as Psychology, Linguistics, Philosophy of Language or Computer Programming. The application of the concept of "affordance" in the context of human-machine interaction in Donald Norman's *The Design of Everyday Things* (1988) opened semiotics to areas involved in user-centred-design, manipulation interfaces, cognitive engineering, modelling systems, organizational semiotics, and so on, some of which are addressed in this volume. The complex relation of distinctive semiotic affordances (potentials and constraints for making meaning) intention, and intermedial variability, alongside questions of social usability in particular contexts, have caused the category of design to move into the foreground of attention in semiotics [33].

Since the 1990s, the widespread use of computer systems has contributed to the development of systemic approaches that contemplate knowledge as made of various (fractal) levels of communication structures; dynamic open systems with permeable interdisciplinary borders which include ideological, political, economic and axiological structures. Very importantly, because all human actions are increasingly performed by means of digital instruments, the changes point in the direction of a huge shift in the ontology of symbolization, involving the foundation of design, development, and evaluation of visualization systems from a semiotic perspective. Thus, the present volume includes various papers on Organisational Semiotics (OS) in Building Information Modelling (BIM), and Functional Requirements Classification Models and Operational Approaches to Conceptual Understanding.

Immersed as we are in the digital revolution, the pedagogic significance of images cannot be underestimated. The corpus of learning resources relies more and more on graphics, charts and icons than it ever did before. Once the amount of content in the World Wide Web has reached saturation levels, design practices are oriented towards the transformation of content and its replication (re-mediation/transmediation) in various semiotic multimodal formats. The image is possibly the most prominent one. Different gains and losses take place when the actions involved in using an artefact are captured onto an image, as it may happen in the context of teaching technological subjects such as physics or mathematics. Debates on the effects of these changes upon representation, and their impact on learning practices have ranged from views on the catastrophe of image-dominance for literary and cognition, to expressions of enthusiasm and attempts to elucidate the effects of the distinctive semiotic affordances (potentials and constraints for making meaning) amid diverse media formats. As pointed out above, the foregrounding of 'design' as a crucial semiotic category, also implies a conceptual shift from the idea of learning competences (in relation to specific educational practices conceived in terms of understanding and following particular conventions) to a focus on agency at both ends of the semiotic chain. Thus, various papers in the volume develop the topic of science education, conceptual change and teaching methods and approaches.

As a conclusion, this introduction has provided a framework for the papers included in this collection. A common thread is the delimitation of interdisciplinary borders at the material level of physical reality as well as in their semio-cognitive and cultural implications. Semiotics continues to provide a framework for emerging knowledge traditions, extending its limits to the non-human realm of biosemiotics and cybernetics, without completely disregarding the hauntings of the past. As body schema expands to its non-human and posthuman dimensions, we need to keep chasing the ghost in the machine.

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Section 2

Existential Semiotics and Mental Models

Semiotics of Conscience

Rufus Duits

Additional information is available at the end of the chapter

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Abstract

This chapter offers a long-overdue semiotic analysis of the phenomenon of conscience. It is remarkable that such an analysis has not yet been attempted, because conscience has always been understood as something like a voice signing, and not just unimportantly, but as the voice of God. One could well have expected that an analysis of conscience would have been first on the semiotician's tick list. Using Martin Heidegger's phenomenological analysis of conscience as a guide, it turns out that a simple Peircean analysis in terms of *representamen*, *object* and *interpretant* is at least a good way of opening the phenomenon up with the semiotician's tools. My conclusions point to the uniqueness of the sign of conscience among all signs. For it is one sign where all three moments—representamen, object and interpretant—*are the very same entity*. Given the existential semiotic reduction—without remainder—of the subject to a structured network of signs, one can then glimpse the extraordinary conclusion that in the phenomenon of conscience we encounter the signing of semiosis itself—the sign of signs. It is no wonder, then, that it has been understood to be the voice of God. I finish by developing the ethical ramifications of my analysis for semiotics.

Keywords: conscience, Heidegger, peirce, *enkratic* principle, existential semiotics

1. Introduction

It is very remarkable that a semiotic analysis of conscience has not yet been attempted. Conscience has always been understood as something like a voice signing—but not just any voice: it has largely been identified with the signing of the voice of God, expressing God's law, intentions, thoughts, etc., or the law of God 'written on our hearts'.[1] One may have thought, therefore, given its potential importance that it would have been first on the semiotician's

[1]Romans 2:15.

ticklist for analysis. In fact, quite the reverse appears to have been the case, and even moral philosophers, on whose conceptual territory conscience traditionally has been thought to lie, appear to have left the topic well alone over the last half-century. There has been very little in the way of comprehensive and systematic attempts to elaborate theories of conscience since Heidegger made it central to his existential analysis of *Dasein* in *Being and Time* [1].

This lacuna needs explanation. Langston [2], in his historical survey of theories of conscience, suggests that the turn away from faculty psychology left no room for conscience as a psychical component. But this is unlikely to be a sufficient explanation, because it is not necessary to posit conscience as a faculty, and, certainly, Heidegger's account in no sense at all attributes to the phenomenology of conscience anything like the properties of being a psychical component. I suggest, rather, that theorising about conscience became problematic largely because it had always been understood as a totalising and authoritarian phenomenon that the shift towards disseminated subjectivity, deconstruction of conceptual hierarchies, and suspicion of power relations found almost impossible to accommodate. Scepticism towards the authority of conscience has been compounded in the last decades by the terror wreaked by some claiming to 'follow their consciences'.

It may be thought to be paradoxical that Heidegger's existential epistemology, which roots knowing in *Dasein*'s modes of being, both contains a highly-developed theory of conscience, and at the same time sows the seeds of its conceptual demise. In fact, I will try to show that this paradox points at the heart of a renewed semiotics of conscience.

I will argue that the phenomenon of conscience points us towards the origin of semiosis and thus that a semiotic analysis of the phenomenon gives us insight both into the concept of conscience itself and into fundamental semiotic operations. I will also suggest that the analysis can open the way towards a genuinely ethical or critical theory of signs.

2. Heidegger: conscience as the call of being

Many of the most powerful tools of semiotic analysis derive from structuralist accounts of meaning. Conscience, I suggest, however, is a *sui generis* concept that cannot be embedded within the usual patterns of signification. As such, it lends itself much more appropriately to *phenomenological* rather than structuralist analysis. So I am going to use Heidegger's phenomenological account as a route of access for my own semiotic analysis. This route will make clear precisely why the tools of the structuralist are inapplicable here.

In *Being and Time* [1], first published in 1927, Heidegger makes the concept of conscience a centrally important component of his so-called 'existential analysis of *Dasein*'. I will take the term *Dasein* to refer, perhaps controversially, to the set of ontological preconditions that enable the experience of being as such and thus that enable the sort of experience that, among the animal kingdom, might be thought to be unique to humans: the sort of experience that accompanies *being-a-self*.

All of these preconditions are rooted fundamentally in the phenomenon that Heidegger describes under the title of 'care': *Dasein* is a being whose being matters to it, who cares about its being, who

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is concerned about how its existence or its life 'goes'. All our experience, according to Heidegger, is wholly determined by this basic characteristic; indeed, it is this characteristic that enables in the first place human experience. If it was not for our care for ourselves, we would have no experience—in the sense we have it—at all; things would not 'show up' for us in the way that they do. Of course, some other form of experience might be possible, the experience associated with the being of nonhuman animals, perhaps, but not that of the distinctively human animal. Things are disclosed to us, according to Heidegger, only within the horizons mapped out by the mattering of our concerns. Only insofar as we are concerned about something for the sake of ourselves can things connected in significance relations to that something first 'show up'. The hammer does not become an object of experience at all until it gets embedded in the relations of use that are organised around those goals of ours that can be accomplished by hammering—building a house, putting up a picture, etc. It may nevertheless be in our visual field—but we do not *see* it, that is, notice it, unless it takes a significance upon itself from the projects that we are committed to for the sake of ourselves. This is not simply to say that there would not be any hammers if we did not need to make them to use as tools to achieve certain projects that we might have. Even if there are hammers all around us, whether they are disclosed in our experience, and the significance that the bear if they are, is determined by the projects that we are engaged with in virtue of the fact that we are concerned about how our existence is going.

Conscience, as Heidegger describes it, turns out to be a 'primordial' result of the phenomenological structure of care. To see how, one needs beforehand Heidegger's concept of *angst*. The primordial anxiety that Heidegger refers to with this term is also a basic function of *Dasein*'s being as care: we are always worried about how our lives are going for ourselves; our existence is given over to us in such a way as to make us responsible for it, whether we like it or not. Anxious about anxiety itself, we 'flee' this ultimate concern into the relative safety and peace of other people's conceptions of what we should do and what values we should hold. To avoid having to take responsibility for ourselves, we 'fall prey' by allowing ourselves to become lost in the public discourse of 'the they'—of others in general. Such anxiety is awakened by the short amount of time we have before our deaths, and thus by the definitiveness of the projects we choose to act upon for defining who we amount to. To escape, we embrace what Heidegger calls an 'inauthentic' mode of being, defining ourselves dishonestly by the categories and values handed to us conveniently by others.

In the clamour of this everyday situation with its gossip and idle chatter, or, in semiotic terms, with its semiotic web of dissimulated and meaningless meanings, conscience is disclosed as an urgent and persistent *call*. Continuing the tradition of interpreting conscience as a voice, Heidegger analyses the phenomenon into three moments: the call (that is, the message), the caller and the one summoned by the call. Heidegger's key claim is that these three moments are all in fact one entity ontologically: *Dasein* as care. He writes: 'the caller is *Dasein* anxious…about its potential… The one summoned is also *Dasein*, called forth to its ownmost potential…And what is called forth by the summons is *Dasein*, out of falling prey to the they…' (p. 277[2]). And thus: 'The call of conscience…has its ontological possibility in the fact that *Dasein* is care in the ground of its being' (p. 278).

[2]Pagination here and henceforth is from the German edition (Sein und Zeit. Tübingen: Max Niemeyer Verlag; 2001).

The anxiety of care thus cuts both ways, it seems, for Heidegger, pushing us both to fall prey to others, and also to retrieve ourselves for an *authentic* mode of being that grasps clearly the responsibility we bear for ourselves which we are unable genuinely to escape from. The more we cover over our possible authenticity by immersing ourselves in the publicness of others, the 'louder' the call potentially is, since the disjunction between *Dasein*'s situation and its potential gets starker.

Thus, conscience, for Heidegger, is not a psychological faculty, added on, by whatever mechanism, to *Dasein*'s cognitive architecture to give it a moral compass for navigating a social environment; it is rather a fundamental necessity of its being, of any being that is like it ontologically. If *Dasein* had no conscience, it would have no experience of being at all; it would not be a site of the disclosure of a world. That is not to say that *Dasein* cannot be psychopathic; i.e., can feel no regret and no empathy in its mistreatment of others; but whether it is psychopathic or not, it is concerned for its being, and thus calls itself back from its flight away from its responsibility for itself.

Note that Heidegger is importantly wholly unspecific about the form of life that an authentic mode of being should take; if he were not, he would precisely not be describing an authentic mode of being that is chosen by *Dasein* itself in the full realisation of its responsibility for itself.

(It is worth remarking that the vocabulary of conscience slips out of Heidegger's texts after the publication of *Being and Time* in 1927. A 'call of being' remains, however, a continual refrain throughout his later texts. For illustration, take this powerful but enigmatic passage from his *Letter on Humanism* (first published in 1947): 'The human being is the shepherd of being. Human beings…gain in that they attain the truth of being. They gain the essential poverty of the shepherd, whose dignity consists in being called by being itself into the preservation of being's truth. The call comes as the throw from which the thrownness of *Dasein* derives' [3]. I have argued elsewhere [4] that the motif of the call of being retains all the conceptual import of the analysis of conscience in *Being and Time*, and thus that this figure of thought remains an integral part of Heidegger's thinking throughout his philosophical engagement).

3. The triune sign

In order to submit the concept of conscience to semiotic analysis, I will use Heidegger's pheno menological researches as a guide. Whilst this methodology may still, at this point, appear *ad hoc*, it will quickly become clear how conscience is a *sui generis* semiotic phenomenon that does not stand in the familiar relationships to other signs, and thus cannot straightforwardly be submitted to structuralist methods of analysis.

Peirce distinguished the following three elements of the sign: 1. the representamen—the sign vehicle, or form that the sign takes; 2. the interpretant—the sense conveyed by the sign; 3. the object—the referent that the sign stands for [5]. Applied to the concept of conscience as Heidegger's phenomenological analyses would have it, these distinctions yield:

1. The representamen/sign-vehicle is no word, no gesture, no grapheme. Heidegger rather insists: 'The call is lacking any kind of utterance. It does not even come to words, and yet it is

not at all obscure and indefinite. *Conscience speaks solely and constantly in the mode of silence*' (p. 273). This cannot mean, however, that conscience does not sign. Rather, in apparent contradiction to Hjelmslev's maxim 'there can be no content without an expression, or expressionless content; neither can there be an expression without a content, or content-less expression' [6], silence is its vehicle, its form of expression. Phenomenologically, talking of silence here, is not, of course, to assume that conscience could ever have been conceived by thinkers as making a *noise*. The point rather is to draw attention to the fact that the call of conscience *adds nothing more* to that which is there already as the concernful—that is, caring—being of *Dasein*. I.e., properly speaking, the vehicle of the conscience-sign just is *Dasein* as authentically concerned about its falling prey. It has no more form or content than that.

2. The interpretant/sense conveyed by the silent call of conscience is the inescapability and necessity of *Dasein*'s responsibility for its being about which it is ultimately concerned. The inauthentic mode of disclosure fails, ultimately, to hide this. Inauthenticity is, rather, revealed to be just one more way of taking care, albeit one that precisely tries to shirk its ultimate responsibility. What the sense of conscience thus amounts to, then, is just *Dasein*'s authentic liability.

3. The object/referent that the call of conscience stands for, or refers to, finally, is *Dasein*'s authentic mode of being, in which it takes care of itself in full realisation of its ultimate responsibility for its finite existence. This is the 'thing' to which the call of conscience inexorably draws attention.

In sum, then, for the conscience-sign, the sign vehicle, the sense and the referent of the sign *are all the same thing*: *Dasein* in its authentic mode. The moments of the conscience-sign are ontologically identical. This makes conscience, I suggest, unique among signs, *sui generis*; it is a *triune* sign.

It might be riposted that in this case it cannot be a sign at all, at least not in the traditional sense because a sign, at the very least, must refer to something other than itself. But this would be a difficult view to sustain: not only is it self-evident that in conscience something is given to understand, hence signified, and thus that there must be some semiosis going on; also, it appears plausible—as I have attempted to show—to separate out in the analysis of conscience the different moments corresponding to Peirce's triadic analysis of the sign. A semiotic analysis of conscience is possible. Thus, a better conclusion would seem to be that we have here a case of a liminal sign, a sign at the boundary of semiosis, a sign from the point at which semiosis begins or ends. A sign that stands right on the boundary of the 'unlimited semiosis' that weaves the semiosphere.[3] Conscience, I suggest, is a special sort of sign, but a sign nonetheless.

[3]Lotmann coins this very useful term in his [7], defining it as 'the semiotic space, outside of which semiosis cannot exist'. He conceives it as the set of structural preconditions of any semiotic operation at all: 'only the existence of such a universe-the semiosphere-makes the specific signatory act real.'

Interpreting conscience in this way, however, does draw into question Saussure's principle of the arbitrariness of the sign [8]. Once the signified and the signifier are united in the way indicated, there is no room for any arbitrariness in the representation of the sign: the call of conscience cannot in principle take any form other than that which it in fact takes. Again, however, this need not be propounded as a counterexample, so much as a limiting case. The conscience-sign is just especially dense, a sort of black hole of semiosis. On a Peircean taxonomy it could possibly be construed as a special sort of *indexical* sign, indexicals being, for Peirce, those signs that support a wholly non-arbitrary and thus natural or direct connection between the representamen and the object, and thus 'direct the attention to their objects by blind compulsion' [9]. The immediacy of 'blind compulsion' perhaps captures well the irresistible urgency of the summons of conscience. But unlike other indexicals, in the conscience-sign, not only is there such a direct relation between the representamen and the object as to be a relation of identity, the interpretant is also ontologically identical to its representamen and object. That it is semiotically *sui generis* is, I think, a more convincing conclusion.

It is also worth highlighting that in this account of conscience the emitter and the interpreter of the call are one and the same, too—albeit, for Heidegger, the same entity in different modes: 'the caller is *Dasein* anxious…about its potential… The one summoned is also *Dasein*, called forth to its ownmost potential' (p. 277).

4. Semiosis: a con-science analysis

Now since the unusual is often what best shows us what is usual, just as pathologies illuminate functional health, it is worth attempting to see what the possibility of the sort of sign that I have roughly suggested conscience to be indicates about the processes of semiosis and meaning in general.

In the first place, it is important to distinguish what could be termed internalist and externalist theories of conscience. An externalist theory would be one in which the originator of the conscience-sign would be something ontologically separate from the interpreter. Cardinal John Henry Newman's claim that conscience is the 'voice of God' [10] would be an example of the commitments of such a theory. On an account like this, conscience is interpreted by the agent to which the voice is addressed, but the voice itself originates from 'outside' the agent, in this case, in the agency of God. On Erich Fromm's two consciences theory, on the other hand, the authoritarian conscience derives from the external persona of the authority figure, and the humanistic conscience derives from humans' internal capacity for love, freedom and flourishing [11]. So this would be an example of a theory of conscience that is both internalist and externalist in different respects. For a purely semiotic account, however, this distinction is irrelevant, since we have only to do with the significance of the sign itself and its interpretation rather than the provenance or emission of it.

Suppose that Heidegger is right about the phenomenology of conscience as we outlined it above. In that case, it would appear that the conscience-sign arises at the intersection between two 'modes of disclosure': inauthentic and authentic being. In each of these modes, things, all things, are disclosed as determined in a particular way—either by the publicness of the 'they', or by *Dasein*'s 'ownmost' potential; that is, things take on a particular significance or meaning depending on how *Dasein*'s care for itself is manifesting itself. But as the two fundamental modes of disclosure, this must mean that *semiosis in general* is a function of *Dasein*'s concern for itself; i.e., significance as such is a particular and general result of the projects, cares, concerns, inclinations, motivations—and all those psychological phenomena that can go under the rubric of *desire* in its widest sense—that *Dasein* manifests. Derrida moots such a view in the opening section of *Of Grammatology* [12], despite his insistence that the structures of language are basic to meaning. Language acts as a repository of meaning, certainly, but it is not more, on this view, than a *medium* of the origination of meaning—not the originator itself. Heidegger saw the same thing: 'In this way language is the language of being, as clouds are the clouds of the sky. With its saying, thinking lays inconspicuous furrows in language. They are still more inconspicuous than the furrows that the farmer, slow of step, draws through the field' [13]. Language, even in its widest sense of semiosis in general, is not ontologically prior to meaning and signification; it is rather the system or expression of significance and meaning that itself is grounded in human concern for self. It is the latter that first makes possible humans' particularly human experience. The cares that humans have and the projects grounded therein thus first make semiosis possible, and sustain it. Language merely records its particular configurations for posterity.

On this view, Saussure's proposal of a general theory of signs [14], then, would amount to a semiotic equivalent of Heidegger's phenomenological 'existential analyses'. Here, Heidegger interprets the 'world' of *Dasein*'s experience in terms of the networks of meaning generated by *Dasein*'s concernful projection onto future possibilities of action, projections which express its concern for itself. For example, the thing becomes significant as a hammer only within the context of the potential hammering-uses with which *Dasein* might concern itself: putting up a house for shelter, putting up a work of art to appreciate, etc. Wholly independent of these sorts of concern, the thing cannot *be* a hammer at all. The linguistic sign 'hammer' functions, on the other hand, merely as the fixer, not the determiner, of this web of potentialities, enabling the communication, by conventional codes, between *Daseins* of the hammer's significance to its concernful being-in-the-world.

The two fundamental modes of disclosure—authenticity and inauthenticity—amount thus to two basic determinations of the semiosphere as a whole: authentic and inauthentic semiosphere. If conscience is the sign that discloses to inauthentic *Dasein* the mode of being of authenticity, then we are warranted in drawing the following stark conclusion: *conscience is the signing of semiosis as such, the sign of signs*. It reveals the entirety of the semiosphere as determined inauthentically or authentically. It would be for this reason that it is a sign *sui generis*; it stands above and apart from the semiosphere as the sign which represents the semiosphere itself to concernful thinking and communication, thus imbuing it with an overarching meaning. It is the vertical limit, the stopping point, so to speak, of 'unlimited semiosis' that is only unlimited 'horizontally'. There is a sense then, insofar as it *transcends* the signing-process whilst signing itself, that is it analogous to the *voice of God*, at least to the extent that it performs the function of ultimately determining the semiosphere's overriding meaning. Just as the concept of the voice of a transcendent God is oxymoronic, so the sign of conscience is both sign and beyond signification as its ultimate arbiter.

The same conclusion can be reached from a different direction. Our semiotic deployment of Heidegger's insights produced the result that *Dasein* in its authentic mode is the representamen, the object and the interpretant of conscience all at once. But given our phenomenological interpretation of semiosis in terms of *Dasein*'s concernful disclosure, and given the existential semiotic reduction—without remainder—of the subject to a structured network of signs (Duits, Tarasti et al. [15, 16], but also Derrida, Barthes, etc.), there is nothing else for conscience to sign but the semiosphere as such. *Dasein* can be construed as reducible without remainder to the possible structures that conform the semiosphere. Thus, the authentic *Dasein* signified in conscience is not ontologically distinguishable from the structures that conform authentic semiotic disclosure. Conscience must be construed to signify the semiosphere such as it authentically is.

5. Towards ethical semiosis

In this final part, I want to point towards what I take to be the possibility of a genuinely ethically engaged semiotics that is rooted in this conclusion. The hope is that this would amount adequately to a *critical semiotics*, a semiotics with the conceptual resources to justify claims critical of systems of signs, of processes of semiosis, of individual signs and of the semiosphere as such, and thus to point towards better semiotic alternatives.

The normativity of conscience, I suggest, binds *Dasein* in two distinguishable aspects: as *interpreter* and as *agent*.

5.1. *Qua* interpreter

In the first place, it is important to be clear about the nature of the normative demand that conscience makes. Heidegger, as we have seen, construes it as a 'summons' to the authentic mode of disclosure. A summons, in the usual sense, has judicial power behind it; in this case, however, rather than being summoned to face judgement, the summons constitutes the judgement. But what is the justification for the summons? What is its warrant? Why should *Dasein* obey? The answer for Heidegger is that *Dasein*'s being as *care for itself* cannot but both summon and heed the summons; it cannot ultimately tolerate its lostness in the 'they'. Its call is warranted because *Dasein* of necessity accepts the presupposition on which it is based: that *Dasein* cares about its existence. But such a conception runs into obvious difficulties connected to the rigor of this binary opposition authentic/inauthentic. For example, what if *Dasein* authentically decides—that is, decides with the finitude and facticity of its life wholly disclosed to it—to lose itself in the 'they'? What should we call *Dasein* then—authentic or inauthentic? Or authentically inauthentic? Secondly, if the warrant of the call of conscience is constituted by *Dasein*'s concern for itself, then does not *Dasein* have to be already in the mode of being of authenticity in order that the call be made? For if *Dasein* were wholly inauthentic it would be no longer concerned with its being as such.[4] Is it the case, then, that *Dasein* is

[4]Stephen Mulhall pursues this point in detail in his [17].

authentic as such? But then Heidegger insists that inauthenticity is the mode of being that *Dasein* inhabits always already and for the most part. Must it not be the case then, that *Dasein* is better understood as being in both modes simultaneously? A better picture, I suggest, might see authenticity and inauthenticity not as two exclusive modes, but as two poles of a continuum on which the more *Dasein*'s semiosphere is configured in accordance with *Dasein*'s ultimate projects, the closer *Dasein* is to authenticity—ultimate projects being those aspects of *Dasein*'s motivational set that are conformed in full realisation of its being-towards-death. In this way, *Dasein*, as concerned being-a-self, would continually be summoned towards the 'outer layers' and a 'greater perspective' of semiotic disclosure. And this summons would be conscience. The significances of any 'inner' layer would be able to be criticised from the perspective of a more authentic 'outer' layer; criticised, in the light of *Dasein*'s self-concern, in terms of their justifiability.

An example would help here. Suppose, perhaps heeding Barthes' analysis in *The Fashion System*, I am enthralled by fashionable clothes [18]. There is no doubt that such clothes and the various forms of media, publication and celebrity concerned with them constitute an intricate semiotic web. Nonetheless, allowing my purchasing power, my sense of self-identity, the comfort—both physical and emotional—I feel in the presence of others, etc., to be so thoroughly determined by this semiosis might be something that, from a more fundamental perspective on the possibilities of my life, I may object to. On the other hand, I might not; I might decide, from an authentic perspective, that the fashion system is what I want to devote my life wholeheartedly to. In any case, the possibility of criticism is opened up. Beneath entire systems of meaning, individual signs may be subject to criticism from the same account. Suppose I construe myself authentically as post-gender, or as post-nationality, etc. I may find wholly unhelpful and to be avoided the application of the signs 'male' and 'female', the adjective 'English', etc. I may want to resist carving the world up in this way. And this may be true both in regard to myself and in regard to others. I may take signs such as 'Jew' or 'Muslim' to connote in my culture in a way incompatible with a more authentic perspective on human being that I endeavour to maintain.

5.2. *Qua* agent

So much for the normativity of *Dasein* insofar as it interprets and discloses. *Qua agent*, *Dasein* must also heed the summons. Lacan [19] uses the term '*objet petit a*' to refer to the object of desire that is so 'scopically' basic such as to constitute the subject as such. Without wishing to do too much violence, either to Lacan's concepts or to Heidegger's, I think that this concept can be usefully imported into a discussion of the ethics of authenticity. The Heideggerian conscience—just like Lacanian psychoanalysis—is really telling us never to give up on our ultimate desire, to be resolute in our projection onto the possibilities of being that are chosen in the light of authenticity. This is the existential imperative, the *enkratic* principle. The *objet petit a*, the telos of such ultimate projects, configures the semiosphere as the lack around which it is arranged. Conscience thus calls for a particular semiotic configuration that it is up to us to realise as embodied *agents* in a factical world. I.e., the disclosure that the call of conscience is calling forth is one that our actions are required to realise, as the means to our ultimate *teloi*.

In the language of practical reasoning—more familiar to moral philosophers—, conscience, on the analysis I have proposed, summons us *qua* agents to do *that which we take ourselves to have overriding reason to do*. Our ultimate desires, configured psychoanalysis tells us, around the ultimate ends of our subjectivity, ground reasons for acting in ways to attain or realise those ends. On this broadly instrumentalist account of practical reason, the more fundamental a desire is, the more overriding the reasons it grounds. The *objet petit a*, as the end of our ultimate desire, thus provides us with reasons for action that override all other reasons for action that we might have. Whilst what we take ourselves to have reason to do might not be the same as what we actually have reason to do (this is the thrust of the ferocious contemporary debate between 'externalism' and 'internalism' about practical reason in moral philosophy), conscience, as the call resulting from the *internal* configuration of subjectivity, takes no notice of this: it calls us to do what *we take ourselves* to have overriding reason to do.

5.3. The everyday notion of conscience

It may be rejoined that the analysis of conscience we have given misses many of the phenomenological facts that are captured by the ordinary or everyday notion of conscience. It may be said that, no matter for what has been given so far, a semiotics of conscience must also capture the notions of guilt, of bad conscience, of the generally moral nature of conscience, as well as the fact that the call of conscience seems to sound only with regard to *specific deeds*—not all the time, or continually, as the analysis we have presented so far might seem to indicate. Certainly, a semiotic account of these everyday features of the notion of conscience needs to be given if our analysis is to be considered in any way comprehensive. Again, we can follow Heidegger's lead here; he clearly distinguishes the existential interpretation of conscience from its 'vulgar' interpretation.

There are two ways in which the everyday notion of conscience and the existential interpretation might be related. On the one hand, one could argue that there is in fact more than one type of conscience—a plurality of consciences. Or, alternatively, one might argue that the everyday interpretation is the inauthentic disclosure of the existential call of conscience. Perhaps unsurprisingly, it is the latter that Heidegger proposes.

On this account, everyday, or inauthentic, *Dasein* misconstrues or misinterprets the conscience-sign. Our semiotic tools give us a new way of characterising this mistake that *Dasein* makes. For the everyday notion of conscience:

1. The representamen/sign-vehicle is a specific utterance: 'You should not have done that!' Its specificity does not mean that it actually comes to language and breaks the mode of silence; rather its specificity serves to conceal what is authentically disclosed in conscience, namely, *Dasein* as authentically concerned. *Dasein* is thus misled to focus, using language familiar from the later Heidegger, on beings, things, rather than on its being as such.
2. The sense/interpretant is the *badness* or *wrongness* of the deed that was done, the sense that *Dasein* has been *immoral*, and done something *impermissible*. *Dasein ought not* to have done it.

Thus *Dasein*'s responsibility is alluded to, but not in the sense of its responsibility for its being as such, but rather, merely, in the sense of its responsibility for a particular being—the deed that it ought not to have done.

3. The object/referent is *Dasein*'s impermissible deed itself, whatever it might have been. This is what the everyday conscience-sign is drawing *Dasein*'s attention back to.

Several important conclusions can be drawn from this analysis of the everyday conscience-sign. In the first place, it is clear how significant the misunderstanding of the conscience-sign of inauthentic *Dasein* is. It is significant enough for it to totally dissimulate the original sense of conscience and thus conceal the urgency of retrieving itself from the 'they'. Structurally, this dissimulation operates by breaking up the original ontological unity of the semiotic moments of the conscience-sign. In its everyday version, the semiotic moments are differentiated such that the sign becomes *just one sign among others*, a standard Peircean symbol, rather than *sui generis* and triune. Its special particularity and urgency is thereby lost. In Heideggerian language, being as such is concealed in favour of the disclosure of particular beings. Given the semiotic account above, it could be added: semiosis as such is concealed in favour of particular semiotic events. Thus the proper significance of the conscience-sign collapses. Calling it the 'voice of God' only serves to compound, rather than to overturn, the dissimulation.

This is not a random misfortune for *Dasein*, argues Heidegger. Rather, it is one way that *Dasein* copes with the anxiety it experiences about its responsibility for itself. Its responsibility for its being as such is dissimulated to resemble a liability for a mere deed, which is at least superficially comforting for *Dasein*. The conscience-sign is deliberately, if not consciously, misunderstood—a misunderstanding which is just another way of *Dasein* caring for itself. *Dasein* cleverly, if unknowingly, figures out a way of avoiding having to heed the conscience-sign as it authentically signs.

Given the moral connotations of the everyday conscience-sign, the foregoing analysis warrants a comment on the status that should be afforded to moral thinking. Suppose the *enkratic* principle as outlined above conflicts with the demands of morality as ordinarily understood—i.e., suppose, for any given agent, that the former prescribes one action, whilst the latter prescribes another, and the given agent cannot pursue both. What should the agent choose? Whilst we may not be in a position to answer this question decisively, it can at least be pointed out that the normativity of the call of conscience *subtends* the normativity of ordinary morality, since whilst the agent may have good reason to adhere to the demands of ordinary morality, whatever they may be in any given situation, the agent has, on the account above, an *overriding* reason to adhere to the prescriptions of its ultimate concerns. In other words, it will always be more *rational* for the agent to heed the authentic call of conscience above considerations of ordinary morality if there is ever a contradiction between the two. The *enkratic* principle is thus more fundamentally binding than any ordinary moral principle could be. Indeed, on this account, ordinary morality might tend to appear, as Heidegger thought, as a dissimulation of the authentic normativity of existence.

6. Concluding remarks

In conclusion, the semiotic analysis of the conscience-sign has revealed its uniqueness and importance amongst signs. This has made the lacuna of it being ignored hitherto by semioticians all the more striking and curious. Heidegger, of course, traced this sort of ignorance in every instance back to the inevitable inauthenticity of everyday thinking, even of the most rigorous philosophical thinking. It has also disclosed fertile paths for new research:

It indicates that the source of semiosis as such is our concern for ourselves. Daniel Chandler begins his well-known introductory text on semiotics with the words 'We seem as a species to be driven by a desire to make meanings' [20]. And this is characteristic of what could be construed to be the semioticians most basic mistake: it is not that we desire to make meanings; rather, *we desire—and that creates meanings*. Concern is the origin of semiosis. Elsewhere, I have tried to reduce semiotic configurations down to their original starting points in the teleological schemes that are grounded by such concern [21].

It also opens up the possibility of an ethically engaged semiotics that can propound fundamental normative justifications. Indeed, once conscience has been legitimately construed as the signing of signification as a whole, it is not clear how semiotics can avoid becoming ethical—in the sense of critical. That it has endeavoured, by and large, to remain purely 'theoretical', practically neutral, is, on this account, not a strength but a weakness. Understanding that processes of semiosis are always rooted in concern for self and that concern for self has essentially a normative dimension or aspect compels a way of thinking about semiotics that is inherently critical. In this case, the semiotic analysis of conscience has the potential to reorientate fundamentally semiotics research.

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Chapter 3

Mental Models are Compatible with Logical Forms

Miguel López-Astorga

Additional information is available at the end of the chapter

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Abstract

The mental models theory is a current cognitive approach claiming that human intellectual activity is essentially about semantic possibilities and that syntax and logical form are not relevant. Many experimental results support this theory and its predictions. So, it appears to be justified to assume its main theses. However, in this paper, I argue that the acceptance of the mental models theory does not necessarily have to lead to a rejection of logical forms. Clear relationships between the theory and standard logic can be easily found, and I try to show this in two ways. On the one hand, I claim that the models that the theory assigns to sentences are compatible with truth tables. On the other hand, I also defend that the definitions of a connective by means of another one that can be given in standard logic hold in the mental models theory too, since the sentences that are equivalent in the former have exactly the same models in the latter.

Keywords: logical form, mental models, semantics, standard logic, syntax

1. Introduction

The mental models theory (MMT) is a very important framework explaining human reasoning. Its main theses are to be found in many works (e.g., [1–14]). However, the most important aspects of it for this paper are related to language. The theory states that what is most relevant to individuals in a sentence is its content and meaning and not its syntax or its logical form. This is so because people reason and make inferences mainly reviewing the semantic possibilities that can be attributed to sentences, and not considering their formal structure.

MMT has become a very successful theory, since many experimental results seem to support its assumptions and confirm its predictions. Indeed, it appears to be able to account for human reasoning in a way in principle impossible for standard propositional calculus. True, the natural deduction system proposed by Gentzen [15] cannot explain certain usual responses given by people in reasoning tasks. For example, in that calculus, there is a rule that people do not often use. That rule is the disjunction introduction rule, that is, the one that enables to infer a formula such as [p ∨ q] (where ∨ stands for disjunction) from a formula such as [p], and, as said, individuals do not apply it in many occasions (e.g., [13]). Another example can be the difficulties related to the principle of explosion (*ex contradictione quodlibet sequitur*). Following standard calculus, given a contradiction such as, for instance, [p ∧ ¬p] (where ∧ represents conjunction and '¬' is negation), every formula that one can imagine can be derived, and this is something that, obviously, people do not usually do (e.g., [5], p. 204) And a third case can be that of the infinite conclusions that can be built in standard calculus. In this calculus, from a formula such as, for instance, [p ∧ q], an indeterminate number of formulae can be derived, some of them being, for example, [p ∧ q ∧ q], [p ∧ q ∧ q ∧ q], [p ∧ q ∧ q ∧ q ∧ q], and so on (e.g., [9], p. 202).

Of course, more examples of problems of standard logic in explaining human reasoning can be given. However, what is important for this paper is that, as shown below, MMT proposes a framework in which those problems either disappear or make no sense. I will not challenge this fact here. My basic aim is just to argue that although MMT is assumed, that does not in general mean that logic and logical forms have to be ignored, since it is easy to find correspondences between the combinations of possibilities that MMT assigns to some of the traditional connectives in standard logic (e.g., the conditional, conjunction, and the inclusive disjunction) and the truth values and the definitions that this last logic attributes to those same connectives. Actually, this idea is not absolutely new. In papers such as, for example, those of López-Astorga [16, 17], work in a similar direction has already been done. However, in this paper, I will try to indicate the relationships between MMT and standard logic in a clearer and more obvious way.

Thus, to achieve my goals, I will begin by describing the general theses of MMT that are relevant for my argumentation, that is, its general theses on connectives such as the conditional, conjunction, the inclusive disjunction, and their negations. Then, I will show that the possibilities or models that, following MMT, correspond to those connectives and their negations are evidently compatible with the truth tables in standard logic for those very connectives and their negations. Finally, I will also propose that the models that MMT assigns to the aforementioned connectives are consistent with the definitions of them by means of other connectives that are valid in standard logic as well. So, the first section is about some general theses of MMT.

2. MMT, some logical operators, and their negations

As said, logical form is ignored by MMT [5]. According to it, what is interesting in language and reasoning is just the combinations of semantic possibilities, which are in general called 'models' by the theory, related to every sentence. However, the word 'semantic' does not have in this theory the same meaning as in standard logic. In describing a model, letters such as 'p' or 'q' can be used, but just to shorten. Based on theses such as those of Peirce [18], MMT claims that the models are 'iconic', and that they reproduce the complete structure of a situation in the world (e.g., [6], pp. 135–136; [9], p. 207).

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Another important point of the theory is that it states that people do not always identify all the models that can be linked to a sentence. To detect all of them, it is necessary to make certain effort, and individuals do not often make enough effort (see, e.g., [6], p. 138, Table 9.2). Nevertheless, for simplicity, I will work here only with ideal circumstances in which individuals identify all of the possible models. Likewise, I will use a form to express the models different from the usual form of MMT. The reason for this is just that the form that I will use here enables to make the equivalences to standard logic explicit in a clearer way. Usually, the theory describes the different models or semantic possibilities as follows:

(I) p q

(II) p ¬q

(III) ¬p q

(IV) ¬p ¬q

Obviously, [I] represents a possibility in which both [p] and [q] happen. In [II], [p] happens but [q] does not. Exactly the opposite occurs in [III]: [p] does not happen and [q] does. Finally, in [IV], neither [p] nor [q] happens. Thus, for example, if [p] means that 'Johns is smart' and [q] that 'John studies', [I] refers to a scenario in which John is smart and studies, [II] denotes a situation in which John is smart but he does not study, [III] is the case in which John is not smart but he studies, and [IV] shows the circumstance in which neither John is smart nor he studies.

But, as stated, I will refer to these possibilities in a way that will allow a smoother writing. That will be this one:

(I) (p, q)

(II) (p, ¬q)

(III) (¬p, q)

(IV) (¬p, ¬q)

There is no doubt that the use of brackets and commas will make it possible that the writing is not continually interrupted and the sentences are not constantly cut. And, in this way, the complete sets of possibilities that, based, for example, in Table 9.2 in Ref. [6], p. 138, are attributed by the theory to the mentioned connectives that can be expressed in this simpler manner:

Conjunction, that is, 'and' in sentences of the type 'p and q', for example, 'John is smart and he studies': (p, q).

Conditional, that is, 'if… then…' in sentences of the type 'if p then q', for example, 'if John is smart then he studies': (p, q); (¬p, q); (¬p, ¬q).

Inclusive disjunction, that is, 'either… or… or both of them' in sentences of the type 'either p or q or both of them', for example, either John is smart or he studies or both of them: (p, q); (p, ¬q); (¬p, q).

As far as the denied sentences are concerned, MMT provides a method to detect its models: taking into account the set consisting of [I]–[IV], the missing model(s) in the positive form of the sentence is (are) the model(s) of the negative form of that very sentence (see, e.g., [10, 11]). Accordingly, the complete sets of possibilities corresponding to the denials of the previous connectives are these ones:

Denied conjunction, that is, the case of the sentences of the kind 'it is not the case that p and q', for example, 'it is not the case that John is smart and he studies': (p, ¬q); (¬p, q); (¬p, ¬q).

Denied conditional, that is, the case of the sentences of the kind 'it is not the case that if p then q', for example, 'it is not the case that if John is smart then he studies': (p, ¬q).

Denied inclusive disjunction, that is, the case of the sentences of the kind 'it is not the case that either p or q or both of them', for example, 'it is not the case that either John is smart or he studies or both of them': (¬p, ¬q).

In this way, with all this machinery, MMT can explain the habitual response that people give in most of the reasoning tasks used in the cognitive science literature. For example, given an inference with the premises 'if p then q' (e.g., 'if John is smart then he studies') and 'not-q' (e.g., 'John does not study'), if all of the models of the conditional are detected, that is, (p, q), (¬p, q), and (¬p, ¬q), it is only possible to infer 'not-p' ('John is not smart'), since 'not-q' appears only in the third model, that is, in [IV], and, in that model, 'not-p' appears too and 'p' does not appear (see, e.g., [1], p. 283).

Likewise, MMT can also account for the reasons why the disjunction introduction rule is not usually applied. People do not deduce 'either p or q or both of them' (e.g., 'either John is smart or he studies or both of them') from a premise such as 'p' (e.g., 'John is smart') because, as indicated, the former refers to the models (p, q), (p, ¬q), and (¬p, q), and, as it can be noticed, in the third model, that is, in [III], the premise 'p' is false ('not-p' appears). So, contrary to what standard propositional calculus provides, from a premise, in principle, it is not possible to draw a disjunction in which that same premise is one of the disjuncts, since the disjunction is related to a possible scenario in which the premise is false (see, e.g., [13]).

Furthermore, it is clear that problems such as that of the principle of explosion or that of the possibility to derive infinite conclusions, as said, make no sense in this framework, as, simply, those kinds of deductions are not possible given the semantic machinery of MMT. However, another relevant concept of the theory further stresses the important role that semantics plays in the human intellectual activity. That is the concept of modulation. Modulation is 'the process in the construction of models in which content, context, or knowledge can prevent the construction of a model and can add information to a model' ([9], p. 202). This certainly means that semantics or pragmatics can remove some models, make other models hard to identify, and better describe other models. An example can be useful to show how modulation works. Let us consider this conditional sentence:

'If the workers settle for lower wages then the company may still go bankrupt' ([8], p. 663, Table 4).

Because the structure of this sentence is 'if p then q', one might think that, given 'not-q', that is, in this case, 'the company does not go bankrupt', 'not-p', that is, 'the workers do not settle for lower wages', should be concluded. Nevertheless, this is not so for this sentence, since modulation modifies the models corresponding to it. Now, the models are not the previous ones mentioned for the conditional in general, but (p, q), (p, ¬q), and (¬p, q). The reason is evident: (¬p, ¬q) is not a possibility for this conditional because it is not possible that 'the workers do not settle for lower wages', that is, 'not-p', and, at the same time, 'the company does not go bankrupt', that is, 'not-q.' On the other hand, (p, ¬q) must be added because it is possible that 'the workers settle for lower wages', that is, 'p', and that, at the same time, 'the company does not go bankrupt', that is, 'not-q.' In this way, the final result is that, given the conditional and the information that 'not-q', 'not-p' cannot be derived, since, in this particular case, the only model in which 'not-q' appears is a model in which 'p' appears too (see, e.g., [8], p. 663, Table 4; [19], pp. 287–288).

Obviously, all this demonstrates that MMT has a great potential and that, as stated, can account for most of the answers that people often give in reasoning tasks. And, as also indicated, these facts will not be challenged in this paper. My intention is only to show that this theory does not lead necessarily to a rejection of syntax and logical forms as important parts of human communication and thought. In this way, in the next section, I will argue that the models assigned by MMT to the connectives reviewed are clearly consistent with the truth tables of standard logic. As also said, to make the explanation clearer and simpler, I will only consider ideal situations in which all the models of a sentence are detected. In the same way, and for the same reason, I will ignore the situations in which the models change because of modulation as well.

3. The combinations of possibilities of MMT and the truth tables

Really, it is almost trivial to claim that the models of conjunction, the conditional, the inclusive disjunction, and their denials are related to the truth tables of standard logic, since it is evident that such models correspond to the cases in which the logical structures to which they are attributed are true in a truth table. Nonetheless, it can be interesting to make this explicit in order to show that, indeed, it is necessary to acknowledge the role played by logical form even though the main theses of MMT are correct.

A first important point in this regard is that, following papers such as, for example, those of López-Astorga [16, 17], the different combinations of possibilities can be transformed into well-formed formulae of standard logic by means of conjunction. It is enough to link their elements with a conjunction and consider them to be conjuncts of that conjunction. Thus, [I]–[IV] can be transformed into these formulae:

(I) $p \wedge q$

(II) $p \wedge \neg q$

(III) $\neg p \wedge q$

(IV) $\neg p \wedge \neg q$

This clearly means that it can be thought that there are logical forms related to the models of MMT. However, even one more step is possible. Following, in the same way, the general theses provided in papers such as those cited, given that the models are really possibilities, they can be linked in turn by means of disjunction. For instance, if the models of the conditional correspond, according to what has just been said, to the formulae [p ∧ q], [¬p ∧ q], and [¬p ∧ ¬q], it can be stated that its models set can be expressed by means of this more complex formula: [(p ∧ q) ∨ (¬p ∧ q) ∨ (¬p ∧ ¬q)]. This clearly makes sense, since, because the models are, as indicated, possibilities, it is not hard to consider them to be disjuncts in a disjunctive formula (remember that, in a disjunction, only one disjunct needs to be true).

But, if this is so, the correspondences to standard logic are obvious. As mentioned, the formula that can be assigned to the conditional is [(p ∧ q) ∨ (¬p ∧ q) ∨ (¬p ∧ ¬q)], and this last formula and [p → q] (where → stands for conditional relationship) are true in exactly the same cases in standard logic. Indeed, if, as, for example, in López-Astorga [16, 17], we assume that 'v(α)' refers to the truth value of [α], it can be claimed that

$$v(p \rightarrow q) \ = \ v[(p \wedge q) \vee (\neg p \wedge q) \vee (\neg p \wedge \neg q)] \tag{1}$$

And this is evident because v(p → q) = 0 if and only if v(p) = 1 and v(q) = 0 (where '0' denotes that the formula is false and '1' represents the case in which the formula is true), and, in the same way, v[(p ∧ q) ∨ (¬p ∧ q) ∨ (¬p ∧ ¬q)] = 0 if and only if v(p) = 1 and v(q) = 0 as well.

On the other hand, if we think about conjunction, all of this is even clearer. The reason is that, if the model of conjunction is transformed into a well-formed formula of standard logic in accordance with what has been indicated, the result is a formula that exactly matches the way conjunction is expressed in this last logic: [p ∧ q]. Thus, there is no doubt that

$$v(p \wedge q) \ = \ v(p \wedge q) \tag{2}$$

Furthermore, as it is well known, v(p ∧ q) = 1 if and only if v(p) = 1 and v(q) = 1, and this seems to apply to both the formula in standard logic and the model in MMT.

In connection with disjunction, its formula would be, obviously, [(p ∧ q) ∨ (p ∧ ¬q) ∨ (¬p ∧ q)], and, again, it is clear that

$$v(p \vee q) \ = \ v[(p \wedge q) \vee (p \wedge \neg q) \vee (\neg p \wedge q)] \tag{3}$$

In both cases, the value of the formula is 0 if and only if v(p) = 0 and v(q) = 0.

As far as denials are concerned, the situation is not different. Based on the accounts and arguments above, it can be said that the negated conjunction can be related to a formula such as [(p ∧ ¬q) ∨ (¬p ∧ q) ∨ (¬p ∧ ¬q)], and equivalence is evident here too, since

$$v[\neg(p \wedge q)] = \ v[(p \wedge \neg q) \vee (\neg p \wedge q) \vee (\neg p \wedge \neg q)] \tag{4}$$

Indeed, these two formulae are false in just a circumstance: if and only if v(p) = 1 and v(q) = 1.

With regard to the denied inclusive disjunction, the formula would be hence [¬p ∧ ¬q], and once again

$$v[\neg(p \vee q)] \;=\; v(\neg p \wedge \neg q) \tag{5}$$

Both $v[\neg(p \vee q)] = 1$ and $v(\neg p \wedge \neg q) = 1$ if and only if $v(p) = 0$ and $v(q) = 0$.

Finally, the case of the negated conditional is not difficult either. Its formula is clearly $[p \wedge \neg q]$ and it is also clear that

$$v[\neg(p \rightarrow q)] \;=\; v(p \wedge \neg q) \tag{6}$$

There is only one scenario in which these two last formulae can be true: if and only if $v(p) = 1$ and $v(q) = 0$.

So, given these arguments, it is hard to hold that the models of MMT have nothing to do with standard logic and its logical forms. It is true that, from critical perspectives, it has already been said that MMT reproduces the truth tables of standard logic (e.g., [20]). However, the difference between this paper and such perspectives is that this paper is not so critical of MMT. It assumes its main theses and only tries to show that those theses do not actually lead, as its proponents often claim, to a rejection of logical forms. In this section, I have shown that, true, very simple logical forms (in which only negations, conjunctions, and disjunctions are included) can be attributed to the models of MMT. Nevertheless, this idea is further supported in the next section, in which I argue that the definitions of the logical operators by means of other different logical operators that are correct in standard logic are also valid in MMT.

4. The definitions of the logical operators and MMT

Certainly, standard logic enables to define each logical connective linking two clauses by means of any other connective along with the negation. Thus, in the case of the conditional, these definitions hold:

$$p \rightarrow q \;=_{df} \neg(p \wedge \neg q) \;=_{df} \neg p \vee q \tag{7}$$

(e.g., ‘if John is smart then he studies’ is equivalent to both ‘it is not the case that John is smart and he does not study‘ and ‘either John is not smart or he studies or both of them‘).

The reason is, of course, that, according to the truth tables in this logic,

$$v(p \rightarrow q) \;=\; v[\neg(p \wedge \neg q)] \;=\; v(\neg p \vee q) \tag{8}$$

But this leads us to another important point about MMT, since the model sets that can be assigned to the expressions in natural language with these three logical structures are, in principle, the same. As said, the models of $[p \rightarrow q]$ are (p, q), $(\neg p, q)$, and $(\neg p, \neg q)$, and these are the same as those of $[\neg(p \wedge \neg q)]$ and $[\neg p \vee q]$. Indeed, if the only model of $[p \wedge \neg q]$ is $(p, \neg q)$, the models of $[\neg(p \wedge \neg q)]$ must be, as explained, the remaining ones, that is, (p, q), $(\neg p, q)$, and

(¬p, ¬q). Likewise, the models of an expression such as [¬p ∨ q] are clearly (¬p, q), (¬p, ¬q), and (p, q), that is, in different order, again, the same as those of the conditional.

But something similar happens to the definitions corresponding to conjunction. Those are the following:

$$p \wedge q =_{df} \neg(p \rightarrow \neg q) =_{df} \neg(\neg p \vee \neg q) \tag{9}$$

(e.g., 'John is smart and he studies' is equivalent to both 'it is not the case that if John is smart then he does not study' and 'it is not the case that either John is not smart or he does not study or both of them').

Here, it is true too that

$$v(p \wedge q) = v[\neg(p \rightarrow \neg q)] = v[\neg(\neg p \vee \neg q)] \tag{10}$$

Nonetheless, what is actually interesting about this for this paper is that while [p ∧ q] has just a model, (p, q), that is, exactly the only model of both [¬(p → ¬q)] and [¬(¬p ∨ ¬q)] as well. As stated, a conditional such as [p → q] has three models: (p, q), (¬p, q), and (¬p, ¬q). Therefore, a conditional such as [p → ¬q] has to have these models: (p, ¬q), (¬p, ¬q), and (¬p, q). And the only model of a denied conditional such as [¬(p → ¬q)] can only be (p, q). In the same way, if the models set of [¬p ∨ ¬q] are (¬p, ¬q), (¬p, q), and (p, ¬q), only a model is possible for [¬(¬p ∨ ¬q)]: (p, q) again.

Furthermore, the case of the inclusive disjunction is not different. Its definitions are these ones:

$$p \vee q =_{df} \neg p \rightarrow q =_{df} \neg(\neg p \wedge \neg q) \tag{11}$$

(e.g., 'either John is smart or he studies or both of them' is equivalent to both 'if John is not smart then he studies' and 'it is not the case that John is not smart and he does not study').

And here, it is also correct that

$$v(p \vee q) = v(\neg p \rightarrow q) = v[\neg(\neg p \wedge \neg q)] \tag{12}$$

Nevertheless, as far as my aims in this paper are concerned, the most relevant point is that the models of the three formulae match in this case as well. As said, the models of [p ∨ q] are (p, q), (p, ¬q), and (¬p, q), and it is evident that those of [¬p → q] are (¬p, q), (p, ¬q), and (p, q), that is, exactly the same models. On the other hand, if the model of [¬p ∧ ¬q] is (¬p, ¬q), it is clear that those of [¬(¬p ∧ ¬q)] are also (p, q), (p, ¬q), and (¬p, q).

Thus, it is hard to question that certain correspondences and equivalences related to logical forms in standard logic are present in MMT too. As stated, this does not mean that this last theory is wrong. It only implies that, although MMT wants to ignore logical form, it cannot do that absolutely. All of its other theses can be correct and it is very possible that it describes the real mental processes why the human mind reasons and interprets language.

However, as shown, this does not necessarily remove the role that the formal structures and syntax can play.

5. Conclusions

However, what does appear to be true is that the human intellectual activity does not follow Gentzen's calculus [15]. Examples such as the ones mentioned above (that of the disjunction introduction rule, that of the principle of explosion, or that of the possible infinite conclusions) are clear proofs in this regard. But this does not prove, at the same time, that no kind of logic or syntactic forms can be related to the human thought. This paper has shown that, even accepting a purely semantic theory such as MMT, it is possible to continue to speak about logical forms and to find links between the mental activity and such forms. In this way, given that standard logic is about more than just Gentzen's system [15], the rejection of the latter does not have to lead to the rejection of the former. Thus, while standard propositional calculus does not work to account for the human mind, maybe some aspects of standard logic linked to its truth tables can do that.

In fact, following arguments such as, for example, those of López-Astorga [16, 17], it can be said that, by trying to avoid logical forms, MMT really gives a procedure to recover them. Based on this idea, it can also be stated that MMT reveals that the true forms of conjunction, the conditional, and the inclusive disjunction are, in principle, $[p \wedge q]$, $[(p \wedge q) \vee (\neg p \wedge q) \vee (\neg p \wedge \neg q)]$, and $[(p \wedge q) \vee (p \wedge \neg q) \vee (\neg p \wedge q)]$, respectively, and that, therefore, the human mind does use logical forms, albeit such forms are simple enough so that they only include conjunctions, disjunctions, and denials.

An objection against this idea can be that MMT assumes that, as explained, in certain circumstances, many people do not identify all the models corresponding to a sentence, this being what allows the theory to account for the reasoning mistakes. Following an example indicated above, it can be claimed that, according to MMT, the inferences that have as premises sentences such as, for instance, $[p \rightarrow q]$ and $[\neg q]$ are sometimes difficult for individuals because, as indicated, to make them and conclude $[\neg p]$, it is necessary to detect the third model of the conditional $(\neg p, \neg q)$, which does not always happen (e.g., [1], p. 283). In this way, one might think that this idea refers to processes and facts that actually have no relationship to logical forms. However, from a syntactic perspective, it can also be thought that an individual that does not detect the third model of the conditional is just an individual that fails to note that its logical form is $[(p \wedge q) \vee (\neg p \wedge q) \vee (\neg p \wedge \neg q)]$, and that, because he (or she) has not identified all of its possibilities, attributes to a logical form such as, for example, $[p \wedge q]$ (if the usual arguments given by the proponents of the theory are taken into account, this would be the most probable case) or $[(p \wedge q) \vee (\neg p \wedge q)]$. So, this aspect of the theory is not really in conflict with a possible role of logical form either.

Likewise, modulation would not be a problem. If we consider the example taken from Johnson-Laird and Byrne ([8], p. 663, Table 4) again, that is, 'If the workers settle for lower wages then the company may still go bankrupt', we have to acknowledge that its logical form is not actually the one of the conditionals, but, following that indicated above, $[(p \wedge q) \vee (p \wedge \neg q) \vee (\neg p \wedge q)]$. But, as said, this is not a difficulty either, since it can be interpreted that what it truly shows is that MMT has theoretical mechanisms such as that of modulation that help detect the real logical forms of sentences. In fact, an old problem in logic is, as it is known, the one of the translation of sentences in natural language into well-formed formulae, as there is no exact correspondence between the expressions in natural language (e.g., 'if… then…', 'either… or…', or '…and…') and the logical operators (see, e.g., [16, 17]). And, obviously, from this point of view, it can be claimed that what modulation really seems to reveal is the way the true logical forms of the sentences can be found, and not that logical form is not necessary (see, e.g., [16]). Thus, in the particular case of the aforementioned example, what modulation appears to indicate is that, in spite of the fact that the sentence is expressed by means of the words 'if' and 'then', it is actually an inclusive disjunction. This is so because the formula $[(p \wedge q) \vee (p \wedge \neg q) \vee (\neg p \wedge q)]$ is the one corresponding to this last operator. Hence perhaps it would be better to express the sentence as follows: 'either the workers settle for lower wages or the company will go bankrupt.'

So, that this paper has been mainly focused on ideal situations in which all of the models are identified and modulation plays no role does not seem to be a clear limitation of it. Thus, the paper appears to demonstrate that, although, as stated, Gentzen's calculus [15] is not the criterion for the human mind, it is worth continuing to carry out studies in the same direction as, for example, those of López-Astorga [16, 17], that is, studies on the relationships that can exist between the models of MMT and logical forms.

Finally, maybe it is also important to mention the relevance that this problem of logical forms and their semantic possibilities can have in very different fields. On the one hand, given that MMT is a cognitive theory, it is absolutely clear that it is relevant in Psychology of Reasoning. On the other hand, speaking about syntax and semantics is always speaking about linguistics. Thus, the arguments provided in this paper can be interesting in several kinds of studies on language, including, for example, Philosophy of Language. As far as this last point is concerned, it can be stated, in addition, that the identification of both the semantic possibilities to which sentences refer and their logical forms can make it possible that a computer program or a software tool can work more easily from sentences in natural language (which could be translated into logical forms and the program or software could work considering just these last forms). Furthermore, it is obvious that identifying logical forms is identifying deep forms in linguistic messages. Therefore, the possibilities of researches in this direction are diverse and, as said, it seems that the analyses about the connections between semantic models and syntactic forms must be continued and taken into account.

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Section 3

Semiotics and Gesamtkunstwerk

The Art of 'Scoring' Cosmopoiesis in Archaic Melic Verse: How the Singing-Poets of the Hellas of Yore Musically Mapped Their *Lebenswelt*

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Additional information is available at the end of the chapter

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[…] it is not clear in what respect the poet's song and voice are literally θέσπις ἀοιδή.

—Andrew Ford.

Abstract

Among the Hellenes in archaic 'Song culture', it was axiomatic that when the 'inspired' *aoidos* declaimed 'sacred song' (θέσπις ἀοιδή), the voice of the divine itself sounded forth. But what credited such a claim? What property of 'melic verse' encoded the voice of the Gods? Pursuant to what semiotic rationale? To answer these questions, this chapter looks at (1) what counted as the 'divine' for the early Hellenes, (2) how the 'inspired' *aoidos* was able to 'source' it, (3) how he made it afford intelligence about cosmopoiesis and, finally, (4) how he gave this intelligence an expression that was legible to his listeners. The case is made that information about cosmopoiesis was encoded in the *melodies* and *metre* that accompanied the ordinary words used in melic verse. The semiotic rationale behind this claim was a mimetic correlation between (i) the 'arithmology' used to compose melodies and rhythms and (ii) the 'arithmology' used to quantify the blends of cosmic energies that powered the song's subject matter into its 'complexion'. Hence, listening to 'sacred song' amounted to hearing two narratives about the object of the song: one in the 'ordinary' words of mortals recounting what it means '*sub species hominis*', the other in melody relating its 'sacral', cosmopoietic significance.

Keywords: archaic melic verse, sacred song, hieroglossia, semiotics and *mousiké*, encoding environmental affordance, semiotics and arithmology

1. Introduction

'The very voice of the divine itself sounds forth in what is heard'. This is the tenor of what Plato says in the *Ion* and in *Laws* about a variety of melic verse now generally called 'sacred song' (θέσπις ἀοιδή) when sung by an 'inspired' singing-poet or *aoidos*.[1] Modern first-time readers of the relevant passages would quite naturally assume this is said for dramatic effect or that it reflects some sort of tradition consecrated *fable convenue* or literary convention. However, better-informed and more context sensitive readings are not so dismissive. They tend to suppose that this sort of claim was meant to be taken literally and therefore ought to be treated as such.[2] What encourages them to say this more than anything else is the abundance of similar sounding language in the surviving works of Alcman, Hesiod, Pindar, Theognis, Bacchylides and many others. And let us not presume that what is purported by these self-styled 'emissaries of the Muses' boils down to no more than the predictably self-serving rhetoric of an 'aedic ideology'. That would suppose that poetry and song listening publics were less convinced of the validity of the claim than the performers who made it, and until the fifth century BCE there is very little proof of that.[3]

But if this 'conceit' should be taken literally, what could justify such a bold statement? What *property* of verse encoded what counted as the voice of the divine? What semiotic engineering was required to make 'θέσπις ἀοιδή' a signifier of something as incommensurably otherworldly as the voices of the immortals? Alternately, what 'theory of the sign' lent this conceit the credence it evidently enjoyed?

To wend our way to some sort of clarity on this semiotic *punctum caecum*, I begin by placing a question mark beside those passages in the works of Plato where he suggests that the answer is to be found in the *melody* and *metre* modulating the ordinary words used in poetry. A good example of the kind of passage I refer to can be found in Plato's *Laws*.

> *[…] the gods, in pity for the human race thus born to misery, have ordained the feasts of thanksgiving as periods of respite from their troubles; and they have granted them as companions in their feasts the Muses and Apollo the master of music, and Dionysus, that they may at least set right again their modes of discipline by associating in their feasts with gods. […] Now, whereas all other creatures are devoid of any perception of the various kinds of order and disorder in movement (which we term rhythm and harmony), to men the very gods, who were given, as we said, to be our fellows in the dance, have granted the pleasurable perception of rhythm and harmony, whereby they cause us to move and lead our choirs,*

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[1]On 'ὁ θεὸς αὐτός ἐστιν ὁ λέγων', cf. *Ion*, 534d, *Phaedrus*, 245a & *Laws*, 719c. On 'sacred song' (θέσπις ἀοιδή or θεσπιῳδία), cf. [1, 2]: 178-193 & [3]: 21-26.

[2]Cf. [4]: 38*ff*., [5]: 13, [6]: 36, 40, 64, [7]: 100*ff*., [8]: 28*ff*., [9]: 10-11, 16-17, 80-81. Comp. [2]: 178*ff*., [10], [11]: 116*f*., [12]: 78-79 & [13]: 34. For more sceptical or opposed views, cf. [14]: 171-172, [15–18]. For an up-to-date bibliography on the whole question, cf. [19]: 64n.18.

[3]Cf. [20]: 54n.56 on [12, 21, 22] and others who have studied the gradual transformation of poetic practices entrained by the pressures on rhapsodes to tailor their productivity and performances to the tastes of civil authorities and the general public and how this resulted in the view that Singing-Poets were 'lying' when they claimed they were emissaries of the Gods. Needless to say, we are unconcerned with poetic productivity in this 'disenchanted', post-archaic age. Also beyond the scope of this chapter, are what can be called the 'lays of men' ([3]: 17), which, in so far as they are 'non-sacral', should be contrasted with 'θέσπις ἀοιδή'.

linking us one with another by means of songs and dances; and to the choir they have given its name from the "cheer" implanted therein. Shall we accept this account to begin with, and postulate that education owes its origin to Apollo and the Muses?[4]

Unquestionably, the main interest of this passage concerns Plato's 'conservative', not to say 'reactionary', views on the importance of music, melody and rhythm for educational purposes. But something else comes across quite distinctly in this passage which is highly relevant to early Hellenic ideas on the semiotics and semantics of the 'musical arts' like 'μουσοποιά', 'μελοποιία' and 'θεσπιῳδία'. For it would seem that the goal of the 'inspired' singing-poet was to semantically and narratologically 'bi-nature' what one heard in his 'sacred song' and do so by 'over-signifying' what it related about its subject matter in 'profane', ordinary words ('πεζός λόγος') with a second, 'hieratic' or 'hieroglossic'[5] meaning encoded in melodised tones and metred rhythms.

What finality was subserved by 'over-signifying' verse with this melodically and metrically encoded hieratic meaning (σημεία, αἶνος, ἔννοια)? To judge from a close reading of texts like the one above, one might assume that it was primarily 'parainetic', *i.e.*, to instil in listeners certain tradition-hallowed values, norms and aspirations and thereby federate them around community binding 'ultimate sacred postulates'. Less narrowly focused readings, however, notably those that consider the point of prefacing melic verse with a hymnic 'proem',[6] would assume that something more fundamental was aimed at. Namely to express or 'epi-*phon*-ise' the song's subject matter 'κατὰ τὴν τοῦ θεοῦ ἐνέργειαν', *i.e.*, to the power of the 'cosmic' agencies to which it is beholden for its Being-in-the-world. The reference to Apollo and Dionysus in the passage above credits this view in as much as these appellations are, in the final analysis, metonyms for 'starry Ouranos' and 'all-bearing Gaia' and the role these 'Ouranides' (Οὐρανίωνες) play in the 'unveiling' (ἀνακάλυψις) of the world (cf. *infra*, note 21). A point which is important to stress here because it suggests that what made melic verse the 'voice of the divine' was its ability to signify or 'mime' the role played by Ouranos and Gaia in giving to the object sung about its Being-what-it-is. And even if it is not feasible here to go into all the scholarship from Dieterich [29] to Clay [30] on early ideas about *Mutter Erde*, it should be made perfectly clear right from the outset that what will be said in the following about the 'Sacred' or the 'divine' will be devoid of the least worth or meaning if it is confused in any way, shape or degree with any posterior acceptations of these words. And by 'posterior acceptations' I do not merely mean 'monotheological' models of a 'supreme being' or any of their 'post-theological' *Aufhebungen*. Nor do I refer only to the ideal of the divine in

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[4]*Laws*, 653c-654a. Comp. *Symposium*, 187a-e, Homer, *Il.*, 1.603*f.*, Hesiod, *Theogony*, 36-55, Pindar, *Pyth.*, 1.1-10 & *Pyth.*, 3.88-95 & – somewhat asyndetically – Theognis, 15-18.

[5]For what I mean by 'hieroglossia' cf. Robert [23]: 'the hierarchical relationship between two or more languages in which one is held to be the primordial idiom in the ordering of the representation of the world and the other, or others, receive the core of their meaning from the first. In other words, the value of the words of one language will be validated by their reference to another'. While Robert and I agree on this, we differ on what the expression 'primordial idiom' can mean. For unlike Robert, I do not think it must refer only to a second 'language', *e.g.*, Chinese as opposed to Japanese. It can also refer to another *medium*, *e.g.*, 'music' as opposed to 'ordinary speech'.

[6]On the hymnic proem as a ritual 'performative utterance' whose aim was to summon various cosmopoietic agencies, cf. [24]: 6-7, [25]: 8-9, [26]: 493-94, [27]: 47-53 & [28]: 305*ff*.

'*polis* religion' in which the Sacred was '*devocavit e coelo, et in urbibus collocavit*'.[7] I am also, and even above all, referring to the 'astrocentric' paradigm of cosmopoiesis usually referred to as the 'harmony of the spheres'. This is a cosmopoietic ideal that emerged in the course of the fifth century BCE and differs radically from earlier cosmopoietic models in that prior to then 'life-bearing Gaia' (γαῖα φερέσβιος) was as much a cosmopoietic agency as Helios, Zeus or Apollo.[8] In any event, all we care about in the following is the semiotics of the way 'sacred song' 'epi-*phon*-ised' the voice of the divine because the melodies and rhythms accompanying and modulating the 'mere words' in melic verse encoded intelligence about the way Ouranos and Gaia gave to the subject matter of song its Being-what-it-is.

What, then, is the semiotic rationale that is operative in the claim that melodies and rhythms literally 'lend a voice' to the 'divine'? Alternately, *how* can melody and rhythm 'mime' the powers that produces the cosmos and its content and therefore constitute a semiotic resource or 'signary' that one *must* use when it is one's intention to 'epi-phon-ise' the 'divine nature' (θεία δύναμις, θεία μοίρα) of the object of sacred song?

The first point to be addressed by raising these questions is the extreme difficulty of providing them with adequate answers. This is mainly due to a total lack of anything anyone could consider reliable, first hand evidence. In fact, all we have is a mass of tantalisingly suggestive bits and pieces which, partially revelatory though each may be in their own way, are nonetheless extremely difficult to join together in such a way as to reconstruct the Humpty-Dumpty of which they are the debris. And the challenge is made all the greater when we make allowances, as we must, for the fact that none of the terms of our heuristic can be matched to anything resembling a stable, univocal referent. This is so because we have to assume that from the Bronze Age to the end of the Archaic period, anything referred to as 'music' or 'song' (*e.g.*, 'μουσική', 'μολπή', 'μελοποιία', 'ῥαπτὰ ἔπεα' etc.) was subject to lively discussion among both theorists and practitioners, and not just as concerns their 'signifying function' in sacred song. Consequently, it would be rash to suppose that it is riskfree to speak of any of our key terms *singulare tantum*, even in a narrowly circumscribed timeframe.

To get around the hurdles this represents, we have no alternative but to resort to the same *faute de mieux*, 'cladistic' strategy resorted to by all philologists when confronted with a similar goal. In other words, we will assume that a certain logic is operative in, through and as all the evidence we have suggesting that, in some sense, the 'Immortals' really did sing forth in 'sacred song' and that this basic underlying logic is legible in varying ways and degrees in each of the bits of testimony we have. Consequently, what is required to elucidate the enigma at hand is to (a) identify the various expressions of the basic underlying logic, (b) look at what is opaque or obscure about each of them in the light of what is less opaque or obscure in other expressions of the same basic idea and, finally, (c) describe how each seem to be *membra*

[7]Wrested from the heavens, and relegated to the municipality' (Cicero, *Tusculane disputations*, V, iv, 10).

[8]To have a sense of this difference, consider all the celebratory references to 'life-giving Gaia' (γαῖα φερέσβιος, γαῖαν παμμήτειραν, αἰθέρα καὶ γαῖαν πάντων γενέτειραν) in Hesiod (*Theogony*, 693), Pherecydes (DK7B2), Aeschylus (*Persians*, 618, Fragment 44), Euripides (*Phoenicians*, 685*f*., *Bacchae*, 275*f*.) and *Homeric Hymn to Earth Mother of All*, then compare this with the cerebral astro-centrism of Plato's *Timaeus*, 36e, 90a, *Republic*, 529d & *Laws*, 898e as well as Aristotle's *Metaphysics*, 1072a10*ff*. & *Ethica Nicomachea*, 1177b27-34. Cf. also [28]: 179*ff*., [29], [30]: 15-26, [31] II: 251-60, [32] & *infra* note 20.

disjecta of one 'originary' *unitas multiplex*. To this end, I will attempt to supply what I hope will be considered uncontroversial answers to the following questions.

1. What was the vocation of the inspired singing-poet and the finality of his art?
2. Why was some sort of commerce or dialogue with the 'divine itself' considered essential to practicing his art successfully?
3. What was the *modus operandi* of this dialogue between mortals and immortals?
4. Why was this sort of activity relevant, important and even vital to the community the inspired poet belonged to?
5. How did the singing-poet make melody, metre and musical sounds a 'signary' he could use to 'mime' or 'epi-*phon*-ise' the very voice of the Sacred?

2. The vocation of the *aoidos* and the finality of his art

Readers of literature on Indo-European Comparative Poetics will know that it is common to characterise the archaic *aoidos* as his community's 'tribal encyclopaedist'.[9] This basically means that he was the memoriser of the survival guaranteeing lessons learned from the collective experience of his client community communicated in allegorical form via the heroic feats of the tribe's great men.[10] This is true. Little else can be made of all the myths and legends that singing-poets were supposed to learn by heart and of which emblematic works like the *Iliad* are clear and eloquent testimony. But this pre-occupation was very much '*en abyme*' relative to a far greater imperative. Namely that of attempting to 'homologise' or synchronise the entire way of life of the singing-poet's community to the existence-structuring periods and cycles of its natural environment. This is why his *métier* was sometimes said to consist of practicing 'meteorology' (μετεωρολογία).[11] What this means is that it was his job to 'explore happenings in the celestial Empyrion and the Earth's vasty deeps' in order to make the 'signs of the sacred' (διοσημεῖαι) dappling his tribe's *Umwelt* 'afford' intelligence about the cosmos-creating, cosmos-orchestrating agencies at work in, through and *as* the natural environment where his community dwelt.[12]

Why this was then considered necessary or important hardly needs explaining. In marked contrast with today, people then did not have the technological capabilities we have to lull ourselves into the false idea that nature is a minor factor in the world we dwell in and that whenever it poses us a problem we can always just 'geo-engineer' 'nature resilient' and even 'nature resistant' living spaces. To the contrary, they were convinced that life itself and the

[9][33]: 36*ff*., [34]: 150, [35]: 189*ff*., [36], [37]: 68-84.
[10][27]: 4-6, [36]: 26, [38]: 57, [39] & [40]: 193.
[11][41]: 3*ff*., [42]: 414*f*., [43]: 393*ff*., [44]: 141*f*. & [45]: *passim*.
[12]On exploring 'τὰ περὶ τῶν οὐρανίων παθημάτων καὶ περὶ τῶν ἐν Ἀιδου', cf. Plato, *Ion*, 531c, *Theatetus*, 173e, *Republic*, 596c, Hesiod, *Theogony*, 119, 669, Pindar, *Nem*., 10.87*sq*. Sophocles, *Oedipus Tyrannus*, 300-301 as well as [34]: 154*ff*., [46]: 139-140, [47]: 130*ff*., [48]: 385*ff*., [49]: 47*ff*. & [50]: 99*ff*.

benefits of everything good it had to offer depended intimately and directly upon being as harmonised as it was possible to be to the cycles and cadences of the astro-meteoro-geological processes of which their *Lebenswelt* was a product.[13] But if this is clear, what is not, is the way the singing-poet distilled the 'intelligence' (εὖ εἰδώς, σύνεσις) that was needed to realise this harmonisation.

Certainly, we cannot rule out the possibility that at least some of them may have practiced geomancy and generated geognosy more or less the way Earth systems scientists do so today. In any event, we know that there existed a form of 'reasoned reflexion' (ἔμφρονος ζήτησις) called 'omen science' (τεκμαίρεσθαι), which because it consisted of 'the discovery of non-evident truths by means of evident signs' ([55]: 240*ff*.) seems to resemble what we today call 'empirico-inductive reasoning'. Still, it would be unwise to focus too narrowly on this manner of analysing 'sacred signs' (διοσημεῖαι) to conduct *meteorologia*. Not, however, because ratiocination as 'sophisticated' as this could not be conjured out of the conceptuality and linguistic resources then available to *meterorologoi*.[14] Rather because the 'τεκμαίρεσθαι' just referred to was not the only way to make the *Lebenswelt* 'afford' insight into the *modus operandi* of the agencies that give it the aspect in which guise it appears to us when we notice it. For alongside this 'conjectural' or 'inductive' mode of reasoning there existed another approach to nature study and *meteorologia*, one usually referred to as 'intuitive' or 'inspirational' reasoning (ἐμπνοίησις, ἐνθουσιαστική, μαντικὴ ἔνθεος, χρησμολογία). What is more, it would appear that this alternative way of interfacing with the *Lebenswelt* and emptying it of the mysteries of its *Dasein* was considered altogether more reliable than the aforementioned reasoned reflection.[15]

Here I refer to the well-nigh universal belief that singing-poets and oracles were unable to vaticinate as they ought to unless they were 'out of their wits' (ἔκφρων) or 'beside themselves' (ἔξω ἑαυτοῦ). The *locus classicus* for this *doxa* is of course the passages of Plato's *Ion* devoted to the 'theoleptic fit' rhapsodes needed to undergo to become the mouthpiece of the divine. Unfortunately, however, this dialogue divulges nothing of any use for elucidating the utility of being '*witless*' for practicing *meteorologia*, which is, again, ransacking the firmament and the Earth's vasty deeps to make them afford intelligence about the mysteries they conceal about cosmopoiesis, coming-to-be and complexity. That is why it would be better to stick to the 'aetiologies' of 'inspiration' (ἐνθουσιασμός) we find in the natural philosophies (περὶ φύσεως περὶ τῆς ὅλης οὐσίας) of the Pre-Socratics, especially those Armand Delatte discusses in his still valuable 1934 study entitled '*Les conceptions de l'enthousiasme chez les philosophes présocratiques*' [59].

[13]Cf. Hesiod, *WD*, 42, Homer, *Il*. 2.484-7, *Homeric Hymns to Demeter*, 216-217, Pindar, *Nem*., 11.44, Sermonides Fr. 1, Simonides, 527, Archilochus Fr. 130, Theognis, 133-36, 1075 & Plato, *Republic*, 274c-d. For commentary and analysis, cf. [11]: 30, [51]: 189, [52]: ch. 7 ('Fate in Sophocles'), [53]: 152-153 & [54]: 10*ff*. [52]: 164 & [53]: 149, 162 can also be profitably consulted as regards the strategies that were resorted to to reconcile 'strong program' fatalism with the exercise of a mortal agent's free will.

[14]Cf. [56]: 28, [48]: 321-22 & [57]: 3*ff*. who all indicate that the relative 'scientific' backwardness of the early Hellenes was due not so much to an inability to 'progress' the way we define it today as to a desire to make progress in a direction and by means that science as we understand it is useless to attain.

[15]This comes across distinctly in Alcmaeon of Croton, DK24A1: 'περὶ τῶν ἀφανέων, περὶ τῶν θνητῶν σαφήνειαν μὲν θεοὶ ἔχοντι, ὡς δ᾽ ἀνθρώποις τεκμαίρεσθαι'. For commentary cf. [58]: 19-22, [31] I: 344*ff*., [25]: 234*ff*.

3. Poetic 'inspiration' (ἐνθουσιασμός) and 'nature study' (μετεωρολογία)

By Delatte's reading of the pre-Socratic aetiologies of inspiration he analyses, being 'ἔκφρων' had nothing to do with being 'delusional', a pathology which was indeed sometimes confused with 'enthusiasm' (ἐνθουσιασμός) but was nonetheless not at all the same thing.[16] What it really meant is that the individual undergoing a 'theoleptic fit' or an '*orgia*' with Muses and Sirens had been liberated from the limitations placed upon anyone who interfaces with their natural environment with no more than ordinary powers of perception.[17] Indeed, while 'unhinged' (ἔξω ἑαυτοῦ), he specifically filters out of his apprehension of his surroundings everything that can be sensed via the perceptual channels the rest of us rely on to sense it. However, this does not mean that he thereby stops interfacing with his *Umwelt* or that while doing so he is not perceiving anything. All it means is that he is using another sort of perceptual channels to do so. Channels which allow the inspired *meteorologos* to, as it were, 'sense past' the complexity adorning the perceptible side of his *phaneron* so that he can 'clairaudiently auscultate' it and in so doing source or 'incubate' (ἐγκοιμάομαι) insight into the way this latter is given its perceptibility.[18] And by using the words 'clairaudiently auscultate', I am not just allusively doffing my hat in the direction of R. Murray Schaeffer's *Tuning of the World*. I am doing so in a very literal sense and for a very specific purpose. Namely to make allowances for those 'otherworldly sounds' ('θαύματ᾽ ἀκοῦσαι', 'χθόνιαι θεαὶ αὐδήεσσαι') or strange 'rumours' ('ὀμφαί', 'ὄσσαι', 'ὀπὶ καλῇ' etc.) that inspired oracles, prophets and *aoidoi* said they heard whilst 'witless' and were wont to impute to various divine interlocutors.

Of course, the Pre-Socratic natural philosophers were sceptical of the idea that anything like a Muse actually existed. They did not withal maintain that when 'inspired' oracles and *aoidoi* were 'beside themselves' and *claimed* that they were hearing Muses, they were not hearing anything or that they were delusional. To the contrary, they assumed that something was indeed heard. But if that be so, if these 'inspired' hearers were not lying or hallucinating, what *were* they hearing? What property of the *Umwelt* emitted the 'rumours' that only the

[16]For the opposition between mantic 'enthusiasm' and delirium attributed to mental illness ('μανίας ὑπὸ νοσημάτων ἀνθρωπίνων'), cf. Plato, *Phaedrus*, 244bd, 265a, *Timaeus*, 71d, *Ion*, 538a, *Republic*, 364b & *Laws*, 772d.

[17]This is what Plato meant in *Phaedrus* 265a in his reference to 'mania' as 'madness arising from a divine release from customary habits' (ὑπὸ θείας ἐξαλλαγῆς τῶν εἰωθότων νομίμων γιγνομένην).

[18]On this point, I am following Delatte's gloze of Empedocles Frr. B110, B129, B132 and Democritus Frr. B112, B116, B129 (cf. [59]: 26-27, 52-56) on the way the 'possessed sorcerer' (μαινόμενος ἔνθεος) was supposed to have engaged in commerce (ἐμπελάζειν) with the instrumental cause of possession (μαντικὸν ῥεῦμα καὶ πνεῦμα). It seems clear that this consisted of a form of what was called 'far thinking' or 'deep thinking' ('δολιχόφρονες', 'φρὴν βαθεῖα', cf. Empedocles DK31B11) in which the inspired *sophoi* takes leave of normal ways of interfacing with the natural surrounding ('τὰ παρόντα') by substituting the ordinary organs of sense perception with one called the '*prapides*' (πραπίδες) which, it seems, was located, like the '*thymos*' (θυμός) and the '*phrenes*' (φρένες), in the midriff. Evidently it was the ability of the inspired *sophoi* to 'stretch' (ὀρέγεσθαι) the powers of perception peculiar to this organ past the perceptible surface of 'τὰ παρόντα' and into their normally imperceptible interiors (βυθοί) which allowed him or her to become 'ἄτμος ἔνθεος' or 'ἐμπιμπλαμένη τοῦ πνεύματος', *i.e.*, capable of divining the cosmopoietic dynamic at work inside the observed object and which deposits it into its outward manifestation.

'inspired' *meteorologos* could apprehend and that needed to be 'tuned in to' to practice geomancy and distil geognosy? The fact that a great variety of appellatives and epithets were used to refer to it ('μαντικὸν ῥεῦμα καὶ πνεῦμα', 'πῦρ ἀείζωον', 'κεραυνός', etc.) would suggest that it is unwise to refer to the source of these 'otherworldly sounds' with a single, univocal term. It is nonetheless without hesitation that I follow Delatte in privileging the appellative 'ἀναθυμιάσεις', a word usually translated as 'exhalations'. To have a sense of the way these 'exhalations' were essential to cosmopoiesis—and therefore to using melodies and metre to 'score' it in 'θέσπις ἀοιδή'—a reminder of early ideas on cosmogony and ontogenesis cannot be avoided.

4. The mechanics of cosmopoiesis and the 'unveiling' (ἀνακάλυψις) of the world

Given the scholarly firepower marshalled behind the view that '*eine Kosmos-'Idee' ist dem frühgriechischen Denken fremd*',[19] there is little chance that anything one could say on this matter will not be controversial. It is nevertheless enough for our purposes merely to develop the point we made above about the 'divinity' of the Sky and the Earth.[20] Though it is well known that the latter enjoyed this status because, in mythopoeic thought, the 'unveiling' (ἀνακάλυψις) of the cosmos was considered to be the fruit of their union or 'hierogamy',[21] it is less well known that these cosmocrators or 'ἀρκτικαὶ αἰτίαι' did not interact with one another directly. They did so via the energies they precipitate at each other, notably in the form of those we call hot and cold, dry and wet, high and low pressure, etc. [41–45]. What is more, these energies were useless for cosmopoiesis unless they encountered each other in the midst of a pre-cosmic, immaculately quality-free medium usually referred to as 'aether' (αἰθήρ) or 'the impossible-to-experience' (τὸ ἄπειρον) or 'the self-natured' (τὸ αὐτοφυής) or simply 'the void' (χάσμα μέγ').[22] This is so because it was only where and when the energies radiating from the Sky and the Earth meet and blend in this undifferentiated milieu that this latter gets 'agitated', 'fretted', 'tempered' (πληγή) or 'concocted' (πέσσεσθαι) until

[19]'A single '*kosmos*-idea' is foreign to early Greek thought', [60]: 60, [34]: 150*ff*., [61]: 205 & [62]: 417*ff*.

[20]For evidence of nature worship in earlier times, cf. Democritus, DK68A75, Prodicos of Ceos, DK84B5, Aristophanes, *Peace*, 406*ff*., Plato, *Apology*, 26d, *Cratylus*, 397cd, 408de, *Laws*, 715e-716b, 886a, 821b, 899b, 950d, *Epinomis*, 985b, 988b, Aristotle, *Metaphysics*, 1074b 1-14, *De Caelo*., 284a 2-18 & Fragment 10. See also [63]: 446-7, [4]: 116, [64]: 170-71, 177-8, [47]: 23, 131, [65]: 14-15, nn.27-29, [66, 67]: 165 & [68]: 102*ff*.

[21]Cf. *Derveni Papyrus*, cols. 14-15, Pherecydes of Syros, DK7B2, Aeschylus, Fr. 44, 1-5, Pindar's Fragment 31 (=Aelius Aristides, 2.142) and Alcman's cosmogony as per [5, 69]: 134-35 & [70]: 5*ff*. Cf. also [41]: 28*ff*., [64]: 63, [71]: 82*ff*., [72]: 256-7, 389*ff*. & [67]: 165. Cf. [73]: 419*ff*. on the way this basic cosmopoietic model is obscured in much of the relevant evidence by the 'diachronic skewing' that resulted from attempts to reconcile or overlook tensions within the tradition of Archaic metapoetics.

[22]Cf. [13]: 22 & [70]: 5-6 on the use of 'αὐτοφυής' as a 'conventional' way of referring to an initial, 'pre-cosmic stuff' or 'πρώτη φύσις πρὸ τῆς οὐρανοῦ γενέσεως'. To this epithet, and to others like it (*e.g*., χάος, νύξ, τι μεταξὺ, χώρα), applies the predicates Theophrastus used to describe Anaximander's 'Boundless', namely 'something whose nature is definable neither qualitatively nor quantitatively' (φύσις ἀόριστος καὶ κατ' εἶδος καὶ κατὰ μέγεθος). Cf. also [74]: 1171-1183 & [30]: 15*f*.

it yields 'complexions' (συμπεπλεγμένα) and 'complexity' (σύμπλεξις).[23] And not just the 'complexity' we today would identify as the naturally occurring meteorological phenomena that decorate our natural surroundings. For the proverbial 'unveiling' that Helios gave Gaia to make her 'presentable', he also gives to each of all-bearing Gaia's 'offspring' (τέκνα)[24] so that they too are unveiled.

Naturally, and importantly, these *doxai* about cosmogony and ontogenesis entailed key epistemological corollaries, notably regarding what counted as 'genuine knowledge' (γνησίη γνώμη) about the 'true nature' of what one encounters in one's average, everyday Being-in-the-world. Knowledge like this was believed to be unobtainable just by observing things with the normal means of perception or by extrapolating 'polymathically' from data furnished in this way. One has 'γνησίη γνώμη' when one knows the way cosmopoietic agencies *give* phenomena the 'complexions' in which guise they are perceived,[25] and to attain that knowledge, one has to be capable of 'δολιχόφρονες' or 'φρὴν βαθεῖα'. This means that one needs to apprehend what one perceives from the perspective of what is going on in the 'abyss' (βυθός) which is dissimulated by the perception's outward manifestation.[26] This is so because it is only there that one can ascertain the 'blends' of Sky and Earth energies that give phenomena their 'complexion'.

Now all this is relevant to the aforementioned 'exhalations' because, in the final analysis, they are the 'instrumental cause' of the complexity-synthesising process going on in these 'depths' and therefore what *meteorologoi* needed to study to know what deposits complexity on to the natural environment's outward appearance.[27] And, in turn, this is relevant to the divinatory techniques utilised in *meteorologia* and 'wonder study' (τερατοσκοπία) because the reason their practitioners entered a 'theoleptic fit' was to 'auscultate' the perceived environment in

[23]Knowledgeable readers will know that the use of variants of 'σύμπλεξις' to translate 'complexity' and the 'complexions' of various perceptibles (μετ' αἰσθήσεως ὄντα) is an Aristotelian choice of word. This I believe is legitimate given that what Aristotle expresses with this sort of terminology is essentially identical to what his predecessors say using other words. A case in point is Columns 14-15 of *The Derveni Papyrus*. Here we find a reference to the birth of Chronos as a by-product of the way Sky and Earth 'smite against each other' (κρούεσθαι πρὸς ἄλληλα). But in the same columns, it is perfectly clear that *everything* is 'born from the sun to the earth because of the way they smite each other'. Similar imagery can be found in numerous other sources, for example, the 'unveiling' (ἀνακάλυψις) of Gaia that Pherecydes describes in DK7B2, the 'impregnation' of 'Chthona' in Aeschylus Fr. 44, 1-5 and Alcman's cosmogony as per [5, 69]: 134-135 & [70]: 5*ff*. Hence, we do not betray the ideas of earlier cosmologists simply by privileging an Aristotelian choice of words.

[24]Aeschylus, *Persians*, 619, Pherecydes, DK7B2 & Philolaus, DK44B1 & B2. Cf. also [75]: 212-213.

[25]Though not easy to discern on a hasty reading, this is what Empedocles DK31B3 is at pains to make clear. For what it says is that we should not trouble over whether one kind of perception is superior to all the others. All that matters is apprehending how *all* perceptible phenomena are manifest 'in *the way by which* each is manifest' (ᾗ δῆλον ἕκαστον). The same point is made in Heraclitus DK22B17.

[26]This is what Anaxagoras refers to in his famed aphorism 'phenomena are the perception of the unperceivable' (ὄψις γὰρ τῶν ἀδήλων τὰ φαινόμενα) (Anaxagoras, DK59B21a). Comp. Leucippus, DK67A9, Democritus, DK 68B9, B11, B117 & Heraclitus DK22B54 & B123.

[27]Particularly useful on this point are the studies on Aristotle's *Meteorologica* by [43, 45] who make it clear that Aristotle's goal in this work was to match descriptions of observable, naturally occurring meteorological phenomena with an account of the way exhalations should behave if they are the efficient causes of the described phenomena. Hence what we observe as comets, auroras, lightening, thunder, wind, rain and seismic activity are really just the outward appearance of exhalations undergoing cooling or heating, desiccating or liquefying, compression or rarefication as they rise or descend between a supreme above and a supreme below.

order to apprehend the 'amazing sounds' made by 'exhalations' as they circulate to and fro (ἄνοδος καὶ κάθοδος) across a vast ethereal gulf in order to 'cook' pre-cosmic aether in to complexions, complexity and cosmos.[28] Without an ability to do that, the pretention that *meteorologia* was of any use or importance to anyone was vain for the whole point and sole worth of the exercise was to discern the cosmos-orchestrating powers at work in, through and as the natural environment so that ancient listeners could harmonise themselves thereto.

So much then for our summary reminder of the cosmology, ontology and epistemology that counted for folks in archaic 'Song culture' and subtended their belief that when the 'inspired' *aoidos* intoned 'sacred song', the very voice of the divine itself rang out. The question now becomes one of establishing how the insight gained by this more-than-normal, 'clairaudient' mode of interfacing with the *Umwelt* passes *from* something only the 'inspired' *meteorologos* can sense *to* something he relates in verse and that his audience understood.

5. Encoding cosmopoiesis and making it intelligible

This is critical. The 'amazing sounds' that 'inspired' *meteorologoi* heard whilst in the throes of a theoleptic trance were heard by no one else. What is more, the 'signs' (σημεία) that came out of their mouths when 'vaticinating under the urging of divine guidance' (θείῃ πομπῇ χρεώμενος) were, if not necessarily pure gibberish, nonetheless never more than 'latently meaningful' (οὐ συνετὰ συνετῶς).[29] Hence, the 'intelligence' (εὖ εἰδώς, ἐννέπειν) *meteorologoi* learned from the Muses while on their katabatic 'divine pilgrimage'[30] could not be of the least relevance to the 'non-inspired' members of their community, much less the foundation for their entire 'encyclopaedia', unless it was somehow made 'legible' (σύνετος, ἐνδεικτικός) to them.[31] So, again, how did target audiences access and decode what the singing *aoidos* had to say when he wanted to relate to others what Sirens and Muses had related to him?

Before offering a response to that question, it should be made clear that the 'melic verse' composed and performed by an inspired *aoidos* was not the only medium in which one could 'mime' sacred referents and in so doing transmit 'hieroglossic' meaning (σημεία). To be convinced of that, one has only to read what Koller and Kowalzig say about Hellenic dance, Hegel and Heidegger about Hellenic architecture, Vernant and Burkert about Hellenic statuary and Gentili and Gadamer about *all* the arts. In addition, even if 'melic' verse was the main 'delivery system', we cannot assume withal that the 'unmarked', 'ordinary speech' in verse ('γυμνὸς λόγος', 'πεζὸς λόγος') could not be used to 'epi-phon-ise' hieratic meaning in the absence of melodies and rhythms. Proof enough of this can be found in the fact that we do indeed know about early ideas on cosmogony in the surviving works of Homer, Hesiod and Alcman, all of it communicated through words bereft of any detectable musical accompaniment. Still, this 'unmarked'

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[28]Despite the evident misgivings of the dialogue's author, we see a good description of this process in *Cratylus* 412d-413c.
[29]It is in this sense that we must understand passages on the semantics of 'oracular utterance' or 'λέγεις ὡς ἐν ἐκστάσει ἀποφοιβώμενος' like the ones we find in Euripides, *Iphigenia in Aulis*, 466, Herodotus, 2.57 and Heraclitus DK22B93 on which cf. [25]: 234-238.
[30]On this 'θείων θεωριῶν', cf. [49]: 47*ff*., [48]: 385-389, [50]: 99*ff*. & *supra* note 12.
[31]From Sappho Fr. 16, Theognis 769-772 and Herodotus 2.57, we know that inspired performers were well aware of the need to satisfy this expectation.

way of communicating cosmopoietic information was less important than the 'marked' features of verse from which the former is distinguished. And by 'marked features of verse', I am not referring to 'allegory' and other 'metaphorical' uses of language which 'hint at' (δι' αἰνιγμῶν εἰρῆται) a gnomically-charged 'under-thought' (ὑπόνοια). I am referring instead to the *melodised tones* and *metred rhythms* which accompanied and modulated the 'naked words' (γυμνὸς λόγος) in melic verse and which in so doing 'over-signified' the latter by 'bi-naturing' (διφύεται) what it should be taken to mean because it was thanks to these melodies and rhythms that the hearers were apprised of the cosmopoietic dynamics (θεία δύναμις) that gave to the song's subject matter its time, place, nature, character, destiny and Being-in-the-world.

But how can melodies and rhythms 'mime' the cosmopoietic dynamics that produces the cosmos and its content and therefore constitute an 'apophantic' resource one *must* utilise when it is one's intention to 'epi-phon-ise' one's objects to the power of what gave them their Being-in-the-world? This brings us back to the semiotic question of the property of melic verse which was supposed to count as the very voice of the divine itself. It also invites us to explain how this property assured some sort of 'co-naturality' (συγγένεια) between signs and signifieds. For in the place and at the time that interests us, in 'Song culture', it was axiomatic that signs were meaningless unless they were consubstantial with their denotata. Obviously such a link or 'co-naturation' could not work or seem to work without the help of something which was common *both* to the 'nature' of the signified cosmopoietic dynamics *and* to whatever property of heard verse was supposed to count as its substance made 'sacred song'. What, then, was the mediating *tertium quid* which assured this 'co-naturality' between signifying melodies and rhythms,[32] on the one hand, and on the other, their 'divine' signified?

6. 'Scoring' com-*plex*-ity

Because of the disparate, ambiguous and inconsistent tenor of the evidence, it is certain that anything one will say about what this *tertium quid* could be or consist of will encounter reserves, objections and reprimands. Still, to judge from the bulk of the extant evidence, it seems certain that when inspired *aoidoi* wanted to 'score' cosmopoiesis they began by attributing a *numerical value* to the attributes (πάθη, διαφοραί, ἕξεις) of the beings it created. More precisely, each of the ever-varying com-*plex*-ions (συμπεπλεγμένα) exhibited by various states of Sun and Earth roasted aether were distinguished from one another—and from the imperceptible aether whence they issue—by receiving 'ratios' (λόγοι) which *quantitatively define* the blend (κρᾶσις) of cosmopoietic principles (ἀρχαί) whose mixture accounts for the way each complexion appears to us when observed. For, again, this is all that com-*plex*-ity was considered to be, a blend of the energy of the Sun and of the Earth which together 'concoct' pre-complexed, diaphanous aether into the perceptibles (μετ' αἰσθήσεως ὄντα) populating our sensoria.

Why was this way of quantifying the energies that produce the cosmos relevant to melic verse and its use as a way to 'epi-phon-ise' the divine? Quite simply because the 'numeri-

[32]For space reasons, we cannot look at the use of metered rhythms to 'epi-phonise' the sacred, which, in any event, has been thoroughly and expertly presented in Georgiades [76].

cal signature' of the blend of Sky and Earth energies that created the song's subject matter was replicated in the 'arithmology'[33] used to structure the melodised tones (μέλος) and metred rhythms (ῥυθμός) modulating 'sacred song'. As a result, this latter was transformed into a 'phonic replica' (ἀγάλμα φωνή) of the cosmopoietic dynamic that gave to the song's denotatum its com-plex-ion. Though some of the details of the method used are to a certain extent discernible in the fragments of Anaximander, Heraclitus, Empedocles and other pre-Socratic natural philosophers,[34] it is better to explain all this in relation to the 'arithmology' of Philolaus of Croton. Not because the historical Philolaus himself provides us with a clearer use of arithmology and its utility for descriptive phenomenology than his peers. The paucity of direct, attested, reliable information about his views makes this impossible. On the other hand, there are sure signs that Philolaus' use of arithmology in his cosmology and phenomenology was the basis for Aristotle's more complete and detailed theorising about phenomenology (περὶ αἰσθήσεως καὶ αἰσθητῶν).[35] Hence, to illustrate the way the *aoidoi* of yore 'scored' complexity, and therefore the 'coming-to-be' that powered it, our approach will be the following:

1. First we will summarise Aristotle's phenomenology and, after that,
2. Identify in it what can only be an Aristotelian use of arithmology then,
3. In what remains, identify what can only be a genuinely Philolean use of arithmology to score complexity and, finally,
4. Justify the assumption that Philolaus' use of arithmology to score com-*plex*-ity offers insight into the way versecraft was practiced in earlier times because some variant of his arithmology was used as a 'template' for composing the 'music' which accompanied melic verse so that, thanks to this accompaniment, the latter was believed to contain the voice of the divine.

What then is there to say about Aristotle's phenomenology and the role played by arithmology in it which helps us on this question?

7. On the 'arithmology' of Aristotle's *De Sensu* - and its Philolaic Palimpsest

Mercifully because all that interests us about Aristotle's περὶ αἰσθήσεως or 'descriptive phenomenology' is the insight it offers into archaic methods for scoring cosmopoiesis, we are spared the hazardous task of involving ourselves in certain controversies about what his

[33]Though I will use this term throughout in the rather general way that Delatte [77] & Burkert [78] use it, I recognise that Zhmud [79] is right to think it is better to use 'number symbolism' to identify what the former refer to and reserve the qualifier 'arithmology' for the pseudo-science inaugurated by Speusippus.
[34]*Inter alia*, cf. [78]: 417 on Anaximander and for the others, cf. [80]: 126-127, 137-138 (Heraclitus), 196, 217 (Empedocles), 201 (Parmenides) & 209-10 (Anaxagoras).
[35]Cf. [81]: 263 on the view shared by Burkert [78] & Huffman [82] that Aristotle is a relatively reliable source as concerns Philolaus. Cf. also [83]: 84.

theorising on the matter actually consisted of.[36] For the same reason, we are unconcerned with the details of the way Aristotle's phenomenological discourse pertains to his views on imagination, cognition and the way the *sensus communis* correlates sensory data from a plurality of sense organs to form a unified idea of what the percipient is perceiving. Indeed, for our very specific purposes it is enough to identify and comment on the main stages involved in the way Aristotle's phenomenology defines 'simple sensations' (ἁπλᾶ αἰσθητά) when they are apprehended 'accurately' (ὅταν ἐνεργῶμεν ἀκριβῶς περὶ τὸ αἰσθητόν, *De Anima*, 428a13).

In its simplest form, one could define the first stage of the process thus: one starts by dividing the realm of the sensible into five 'families of sensibles' (τὰ ὑπὸ τὴν αὐτὴν αἴσθησιν), *i.e.*, seeing, hearing, touching, smelling and tasting (*De Anima*, III, i). After that, the challenge is to define the *full range* of each 'family of sensibles'. This is done by establishing a *maximal and minimal intensity of sensory stimulus* above or below which a normally functioning organ of sense either senses nothing because of the exiguity of the stimulus or is destroyed by the excessive intensity of the stimulus.[37] Between these two 'extremes' (ἄκρα, ἔσχατα, ἀντικείμενα), one finds all the 'com-*plex*-ions' (συμπε-πλεγ-μένα) it is possible to synthesise by blending the two qualitative 'extreme opposites' (μεγίστη διαφορά, τελεία διαφέροντα) at the top and bottom of the scale in differing 'proportions' or 'ratios' (λόγοι τῶν ἄκρων).[38] Hence, in the family of sensibles defined by the extreme opposites called brightness or darkness, a blend of the extremes in which brilliant white is superior to pitch black by a ratio of three parts to two will result in a shade of pale grey whose 'λόγος τῶν ἄκρων' is 3:2.

Once the full range of possible 'simple sensations' (ἁπλᾶ αἰσθητά) has been established in this way for each family of sensibles, it then becomes necessary to *systematically differentiate* the *varieties* of complexions arrayed between these two 'qualitative opposites'. More precisely, the task is to identify a variety of complexions Aristotle calls 'εἴδη πεπερασμένα' or 'definite forms of sensation'. There are two reasons why it is important to limit the different families of sensibles to a finite number of 'definite forms'. The first concerns the fact that the interval between the extremes delimiting each genre of sensible is a *continuum* (συνεχές) comprising *all* the different complexions a given class of sensibles can produce as 'blends', in varying proportions, of its delimiting extremes. However, because this continuum can be divided into an *infinite* number of ratios, using the latter to represent different complexions is of little use for distinguishing between perceptible forms *which are appreciably different from one another* unless the continuum in which these forms are seried is 'discretised' (τέμνεται) into a *finite* number of 'intervals' (διαστήματα) covering segments of the continuum which are neither too small nor too large to isolate a *single*, *self-same* 'simple sensation' (ἁπλᾶ αἰσθητόν) *noticeably* unlike any other in the continuum (*De Sensu*, 445b27-446a21).

[36]This is particularly to be appreciated as concerns the long-running 'literalism-spiritualism debate' pitting Richard Sorabji's 'physiological' reading of Aristotle's theory of perception against Myles Burnyeat's 'formalist' reading. For a summary of the positions and the issues, cf. [84]: 328-30. Proof that this debate was never more than a side-show is the fact that most recent studies on Aristotle's phenomenology have gone back to David Ross's simple, succinct, clear and undoubtedly correct analysis. Cf. [85] and [86] and then compare with [87]: 143-145.

[37]For a succinct and elegance summary, cf. [87]: 143 on *De Anima*, 424a2-10, 26-b1, 426a27-b8, 429a29-b3, 435a21.

[38]For the idea that any given sensation is a com-*plex*-ion (συμπε-πλεγ-μένον) generated as a mixture of the two 'extremes' (ἀντικείμενα, ἔσχατα) which embrace or enclose the family of sensibles the given sensation belongs to, cf. *De Sensu*, 445b24-27, 447b1, 448a10 as well as *De Anima*, 407b32, *Physics*, I, v-vii, *De Gen. et Corr.*, 324a5-9, 329a25*ff*. & *Metaphysiscs*, 1067a7, 1069b2-8. For the way these "μεγίστη διαφορά" are distinguished as either 'penetrative' (διακριτικός) or 'compressive' (συγκριτικός), cf. *Metaphysics*, 1057b8-34, *De Sensu*, 439b26-27, 440b18-21, 442a14.

To illustrate how this works in practice, consider the following illustration: everything contained in the continuum delimited by the extremes, we today would call ultraviolet and infrared belong to the family of sensibles called colours. But to identify the segment of the continuum corresponding to the colour yellow, it has to be distinguished both from the hues higher up on the spectrum that are more green than yellow and from the hues lower down on the spectrum that are less yellow than orange. Until that happens, until the chromatic form called yellow is isolated from the chromatic forms on the scale other than yellow, it is not possible to use a ratio to identify the interval on the scale which is yellow and nothing else besides. Hence, the first reason for limiting families of sensibles to a finite number of 'definite forms' was to be sure that ratios are useful for descriptive phenomenology because they stand for intervals of a 'qualitative continuum' corresponding to perceptible forms (εἴδη) which are *sui generis* because they are *perceptibly* different from all the other perceptibles belonging to the same qualitative continuum.

The second reason why these continua of sensibles need to be divided into a finite number of 'definite forms' (εἴδη πεπερασμένα) might seem to a hasty reading to concern essentially aesthetic considerations. In reality, however, it is about a great deal more, namely to have at one's disposal *a means to systematically and methodically define and organise the entire universe of sensibles according to a single template*. To see why it is fair to say this, we only need to look at the way Aristotle distinguishes between perceptible forms which are 'defined' (πεπερασμένα) and those which are not with the help of the arithmological distinction he makes between ratios he qualifies as 'definite', 'well-ordered' or 'rational' (ἐν ἀριθμοῖς εὐλογίστοις, τεταγμένος, κατὰ λόγον) and opposing them ratios he describes as 'undefined', 'disordered' and 'irrational' (κατ' ἀορίστως, ἀτάκτος, ὅλως οὐκ ἐν λόγῳ, *De Sensu*, 439b29-440a15, 440b20-21, 442a16). What makes the former category of ratios 'rational' and 'pure' (καθαραί) is quite simply the fact that they replicate the ratios of the concords of the heptapartite 'diatonic' pitch scale.[39] In other words, no ratio not expressible in the proportions 1:2, 2:3 or 3:4 can be considered anything but 'irrational' and 'impure'.

Not surprisingly, this manner of discriminating among 'rational' and 'irrational' or 'pure' and 'impure' ratios has implications for discriminating among 'pure' and 'impure' *phenomena* in that *no* simple perception (ἁπλᾶ αἰσθητόν) in *any* class of sensibles can be considered 'pure' or 'rational' unless the mixture of contrary qualities they are synthesised out of can be expressed as one or another of the ratios of the heptatonic pitch scale. And just as the 'pure' tones of the heptatonic pitch scale are said to yield 'concords' (συμφωνίαι) which are 'attractive' or 'pleasant' (ἥδιστα, ἡδονή), perceptions of forms in classes of sensibles *other than sound* too are 'attractive' when the ratios of their constituent blends of contraries replicate those of the pure concords of the heptatonic pitch scale. Hence, Aristotle's descriptive phenomenology consists of distinguishing 'pure', 'regular', 'exact' and 'attractive' 'simple perceptions' (ἁπλᾶ αἰσθητά) for *every* class of sensible by how well the ratios of the heptatonic pitch scale are replicated in the ratios which define complexions in classes of sensibles *other* than musical arrangements of sound. And we can be certain that this 'heptachotomic' organisation of perception does indeed apply to *every* family of sensibles, and therefore to the *totality* of phenomena, despite the fact that it is only in his analysis of colours and tastes that Aristotle makes this point clearly and

[39]For clarity's sake, be it noted that this expression should be considered a simplified variant of what specialists refer to as 'the tetrachordal intervallic structures at the base of the organisation of musical sounds in Greece' ([88]: 31) or 'the whole number ratios that govern the concordant intervals in music' ([82]) or 'the basic divisions of the octave by fifths and fourths from the extremes' ([89]: 442).

explicitly (*De Sensu*, 439b19-440a6, 442a17-29). A consideration of his use of the word 'commensurability' (συστοιχία) at *De Sensu*, 447b26-448a19 helps us see why this is so.

8. The ratios of the diatonic pitch scale as a template for defining 'εἴδη πεπερασμένα'

Typically, Aristotle uses the predicate 'commensurable' (ἐν τὴν αὐτῇ συστοιχίᾳ) when referring to qualities which may be 'different in form' (ἕτερα καὶ ἀνόμοια τῷ εἴδει) but are nonetheless 'of the same family' (ταὐτὰ καὶ ὅμοια τῷ γένει, συγγενῆ, ὁμόφυλα) and as such can be affected by and turn into one another but cannot turn into or be affected by qualities belonging to *other* families of sensibles 'except incidentally'.[40] However, when specified (τέμνεται) in terms of the ratios of the heptatonic pitch scale, phenomena belonging to *different* families of sensibles become 'commensurable with one another' (σύστοιχα ἀλλήλοις) *if and because they are defined by one and the same ratio*. In other words, the qualities 'sweet', 'dry', 'white' and 'soft' all unquestionably belong to different families of sensibles. However, but because the *ratio* of the interval each of them occupies in their respective qualitative spectrum is identical, they are all *eo ipso* 'σύστοιχα ἀλλήλοις'.[41] As a result, Aristotle's descriptive phenomenology is the product of two kinds of 'commensurability': one an 'intra-generic' commensurability *specific to a single 'family of sensibles'* and the other a 'trans-generic' commensurability, superposed upon the former, which is *based on the ratios of the diatonic pitch scale*. The following diagram illustrates how this looks graphically in that the vertical lines represent 'intra-generic' commensurability while the lateral dotted lines indicate 'trans-generic' commensurability.

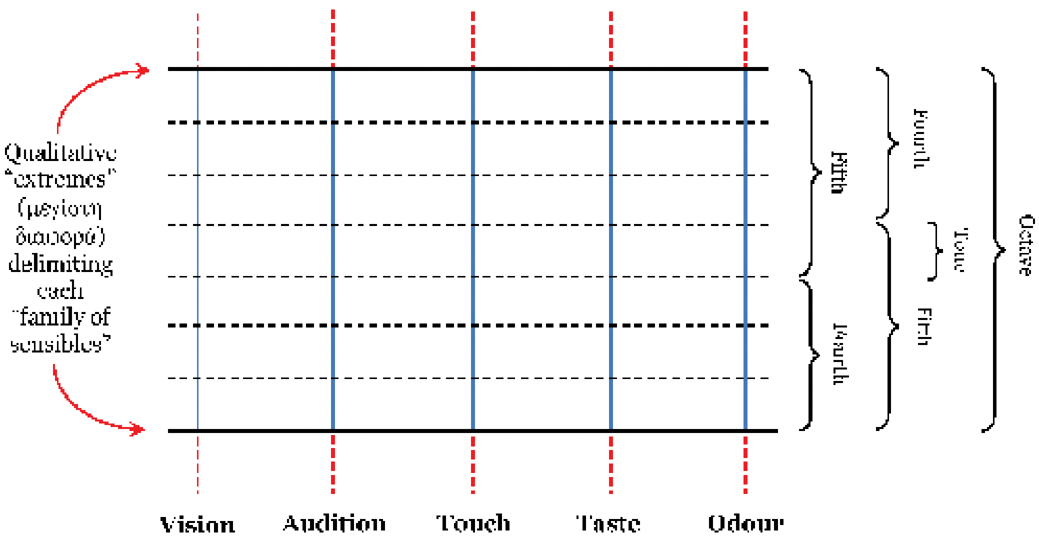

Figure 1. Intra- and trans-generic 'commensurability' in Aristotle's *De Sensu*.

[40]*De Gen. et Corr.*, 323b25-26, *Physics*, 188a32-b8, 224b28*ff.*, *Categories*, 14a20-22, *Post Analytics*, 75a38-b17, *Topics*, 123b1-124a9, 153a35-b24, *De Anima*, 416a 34, *De Sensu*, 447b1-3 & *Metaphysics*, 1057a27-30.

[41]A more detailed but very clear presentation of the same point can be found in [90]: 71-72, especially in his remarks on *Post Analytics*, 78b34-79a6.

To even a cursory glance, it will be obvious to the trained eye that this diagram can make no claim to being 'accurate' as concerns the magnitudes of the intervals that 'heptasect' the vertical lines in it as a function of the basic divisions of the octave indicated on the right hand side.[42] However, it at least has the merit of illustrating approximately how Aristotle's *De Sensu* uses 'the whole number ratios that govern the concordant intervals in music' as a template by which to define simple sensations (ἁπλᾶ αἰσθητά) which are pure, clear, pleasant and well-ordered *no matter what family of sensibles they may belong to*. As for the other, 'impure' simple sensations—unaccounted for in this diagram—, their comparative inferiority is not due to the fact that the blends of qualitative opposites they were synthesised out of cannot be mimed as a ratio; it is due to the fact that their ratios are merely 'κατὰ λόγον τῷ μᾶλλον καὶ ἧττον', *i.e.*, quantifications of blends of qualitative opposites *not* expressible in the whole number ratios 1:2, 2:3 or 3:4.

A longer, more patient treatment of what we have just seen would have given us the occasion to assess some of the voluminous commentary devoted to Aristotle's *De Sensu*. For example, the question of how well Aristotle mastered mathematical harmonics in his fifth-century Athens and, relatedly, whether or not something like a proper 'science' of harmonic even existed at that time [81]. We could also have pondered over why he failed to notice or seemed not to care about certain aporias which were attendant upon his use of arithmology for descriptive phenomenology. For example, the difficulties entailed by using a single ratio to stand for intervals which themselves perforce constitute infinitely divisible continua [93]. But as engrossing as curiosities like these may be in their own right, dwelling upon them will not help us with what matters here, which is ascertaining how all this pertains to 'scoring cosmopoiesis' *the way the composers of melic versets used to do it*. For that is all that interests us about Aristotle's use of arithmology in his descriptive phenomenology—the light it sheds on the way the 'inspired' *aoidoi* of archaic Hellenic 'Song culture' used melodies and rhythms to 'musically map' their *Lebenswelt* and in so doing lend a voice to the cosmic agencies which synthesise the 'sacred signs' (διοσημεῖαι) adorning the mesocosm that hosts our existences. To justify seeing Aristotle as a useful reference for such a light-shedding mission, let us remind ourselves of the still outstanding stages of the heuristic we proposed above, namely: (1) distinguishing between what is *and is not* Aristotelian in Aristotle's use of arithmology in his *De Sensu*; (2) contending that what is not Aristotelian in it is Philolaic and, finally; (3) arguing that what is specifically Philolaic about it does not mean that it cannot withal be considered a means for mapping cosmopoiesis the way it was done by melic versifiers if not 'from time immemorial' at least back to the Bronze age. To expedite the first of these three objectives, let us start with a reminder of what Aristotle says about the 'so-called Pythagoreans' in Book A of his *Metaphysics*.

9. Aristotle and the 'so-called Pythagoreans' in the *Metaphysics*

Though Aristotle was clearly in a hurry to discharge what he had to say about them, his haste does not prevent us seeing him make exactly the same point about the 'so-called

[42]For a systematic treatment on this matter, cf. [91, 92]: 160*ff*., [81]: 12*ff*. & [89]: 133*ff*. It is not unimportant to our point to mention that for practical musical purposes, *e.g.*, tuning a lyre, being 'accurate' about the basic divisions of the octave was often irrelevant given the diversity of 'culturally determined conceptions of musical agreeability' and the consequent proliferation of 'minor resonances' to satisfy these differing criteria ([89]: 136).

Pythagoreans' as the one Plato makes in the *Philebus* about 'the ancients, who were better than we and lived nearer the gods', for in both cases, it is a question of men who had come up with the idea of using the properties and ratios of a musical pitch scale as a means to represent everything in the universe on the assumption that those same properties and ratios structure and arrange everything in the cosmos that is not musical.[43] Alternately, they believed that in the same way that musical tones are blends of extremes delimiting a pitch scale, the substance, parts and attributes of everything peopling the perceptible universe too are synthesised out of blends of opposites delimiting various families of non-musical commensurables.[44]

Even though Aristotle does not identify his sources when speaking of the so-called Pythagoreans, the exegetes who have compared what he says of them in Book A with the attested fragments of Philolaus of Croton have little doubt that the latter's books must be the main source. Granted, this 'likelihood', plus the conspicuous resemblance of Aristotle's use of arithmology in *De Sensu* to the applications of arithmology routinely attributed to the Pythagoreans, is insufficient grounds for assuming that Aristotle had simply 'copied' what he found in his reading of Philolaus. In any event, making such an assumption would be tantamount to ignoring his robust rejection of various aspects of Pythagorean arithmology. For example, their alleged failure to make it subserve a worthy 'final cause',[45] their supposedly unsatisfying explanation of the way 'numbers' define sensibles,[46] their omission of a viable 'material cause' and, finally—and altogether incomprehensibly—the way they are supposed to have 'ontologised' numbers.[47] Still, despite these objections, and the efforts Aristotle makes to distinguish his use of arithmology from that of the Pythagoreans,[48] it cannot be denied that the idea of using 'numerical values' to define 'pure', 'attractive', 'rational' 'definite forms', and doing so the way Aristotle does it in *De Sensu* and elsewhere, is in large measure borrowed from what he found in Philolaus [78, 81, 82, 94].

But if this were so, if it were true that Aristotle's use of arithmology in his *De Sensu* differs but in details from what Philolaus would have said if he had developed a descriptive phenomenology of his own, what guarantee do we have that any of what we have just described reflects anything but Philolaus? The question matters to us because we are looking for reliable information about the way inspired singers of sacred song (θεσπιῳδοί) are supposed to have made melic verse the very voice of the divine because the melody and metre they used in composing it encoded the cosmopoietic significance of what they sang about. Hence, if in reading Aristotle's use of arithmology in his descriptive phenomenology we can be sure we find Philolaus, that would not be of much use to us if what the latter says about using ratios to score complexity was not shared by others, and more particularly by the *aoidoi* and rhapsodes who composed and performed the 'sacred song' in which guise the voices of Muses and Gods

[43]*Metaphysics*, 985b32-986a7, comp. *Philebus*, 17de.
[44]*Metaphysics*, 986b3-8: 'τἀναντία ἀρχαὶ τῶν ὄντων […] ἐκ τούτων ὡς ἐνυπαρχόντων συνεστάναι καὶ πεπλάσθαι φασὶ τὴν οὐσίαν'.
[45]*Metaphysics*, xiii, vi, 8, viii, 9-10, xiv, iii, 15, iv, 2 & vi, 1-2.
[46]*Metaphysics*, 1054a9-19 & 1077b18-1078a31.
[47]For justly severe criticisms of Aristotle on this obvious misreading of the Pythagoreans, cf. *inter alia*, [41]: 69, [82]: 56-64, [94]: 402-403, 456, [95]: 27 & [96, 97]: 164.
[48]This is especially evident in Aristotle's attempts to make *physical matter* rather than 'numbers' the substrate that gets determined by ratios (cf. *De Sensu*, 440b14-23, *Metaphysics*, 989b29, 1069b9, 1089b27).

were supposed to have graced the ears of their audiences. So, once again, why suppose that in reading Aristotle's use of Philolaic arithmology, we are reading anything but Philolaus?

10. Philolaus and musical practices in archaic song culture

As with so much of what concerns us here, the most serious obstacle to a straightforward answer to the question is the scarcity of relevant and unambiguous data. Some things, however, are not subject to doubt. For example, we cannot suppose that the 'science' of harmonics inaugurated by Philolaus, but more likely Archytas (Barker [90]: 29), was without precedent just because Plato, the Academy and Aristotle were so impressed by what they understood of Pythagorean 'mathematical harmonics' and so unimpressed by anything known about harmonics and its applications up to that time.

But if this means that Philoausian harmonics was not unprecedented, what precedents could we be speaking about? Certainly not ones that are traceable back to the 'oriental centres of learning' that some continue to invoke for *any* accomplishment it was once common to identify as a specifically Hellenic innovation [98]. In any case, not as concerns analysing musical arrangements of sound arithmologically and engineering what results from that analysis into a template for applications like descriptive phenomenology or scoring cosmopoiesis [94, p. 315]. For finalities like that Pythagorean speculation on the numerical nature of harmony is indebted to musical practices and theorisation going back to Indo-European times.[49] About this there can be no doubt. It is inconceivable that the archaic Hellenes could have produced and tuned musical instruments as sophisticated and elaborate as we know they were without some sort of arithmology and an arithmology that must have served as the basis of Philolaic and 'Pythagorean' 'number symbolism'.[50] We can also be certain that this same archaic arithmology was essential to the claim that 'music' lent a voice to the divine by being a means to 'mime' what the object of song owes to the cosmopoietic agencies which 'separated it off' (ἀποκριθῆναι) from pre-cosmic aether by 'cooking' it into a stand-alone, com-plex-ed being. And, finally, and even in the absence of any incontrovertible first hand evidence, we can be sure that these assumptions are as valid for legendary *aoidoi* like Orpheus, Tiresias, Musaeus and Bakis as they are for Hesiod, Alcman and the singers of sacred song alluded to in the *Homeric Hymn to Apollo* [5, 99].

Emphasising which is not tantamount to denying the early Pythagoreans all the credit that Plato's Academy, Aristotle and modern 'mathematical harmonics' enthusiasts think they deserve for 'revolutionising' music analysis. And not just for launching harmonics down the developmental path leading to Euclid's *Sectio Canonis* and Aristoxenus' *Elementa Harmonica*. Also by having contributed to doing to harmonics and music theory what the pre-Socratic natural philosophers are reputed to have done to 'the science of Being', namely wresting a

[49]It is revealing that even '*ex oriente lux'* zealots cannot deny this (cf. [99]: 381).

[50]For Philolaus' debt to 'empirical harmonics', cf. [81]: 266 whose careful analysis of the terminology used by Philolaus in the latter's key Fragment 6a makes it clear that 'every significant term in these sentences, with one exception [*scil.* the 'epogdoic'], belongs to the vocabulary of musicians'. Cf. also [89]: 114: 'For all we know, Philolaus' cycle through the four notes of the framework could well reflect the first steps that he carried out when tuning his lyre'.

de-supernaturalised, de-deified, disenchanted concept of Being from superannuated, mythopoeic *doxai* about the Gods ([96, p. 45*ff*.], [100, p. 204*f*.]).

Still, there can be no doubt about the debt of Pythagorean arithmology and 'number symbolism' to an extremely old bardic tradition, and there is no shortage of ways to credit this view. For example, even Leonid Zhmud, who questionably affirms that the heptatonic tone scale is a Pythagorean 'invention' [94, p. 292], nevertheless admits that it was, in some sense, latent in the techniques used by the archaic makers of musical instruments while plying their trade. And M.L. West, Andrew Barker and Carl Huffman make substantially the same point about Alcman, Lasus of Hermione and Epigonus of Ambracia while emphasising that even though there is no reason to suppose there was anything 'Pythagorean' about the way the latter theorised about music, that did not prevent them coming up with ideas on the links between harmonics and cosmopoiesis whose 'arithmology' differed but in details from the 'Pythagorean diatonic' [5, 90, 82].

So, once again, there is no question but that the so-called Pythagoreans brought something original both to music theory and to its applications outside music theory and singularly in epistemology, cosmology, ontology, phenomenology and ethics. Still, like Fraenkel [72], Burkert [78] and Lohmann [101], I believe that it is less accurate to say that the Hellas provided fertile grounds on which specifically Pythagorean ideas on harmonics and their extra-musical applications could take root than it is to characterise those ideas as a distillate or *Aufhebung* of 'theoretical' potential that was latent in that terrain.[51] Something we are at pains to stress here because it is critical to everything we said above about Aristotle's phenomenology and the way it is representative of earlier, 'archaic' ideas on 'scoring complexity' and 'miming' the 'ballet' (*χορεία*) of the cosmopoietic agencies that power the universe into its perceived aspect. For in reading Aristotle's phenomenological discourse in *De Sensu*, we do indeed discern the use of unmistakably Philolaic ideas on harmonics as a template for scoring phenomena as 'definite forms' (*εἴδη πεπερασμένα*). But precisely because we are seeing that, we are seeing a great deal more. In other words—and albeit only approximately, selectively and at the level of general principles—, we are seeing the way early Hellenic *aoidoi* and 'musicians' (μελοποιοί, μουσοποιοί) composed and performed melic verse when it was their intention to make 'sacred song' a means to hear the divine in and as melodised tones and metred rhythms. To illustrate how we can be relatively certain of this, even in the absence of solid proof and incontrovertible testimony, let us go back to the diagram in **Figure 1** on page 15.

For the reasons given above, the manner of melodically mapping complexity illustrated in it must in the final analysis be considered a schematic rendering of *Aristotle's* 'descriptive phenomenology'. It is not withal a melodic signary that legendary singers of sacred song like Orpheus, Eumolpe or Tiresias would have disapproved of.[52] But approve of it though they might, they would no doubt nonetheless have pointed out that something is missing from it. Namely, any reference to what occupies or at least ought to occupy *the spaces above*

[51]Cf. [78]: 298 & [101]: 5-6.

[52]Even though Wersinger does not mention these legendary *aoidoi* by name in her patient analysis of 'le terme *sustoichia*' ([102], p. 232*ff*.), what she says in her gloze of the sources and testimonia she scrutinises nevertheless significantly substantiates the point we are making here.

and below the diagram and which are 'hyphenated' by the vertical lines in it. A remark which is not intended to suggest that Orpheus' illustrious successors had neglected to think of putting something in these spaces. However, where Aristotle would have made use of them to be sure that what is between them semiotically subserves his formal, final, proximal and material causes and Plato would have used them to rhapsodise *ad more geometrico* about the 'harmony of the spheres', the inspired *aoidoi* in song culture would have opted for a simpler alternative. They would have placed this diagram *en abyme* in relation to the 'Ouranides' (Οὐρανίωνες) by reserving the space above for 'starry Ouranos' and the space below for 'all-bearing Gaia'. They would have done that because as far as they were concerned nothing ever crossed—or ever will cross—the stage of the mesocosm hosting our existences that is not a 'passion' or 'birthling' (πάθημα, τέκνα) of the 'sacred marriage' of the Sky and the Earth. Consequently, this 'marriage' is something one *must* signal when it is one's desire to sing of things to the power of the agencies to which they are beholden for their time, place, nature, character, destiny and Being-what-they-are.

The semiotic implications of this view for what is going on in this diagram speak for themselves. For placing the sign system depicted in it *en abyme* relative to these divinities and their cosmos-creating relationship entails more than transforming the vertical lines in it into so many 'hyphens' which conjoin Ouranos above and Gaia below. It entails transforming them into mediums *in, through* and *as* which the cosmos-synthesising dynamics of Ouranos, Gaia and their 'sacred marriage' receive a 'melodic signature' and in the guise of that signature convert any 'sacred song' containing it into the very voice of the divine. That was the point of using the ratios of the diatonic pitch scale to 'heptasect' the qualitative continua these lines stand for. It was a question of being able to 'mime' different 'complexions' in melodised tone and metered rhythms. However, this 'mimesis' was not just 'eikastic'. In other words, the goal was not merely to define or specify different complexions by distinguishing their particular perceived aspects from those of other complexions belonging to the same family of sensibles. It was also, and above all, to quantify the contribution made by the Sky and the Earth to the blend of energies which give complexions and complexity what they appear to be when observed.

In any event, if this sign system could not do that, if in quantifying complexions as 'ratios of qualitative extremes' it did not *always, already, also and thereby* 'co-mime' what blends of Sky and the Earth energies made those complexions be by blistering pre-cosmic aether into their perceptible forms, it could not be a way of 'scoring complexity' that an 'inspired' singer of 'sacred song' could have taken seriously.

11. Concluding remarks

Readers who cast a critical eye back upon what was said in the foregoing will no doubt have reservations about some aspects of what they read. Most likely they will be particularly pronounced as concerns our portrayal of the way melic verse in archaic song culture was used to 'score' cosmopoiesis. For if the point of composing sacred song was to sacralise its referents by 'epiphonising' their cosmopoietic significance, one would have to assume that this applies to subject matter that could be literally epic in scale and complexity. Why then did we limit our demonstration of the semiotics of the process whereby this happens to the way *individual* musical notes stand for *individual* ἁπλᾶ αἰσθητά? Alternately, why was not anything said about the way musical notes could be concatenated and counterpointed in such a way as to epiphonise the cosmic significance of highly complex situations and subject matter in which multiple *composite referents* interact dynamically over time and space with other *composite referents*?

Other readers will wonder why we spoke of 'melodised tone' and 'metered rhythm' together when the only 'sign system' we discussed was one based on the diatonic pitch scale. This could give the impression that 'melic verse' could not 'mime' cosmopoiesis except as melodised tones and that 'metered rhythm' must therefore have played no more than an auxiliary role in the signifying process. This is most regrettable given that it has been argued to great effect that 'the self-declaration by things themselves about their very Being' can be signified through metered rhythms all on their own.[53] Still other readers will feel that space should have been devoted to way the inspired *aoidos* was like and yet unlike the inspired oracles who did not or could not 'sing' and therefore required the assistance of various hermeneutic middlemen (ἑρμηνέων ἑρμηνῆς) to give a legible expression to the intelligence they incubated whilst in a theoleptic fit.

To the readers who raise these objections and others that are just as legitimate, I offer the admittedly lame excuse that only so much can be covered in an article length treatment of the semiotic *punctum caecum* we explored and that some of the resulting insufficiencies will be redressed in a planned book length study devoted to this chapter's *Sache selbst*. I will also add that their reading will not have been in vain if it has succeeded in making them see some merit in the modest point this chapter wanted to make and which I resume thus.

People listening to the 'sacred song' composed and performed by an 'inspired' *aoidos* were hearing the 'melodic signature' of the cosmopoietic dynamics that gave the object of the song the 'complexion' in which guise it was accessible to the 'non-inspired' audience. The semiotic rationale behind this claim was a mimetic correlation between (i) the arithmological characteristics of the melodies and rhythms structuring the sounds one heard in the song and (ii) the arithmology used to give a quantitative expression to the blends of cosmic energies that powered the song's subject matter into its complexion and its Being-in-the-world. As a result, the listener was hearing two narratives about the object of the song: one in the profane, ordinary words of mortals recounting what it means *sub species hominis*, the other in melody and metre relating its sacral, cosmopoietic significance. This is why it is so apt to refer to 'sacred song' or θέσπις ἀοιδή as a form of 'hieroglossia'. For the goal of the hieroglossia peculiar to 'θέσπις ἀοιδή' was to 'oversignify' the ordinary acceptations of the object of verse signified in prosaic words and narrative and do so by telling a separate narrative about the same object in a language whose form was 'musical' rather than 'lexical' and whose semantics were 'hieratic' rather than 'profane'.

[53]On '*das Substantielles sich-bekunden der Dinge selbst*', cf. [32]: 63-69, [34]: 125-126, [76]: 42-45.

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Chapter 5

Music and Semiotics: An Experiential Approach to Musical Sense-Making

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Additional information is available at the end of the chapter

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Abstract

This chapter sketches recent evolutions of semiotics as applied to music. Rather than providing merely a historical overview, it focuses mainly on the pragmatic turn in semiotics and the role of sensory experience in the process of musical sense-making. In order to elaborate on this experience, it delves into theoretical groundings of second-order cybernetics, biosemiotics, and ecological psychology, which are then applied to the field of music. Much effort is made to provide a broader framework to illustrate the transition from a disembodied to an embodied approach to musical semiotics. Special emphasis is laid on the concept of affordance and the role of interactions with the sounds.

Keywords: semiotics, musical sense-making, musical experience, pragmatic turn, biosemiotics, ecology, affordances, embodied cognition, enactive cognition

1. Introduction: semiotics as a discipline

Semiotics has a long tradition as the science of signs. There is, however, no agreement as to a general definition of the field. Three major descriptions have been proposed: semiotics as the science of signs and communication systems, semiotics as a description that leans upon linguistic methodology, and semiotics simply as scientific description [1]. The linguistic strand has received most attention in the past, with a strong impetus from French structural linguists as de Saussure and Greimas. This *structural approach* has been valuable in providing basic conceptual tools, e.g., "signifier" (the material sign that signifies) and "signified" (that which is referred to) [2]. This structural approach has been challenged, however, by its blindness to the role of the "sign user" in the process of sense-making. Semiotics thus had to broaden its field by encompassing also the interpreting mind with a transition from a dyadic to triadic approach as emphasized already within analytical philosophy, action theory, general systems theory, and the semiotic tradition of Morris and Peirce. Basic in this approach is the dynamic relationship between three levels of semiotic reference: the material sign vehicle, the object it refers to, and the final decoding by the interpreter.

This has been most notable in the pragmatic approach to sense-making, with an initial opposition between two traditions in semiotics which were greatly independent from each other: the "Anglo-Saxon tradition" which was oriented mostly to the theoretical framework of Peirce and the "continental tradition" (mostly Italian, French, and Slavic) with a principal orientation to the schools of de Saussure and Hjelmslev. Both positions, however, have started to come nearer to each other as a result of the *pragmatic turn* in philosophy [3–7]. This has been the case also for the domain of music and performing arts in which music has a primordial role [8–11]. There is, in fact, a growing influence of the experiential dimension in the study of music in all its aspects. This embraces theories of externalization (embodiment, corporality, individual biographies of composers/performers/listeners) as well as other disciplines such as theories of performance, neurosciences, and cognitive sciences and other methodological approaches which are based on the subjectivity of expression (presence, effects of presence, transmediality, and relation between body and machine). There is, so to say, a broadening of the field of study which investigates music from the points of view of cultural esthetic practice, the performing process, and historical-cultural forms. Music, in this view, can be considered as a spectacular phenomenon with multiple dimensions which can be studied in its intermedial dimension [12]. As such, concepts as *transdisciplinarity* and *transmediality* have been substituted for interdisciplinarity and intermediality in the sense that the prefix "inter" implies that the different disciplines can at least be distinguished from each other, whereas the prefix "trans" calls forth an interpenetration and abolition of possible differences. This is obvious, for example, in the context of an opera or an installation, in which case it is very difficult to distinguish between what is merely musical and the physical presence of the musician and the poetic language that is used. Many efforts have been done and are being done, therefore, to describe this complexity in a more systematic manner [10, 11].

2. Semiotics: an operational approach

Semiotics, as the "science of signs," has been criticized for the lack of intersubjective validity of its conceptual framework. This holds true for the French tradition but also for the numerous taxonomies of signs that were proposed by Peirce. There is, however, a more operational approach to semiotics which was introduced by Morris [13, 14] who distinguished between three dimensions of the semiotic process with respect to the relation of signs to signs, objects, and interpreters and which he coined, respectively, as *syntactics*, *semantics*, and *pragmatics*. The latter, especially, has broadened the field to include the reactions of sign users.

Pragmatics, in fact, has been fruitful in introducing the observer as part of the semiotic process. It was Peirce, in particular, who put the sign in a triadic relation. Going beyond the scholastic conception of reference—aliquid stat pro aliquo—with the sign process breaking up in something that signifies and something that is signified, he broadened the Saussurian

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distinction between signifier and signified to include the consciousness of the interpreter in the sign process:

> *A sign, or representamen, is something which stands to somebody for something in some respect or capacity. It addresses somebody, that is, creates in the mind of that person an equivalent sign, or perhaps a more developed sign. That sign which it creates I call the interpretant of the first sign. The sign stands for something, its object. [15] (p. 135).*

This distinction between sign, object, and interpretant has been a major contribution to the operational approach of the sign process. It has even received renewed impetus with theoretical elaborations in the field of "second-order cybernetics" and the field of "biosemiotics."

Second-order cybernetics presents a paradigm change in scientific discourse which conceives of the observer as a participant and as part of the observed system, with a major focus on the role of interaction, emphasizing the role of the knower and observer rather than the known things or events [16–23]. It stresses the role of subjectivity and its influence on our reactions to the environmental outer world. As such, it must be considered through the first-person perspective and with active verbs.

Biosemiotics, on the other hand, can be described as that area of knowledge which describes the biological bases of the interaction between an organism and its environment [24–26]. It typically studies those signification processes which are typical for living organisms in general and which are rooted in their biology (for an overview, see [27] and [28, 29] for an application to music) and can be considered as an interdisciplinary field of theoretical and empirical research of communication and signification in living systems, with a focus on the study of the behavior of living systems in their interaction with the environment.

As such, a full description of perceiving cannot be given by analyzing only either the organism or its environment (organism-environment dualism). What is needed, on the contrary, is an approach which is not "animal/organism neutral" but which treats the environment as perceived.

Central in this approach is the role of *circularity* between action and perception. It is an idea which has been retaken in current research, with a culmination in the recent boost of *perception-action studies* [30–36]. They all stress the role of the observer in establishing new semiotic links with his or her environment as the result of previous interactions with the outer world. Starting from seminal contributions by von Uexküll and the ecological framework by Gibson, revolving around the concept of affordance and active search for information, a whole research program has been set up, which is likely to provide a substantial body of empirical grounding for semiotics as the science of sense-making.

Von Uexküll's work (see [29, 37, 38] for musical applications) has been seminal to the field. His key concept of functional cycle (*Funktionskreis*) is a very useful contribution to the study of interactions between a human/animal organism and the objects of its surrounding world:

> *Figuratively speaking, every animal grasps its object with two arms of a forceps, receptor and effector. With the one it invests the object with a receptor cue or perceptual meaning, with the other, an effector cue or operational meaning. But since all of the traits of an object are structurally interconnected, the traits given operational meaning must affect those bearing perceptual meaning through the object, and so change the object itself. [37] (p. 10)*

The basic mechanism of the functional cycle is a simple, recursive loop between action and perception. It stresses the role of the organism as the subject of interaction in terms of sensorimotor integration, with behaviors consisting of perception and action which are organized in a meaningful way. The concept has proven to be fruitful. It has its origins in the concept of the reflex arc, but the linearity of the stimulus-reaction chain is replaced by the concept of circularity. Every stimulus, in this view, presupposes a readiness to react, allowing the organism or animal to select as a stimulus a phenomenon of the environment which has been neutral up to that point. Rather than thinking in terms of reactivity to an external environment, we should conceive of the construction of an internal model of the world. The external environment is objectively there, but it can be assessed only as part of the subjectively perceived environment or *Umwelt*, as von Uexküll coined the term. Such a phenomenal world calls forth a set of "mapping relations" between an organism and the external reality, a semiotic world of subjective meanings imprinted on all objects as a private subset of the world at large [39]. Functional cycles, then, encompass all the meaningful aspects of the world for a particular organism—they make up their respective Umwelts—and are the actual root of intentionality, bringing together the world of sensing and acting through processes of signification which invest the objects with perceptual and effector tones.

The critical element in this approach is the sensitivity to the functional characteristics of the environment. This has also been the basic claim of Gibson's *ecological psychology*, which revolves around the central concept of *affordance* ([40, 41], see also [42, 43]), which stated that animals perceive their environment in terms of what it affords to the consummation of their behavior, rather than in terms of their objective and perceptual qualities:

> *The affordances of an environment are what if offers the animal, what it provides or furnishes, either for good or ill. [41] (p. 127)*

Affordances refer to the environmental supports for an organism's intentional activities by claiming that animals—and by extension also human beings—are sensitive to the functional characteristics of their environment. As such, they can be considered as subjective qualities that render the environment apt for specific activities, such as supporting locomotion, concealment, manipulation, nutrition, and social interaction for the animal. It is a conception that points to an important quality of the world, namely, that its features are meaningful for an active perceiver who perceives this world in terms of functional significance of an object, event, or place.

Affordances, moreover, are interesting conceptual tools. They rely on objective environmental features of the world but also on perceiver-specific qualities, which are variable and subjective to a great extent. As such, they go beyond an objective/subjective dichotomy by claiming that there is no outside standing over against an inside, but only ways to classify experiences [44].

The concept of *functional significance* is really important here. It stresses the importance of sense-making as an act of deliberate attention and epistemic autonomy and brings together ecological, pragmatic, and biosemiotic claims. Listeners, in fact, build up relations with their sonic world by selecting some elements to give them special meanings. In doing so, they construct their own sonic Umwelt, as a collection of subjective meanings that are assigned to a specific subset of the sounding environment.

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3. Semiotics and music

There is actually a huge body of semiotic studies as related to music. Most of the earlier studies are related to structural, phenomenological, or hermeneutical approaches. Though valuable, these approaches do not yet fully embrace empirical facts that validate the grounding theories. An interesting attempt to broaden the field has been initiated by the reliance on Morris' division of semiotics in three dimensions (syntactics, semantics, and pragmatics) and the tripartition proposed by Molino [45] and Nattiez [46] with a distinction between an "esthesic," "poietic," and "neutral" level of description, referring, respectively, to the process of creation (poietic), the process of reception (esthesic), and the form and content (neutral) of the music. This tripartition, which has been contested also to some extent, has enabled semioticians to free themselves from certain constraints that were imposed by mere structural analyses which conceive of music as a closed system.

In the domain of music, the traditional analytical approach has been directed mostly to the *syntactic level*, leaning heavily on the contributions from linguistics. Scholars such as Molino [45], Nattiez [47], and Ruwet [48] have been exponents of taxonomic-empirical research. Starting from a neutral level of description, they have made major attempts to classify the sound (i.e., the empirical data) in an objective and scientific way, using a kind of taxonomy in order to select and identify the classes of objects that can be arranged in terms of similarity and difference. Central in this approach are procedures of division and extraction of structural elements, which offer decoding strategies that work "from text to code" with structural units that are describable in a formal way. To quote Nattiez:

> *…it is no longer a question of knowing whether one of the fragments … is a motif or a cellule: it becomes an a, or A, or x, no matter which, possessing certain characteristics, which are defined by a group of features (melodic, rhythmic) which make it possible to compare it and classify it, that is to place it in hierarchy in relation to all the other segments of the piece. At the level of the metalanguage of the analysis one can guess what the immediate tasks of musicology will be: to develop fully a formal, artificial, explicit language which can take into account all the units one can find in music and their combinations. [1] (p. 63)*

Such an analytical methodology operates at the neutral level of description. It reduces structural units to a purely formal level, stressing the more essential parts and eliminating nonessential aspects as being unimportant. The way of doing this is to use signs and symbols instead of real things. Signs, however, represent objects at a reduced level of cues, which means that the sign will not call forth all the responses that the object itself could do. This is the price we pay for the transposability of the sign system that we use instead of the less transposable original. The advantages, on the other hand, are numerous. They are, however, not sufficient to explain the richness and fullness of a real-time listening experience.

There have been contributions to the level of *musical semantics* as well [49–52], with a distinction between musical meaning being defined as referring to something outside of the music ("external" or "real" semantics) and as referring merely to itself ("internal" or "self-referential" semantics) (see [53] for definitions and [54] for empirical grounding). The level of self-referential semantics, however, is somewhat ill defined, as it conflates somewhat with the syntactic level. It calls forth the syntactization of semantics as advocated already in the 1930s—the logical semantics of Carnap and the model-theoretic semantics of Tarski—with an approach that is accomplished by completely encoding the world so that the elements (mostly formal symbols) are seen in relation to completely logical-symbolic structures without the need of specifying any set of observables and without the need of verifying their truth values with respect to an outer world. In Saussurian terms, this should mean that *signifier* and *signified* blend together and that musical signifieds are internal to the musical system, without any reference to something outside of the system. The signifieds, in this view, are not denotative or lexical but self-reflective [55] which means that they refer mainly to themselves. What matters merely is the identification of sonic events and their interrelations, without any relation to the external world. Music, then, is a carrier of immanent meaning, with sounding elements as recognizable entities that can be assigned some meaning or semantic weight. Unlike language where attention is directed away from the text in order to grasp the meaning outside of the written text—the centrifugal tendency of linguistic meaning—music is characterized by a centripetal tendency with a focus on the auditory material [56].

The distinction between internal and external semantics, however, is not so radical as it may seem. Music, as a sounding phenomenon, relies on both of them in the sense that elements that are referring to themselves may trigger processes of sense-making that refer to the external (the sounding environments) or the internal world of the listener (bodily resonance). To the extent that a listener experiences a particular sound as a real sounding thing that originates in the *external environment*, there is an aspect of external reference and of external semantics. As soon, however, as the listener starts doing mental computations on this sound, there is a shift from presentational immediacy to cognitive mediation. The listener, then, does no longer conceive of the sound in its experiential qualities but at a symbolic level of representation, with processes of recognition and identification that replace the fullness and richness of an actual real-time experience. Music, in that case, is conceived "in absentia" and not "in praesentia," to use de Saussure's terms [57]. The reference to the *internal environment* of the listener, on the other hand, has received considerable impetus from the hard sciences, in particular from cognitive neuroscience and the neurobiological research with a special focus on the inductive power of music and its effects on the body and the brain. It means that stimuli do not necessarily originate from the outer environmental world. They can have their origin in our proper body with all kinds of sensory or motor reactions to the sounds. The issue is somewhat related to the distinction between distal and proximal stimuli in perception. Distal stimuli correspond to what is considered an actual object or event in the environment; the proximal stimulus is more narrowly defined as the pattern of energy impinging on the observer's sensory system. The energy is associated with the distal stimuli, but the observer depends most directly on proximal stimuli for perceiving the world. For certain perceptions, however, there is little distinction between the two. Touch is an example, as the distal stimulus that is responsible for the sensation is created when the object that serves as distal stimulus is in physical contact with the observer [58]. The distinction, however, needs further elaboration as proximal stimuli are situated mostly at the boundary (mostly the skin and special sense organs) between the inside and the outside of the body. Yet, there is also the visceral part of our body, together with our bones, muscles, and connective tissues which all are able to trigger reactions to the sounds to the extent that are resonating to these sounds. This is, in fact,

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the province of vibro-acoustic medicine [59, 60] which investigates the bodily and visceral reactions together with that kind of information processing that is tuned at monitoring the internal environment of our body. It seems, in fact, that sound vibrations may be organized and targeted to arouse certain bodily functions to induce particular physiological responses. Musical sense-making, in this view, cannot be reduced to a detached and disembodied nature of cognition [61]. It calls forth, on the contrary, an embodied and enactive approach that conceives of music users as organisms that are endowed with a sensory and motor apparatus that enables them to carry out interactions with their environment.

This brings us to the third dimension of musical sense-making, the *pragmatic level*, which investigates the relations between sign vehicles and their users and the processes involved in the interpretation of signs. Meaning, in this view, is not to be defined in terms of ontological categories but in terms of dispositions to react to external stimuli. It includes the listener—or more in general, the music user—as a principal participant in the semiotic process, both at the level of reception, action, and mental processing and computation. As such, it calls forth dimensions that go beyond a mere object-centered, esthesic, or poietic approach. The configuration of our body and our cognitive faculties, in fact, determines not only our ways of listening but also the execution and creation of the music, which make it possible to understand and to live a musical experience.

As a discipline, musical pragmatics is still in continuous development (see [10, 11]). Starting, to some extent, from the conceptual framework by Peirce and Morris, it has made considerable efforts to describe the music in a richer and more complex way. This is even more the case nowadays with multiple contributions that are borrowing avidly from other disciplines such as the cognitive sciences, psychology, neurosciences, and even philosophy and neuropragmatics [62–65]. The whole body of music and emotion studies as well as studies on the effects of music and its inductive power are likely to provide substantial empirical grounding for this approach [54, 66, 67].

4. New perspectives on musical sense-making: biology and embodiment

The pragmatic approach brings us to some new perspectives on musical sense-making which are characterized by the conflation of scientific disciplines and levels of semiosis. They can be summarized as belonging to one of the following explanatory theories: (i) the ecological approach to listening, (ii) the biosemiotic approach, (iii) the biological and embodied approach to musical sense-making, (iv) the enactive approach to musical semantics, and (v) the experiential approach and the inductive power of music.

The *ecological* and *biosemiotic* approaches have been described already above. They revolve around the concept of affordance and the construction of an internal model of the sounding world as the outcome of interactions with this world. The concept of *musical affordance* is really important here. It means that we should try to understand music in terms of what it affords to us and not merely in terms of its acoustical qualities [68]. The question, however, is what these musical affordances are? There seem to be four major possibilities: (i) the exploration and investigation of sounding material and the production of musical instruments, (ii) the exploration and mastering of techniques in order to produce musical sounds, (iii) the shaping of the sound by using modulatory techniques, and (iv) the phenomenon of musical entrainment and motor induction.

The whole history of musical instrument building is typical of the first. It can be considered as one prolonged search for applying craftsmanship to raw materials in order to obtain musical sounds. About all kinds of materials have been scrutinized for what they afford to human ears from a musical point of view. Playing techniques, as a second possibility, are also related to this search for sounding materials, but an additional focus is laid on the sound-producing actions, which encompass singular actions like hitting, stroking, kicking, and blowing as well as more complex or compound ones. Examples of the latter are drumming a rhythmic pattern or sliding up and down a melodic contour. But even the metaphors used in talking about music may refer to sound-producing actions (slow, fast, up, down, etc.), and the same applies to musical terms like martellato, leggiero, tenuto, and legato [69]. The shaping of the sound is a further extension of the second possibility for sound production. It is exemplified most typically in string players, wood players, and singers. Strings, e.g., can be plucked or bowed, and within such action categories, there is even a whole spectrum of techniques for further modulation of the sound. The same holds true for a singer who shapes the sounds that result from the air supply provided by the lungs. Singing, in fact, is not merely reducible to the production of vowels and consonants but involves also aspects of intonation and ways of emotional expression such as timing, articulation, dynamics, tone onsets, and vibrato. It embraces a whole gamut of sentic modulation [70, 71], i.e., a general modulatory system that is involved in conveying and perceiving the intensity of emotive expression by means of three graded spectra—tempo modulation, amplitude modulation, and selection of register—somewhat analogous to the well-known rules of prosody.

A last interpretation of music in terms of affordances, finally, is more manifest and involves musical entrainment and motor induction. It calls forth the possibility to move in reaction to the sounding music. Music, then, is a stimulus for movement and is perceived in terms of its motor induction capacities. The movements can be specific and articulate, but they can relate also to more general levels of motor induction, as forces and energies that are inherent in musical structures, which, in turn, account for our perception and imagination of tension, resolution, and movement.

It is thus possible to conceive of music in terms of its *activity signature* with at least five major possibilities: the sound-producing actions proper, the effects of these actions, the possibility of imagining the sonorous unfolding as a kind of movement through time, the mental simulation of this movement in terms of preconceptual bodily experiences or bodily based image schemata, and the movements which can be possibly induced by the sounds [68].

All these examples are musical affordances that refer to the level of sound production. It is possible, however, to go beyond the mere productive level and to conceive of affordances at the level of experience as well. To conceive of music in terms of experience involves at least an aspect of *egocentricity*, in describing subjective experiences in terms of bodily resonance or motor imagery that projects our bodily movements to the music. Affordances, in this extended view, embrace perceptual qualities, mood induction qualities, and socio-communicative qualities, invoking aspects of sense-making, emotional experience, esthetic experience, entrainment, and judgments of value [72–74].

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The *biological approach* is an extension of the ecological and biosemiotic approach [28]. It revolves around the biological concept of adaptation and the possibility of coping with the sounding world. As such, it takes as a starting point the concept of sensorimotor integration, which questions the origin of structural solidarities and functional cohesions that are to be found in the individuation of biological systems and the interdependency of an organism and its environment. The organism enriches, in a way, its repertory of genetic adaptations with acquired dispositions that are the outcome of its capacity to control present activities in terms of personal experiences that are the outcome of previous activities [75] (p. 925).

This brings us to the *embodiment hypothesis* of cognition, which understands perception as "perceptually guided action" and conceives of sensory and motor processes as being inherently inseparable, mutually informative, and structured so as to ground our conceptual systems [76] (p. 173). It is a point of view, which argues for a biological interpretation of the experiential world, allowing observers to explore their environment with their bodies and their senses. As such, the mind is not to be seen as a passive reflection of the outer world, but as an active constructor of its own reality with cognition and bodily activity implying each other to a high degree. The fundamental building blocks of cognitive processes, in this view, are not disembodied propositions and representations but control schemata for motor patterns which arise from perceptual interactions with the environment [77].

Musical sense-making thus calls forth processes of sense-making and engagements that allow the listener to "enact" a musical experience and to react even bodily to the sounds [72]. The claims are closely related to the *embodied* and *enactive approach* to cognition which defines it in terms of "nonobjectivist semantics." It is a promising area of research that defines cognition not as the representation of a pregiven world by a pregiven mind but as "the enactment of a world and a mind on the basis of a history of the variety of actions that a being in the world performs" [76] (p. 9). Understanding cognition, then, is not taking the world naively—this is the claim of *naive realism*—but seeing it as having the mark of our own structure, which we are cognizing with our mind [76] (p. 16). Knowledge, thus defined, is the result of an ongoing interpretation that emerges from our capacities of understanding—this is the claim of *cognitive realism*—which are rooted in the structures of our biological embodiment but which are lived and experienced within a domain of consensual action and cultural history [76] (p. 150). Such a view is a "nonobjectivist" orientation to semantics that views cognition as enaction and that is consonant with the "experimentalist" approach to cognition. It is, in fact, a *cognitive semantics* that accounts for what meaning is to human beings, rather than trying to replace humanly meaningful thought by reference to a metaphysical account of a reality external to human experience ([78] (p. 120), see also [76, 79]).

The epistemological claims of *experiential* and *enactive cognition* define meaning as a matter of human understanding. They are highly dependent upon structures of embodied imagination and highlight the dynamic and interactive character of meaning and understanding [79] (p. 175). As such, they are typical examples of "nonobjectivist semantics": they do not take the world naively, i.e., objectively, but conceive of it the result of understanding, imagination, and embodiment.

The embodied claims have received a lot of attention in recent developments in cognitive science, with a move toward the inclusion of the body in the understanding of the mind as exemplified most typically in the experiential approach of cognitive linguistics (see [29, 78–87] for musical applications), which states that the fundamental conceptual representations in the human cognitive system are schematic perceptual images extracted from all modes of experience.

Cognitive scientists, further, have begun to infer connections between the structure of mental processes and physical embodiment [86]. This viewpoint, also known as *embodied* or *situated cognition*, treats cognition as an activity that is structured by the body which is situated in an environment that shapes its experience. It calls forth a conception of embodied action which is closely related to theories of cognitive organization which treat cognition as an activity that is structured by a body which is immersed in an environment. Cognition, in this broadened view, depends upon experiences which are based in having a body with sensorimotor capacities that are embedded in an encompassing biological, psychological, and cultural context.

Such a theory of *cognitive organization* challenges the propositional approach to sense-making. Rather than thinking in lexico-semantic terms, it reconceives the nature of linguistic meaning by stressing the role of metaphor as a basic structure of understanding. Embodied cognition, in particular, stresses the role of the body in providing "cross-domain mappings" as metaphors make it possible to conceptualize an unfamiliar domain (the target domain) in terms of another more familiar domain (the source domain). The human body, in this view, can function as a primary source for this kind of mapping.

5. The role of sensory experience and real-time interactions with the sounds

The enactive approach to music cognition is a challenging new area of research. It provides a useful theoretical framework for setting up a full-fletched program of empirical research. This holds true especially for the study of musical affordances (see above) but also the study of real-time listening can benefit from this approach. It can even be subsumed under a broader area of research which is related to the musical experience and the way listeners make sense of sounding music (see [57, 88, 89]).

Starting from a definition of music as a temporal and sounding art, it seems arguable to revalue some older contributions by pragmatic philosophers as Dewey [90] and James [91], who elaborated already extensively on the subject of *having an experience*. As Dewey states:

> *Experience in the degree in which it is experience is heightened vitality. Instead of signifying being shut up within one's private feelings and sensations, it signifies active and alert commerce with the world; at its height it signifies complete interpenetration of self and the world of objects and events. [90] (p. 19)*

This heightened vitality has adaptive value, as exemplified in the life of the savage man who is in danger in a threatening environment. Observation, for him, is both "action in preparation" and "foresight for the future." They are not merely pathways for gathering material that is stored away for a delayed and remote possibility, but they function as sentinels of immediate thought and outposts of action [90] (p. 19).

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A musical experience, accordingly, is not basically different from an auditory experience at large. It is continuous with the natural experience or experience proper with a difference in degree rather than in quality. Esthetic perception, and musical-esthetic perception in particular, should be characterized by a rich and full perceptual experience, contrary to the objects of ordinary perception, which mostly lack this completeness. The full perceptual realization of just the individual thing we perceive is then cut short and replaced by the identification of something that acts as an index of a specific and limited kind of conduct, replacing the act of exploring and experiencing by mere recognition.

A somewhat related approach was advocated by James [91, 92] who dealt with the tension between "concept" and "percept." In his little-known but very important doctrine of *radical empiricism*, he stresses the role of knowledge by acquaintance, which he defines as the kind of knowledge we have of a thing by its presentation to the senses. The significance of concepts is not relinquished, but it always consists in their relation to perceptual particulars. What matters in this "empirical view" is not propositional knowledge, but the fullness of reality which we become aware of only in the perceptual flux:

> *We extend our view when we insert our percepts into our conceptual map … but the map remains superficial through the abstractness, and false through the discreteness of its elements […]. Conceptual knowledge is forever inadequate to the fullness of the reality to be known. Reality consists of existential particulars as well as of essences and universals and class-names, and of existential particulars we become aware only in the perceptual flux. The flux can never be superseded. [92] (p. 245)*

Conceptual knowledge is needed only in order to manage information in a more "economical" way. There is, in fact, a difference between the recognition of a sounding object or an event as a discrete entity and the experience proper of its sonorous articulation through time. In the recognition mode, we stop acoustical processing of a sounding event in favor of conceptual processing which allows us to conceive of it in a propositional way. Such kind of processing is much quicker and less demanding as it is much easier to select and delimit events and to pick them up in an act of episodic attention than to deal with them in an act of sustained attention. This is, in a nutshell, the core assumption of *cognitive economy*. It holds true, of course, also for listening to music, which is both an experiential and a conceptual matter. Consisting of *sensory realia* as well as of their *symbolic counterparts*, it embraces both perceptual immediacy and conceptual abstraction.

The experiential framework can be easily applied to music, but it can be extended further by introducing also the conceptual tools of *deixis* and *indexical devices*. This means that we should locate epistemic transactions with the sounds with the listener being considered as the origo of something that happens in a "here" and "now," thus providing a kind of anchoring in a referential exchange.

The very concept of deixis goes back to Bühler [93] (see also [94]) who drew an explicit analogy between gestural and linguistic means for showing direction or place. Conceiving of two basic types of linguistic expressions, which he called deictics (or "pointing words") as opposed to symbols (or "naming words"), he presented as a main thesis that deictic expressions refer to a deictic field of language whose zero point (the origo) is fixed by the person who speaks (I), the place of utterance (here), and the time of utterance (now). Deictic terms, accordingly, are words that pick out or point to things in relation to the participants in a speech situation [95] with terms as "this/that," "here/there," "I/you," "my/your," etc., as typical examples. They are related to the notion of indexicality [96] and the notion of pointing and its correlates [97]. Pointing words, further, act as a source of reference: they locate individual elements in context rather than simply tagging them. They have their origin within the speaking—or listening—situation, with the meaning of deictic expressions depending crucially on when, where, and by whom they are used, allowing each ordinary referential exchange to be systematized in terms of personal, spatial, and temporal deixis (the so-called socio-spatio-temporal axes). Deictic expressions, therefore, make it possible to provide an operational description of space/time moments and their relations to the position and time of utterance and to define an utterance with reference to the referential exchange, its participants, and its settings.

The deictic approach, as applied to music, favors an experientialist as against a merely conceptual-symbolic approach to music. Rather than creating distance and polarization between the listener and the music, it argues for a *dynamic-vectorial* and *directive* approach, stressing the field of pointing rather than the symbolic field of meaning. As such, it holds an *empiricist* position which stresses the first-hand information in perception rather than relying on second-order stimuli. It means that we should conceive of "music as listened to" and "music as perceived," rather than thinking and conceptualizing of music merely at a symbolic level without any connection to the music as it sounds.

Real-time musical sense-making, in this view, needs the transition from the symbolic to the deictic field of meaning, with the actual now moment of sounding music as the context for locating epistemic transactions with the sounds. The field of pointing, in that case, provides an interesting frame of reference for the assessment of the listener's making sense out of the perceptual flux. It calls forth the role of interaction with the sounds, either at the actual level of real sounding music or at the virtual level of imagery and representation.

In order to provide a concrete example, **Figure 1** depicts three representational formats of the "andante grazioso" from Mozart's Sonata No. 11, KV 331. The upper pane shows a waveform notation of a larger section (about 2 min and 15 s), the left lower part depicts the first four bars (about 11 s) in standard notation, and the middle and lower right parts depict the same bars as a waveform (middle pane) and a spectrogram (lower pane). It is immediately clear that the standard notation is *discrete symbolic*: it subdivides the continuous sonorous flux in "discrete" elements that stand for themselves and that are separated from each other. As such, they facilitate cognitive decoding by stressing their "symbolic role" of referring to conventional pitches. What a listener actually hears, however, is not a succession of distinct and separate pitches, but a continuous flow, as exemplified in the waveform and spectrogram notation. As is obvious from the figures, there are no cuts and no blank spaces between the notes, which clearly shows that the discretization is imposed by the listener's mind. Listeners, moreover, are free to mentally point to the sonorous unfolding and to delimit at will focal points or zones in this unfolding. Standard notation may be helpful here, as it provides already a discretization of the flux, allowing listeners to direct their attention to some of its elements (the notes). **Figure 2** provides a rather obvious example. It shows how listeners can select deliberately the most prominent notes of the accompanied melody of one of Schubert's Impromptus for piano. It is up to the listener, however, to decide which elements are selected for giving them semantic weight.

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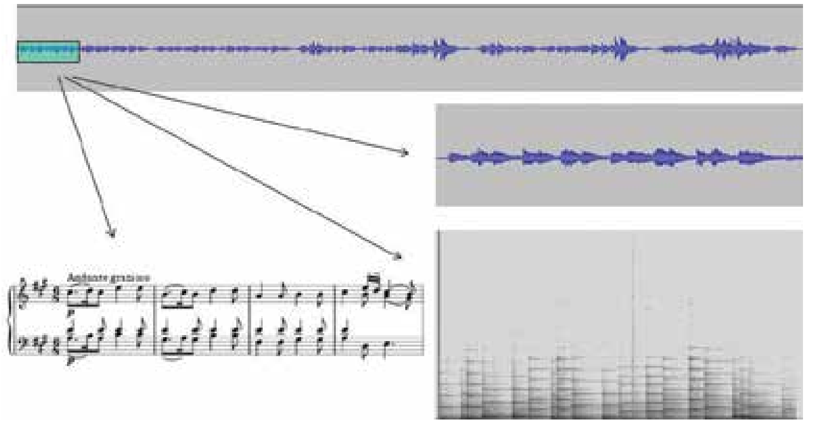

Figure 1. Three representational modes of the beginning of Mozart's Piano Sonata No. 11, KV 331. Andante grazioso.

Figure 2. An example of possible acts of focal attention (encircled notes) for the first bars of Schubert's Impromptu for piano, Op. 90/3.

Focal attention, moreover, is not limited to notes. It can be directed to other structural features such as timbre, dynamics (a crescendo, a diminuendo), harmonic sequences (a succession of chords), aspects of voice leading (simultaneous organization of vocal or instrumental voices), etc. It can even be extended to musical gestures with or without melodic contour. **Figure 3** depicts an example of an alternative notational system (lower pane), by replacing the discrete symbols of score notation by a kind of contour notation that combines segmentation (separate figures) and continuity. It is a hybrid notation as there is an almost one-to-one relationship between the figures (continuous) and the notes (discrete). The example, however, is merely illustrative of a possible translation of a discrete symbolic system to a more intuitive gestural approach. It shows clearly the possibilities of focal epistemic interactions with the sounds with a lot of freedom and subjectivity for each individual listener.

The field of pointing and the symbolic field, finally, are not necessarily opposed to each other. Listeners, involved in real-time listening, are constructing music knowledge, which relies

Figure 3. Standard and contour notation of Mozart's Piano Sonata No. 5, KV 283, I. Allegro.

both on sensation and representation, proceeding both as a moment-to-moment history and giving way to a kind of synoptic overview that is constructed in imagery and representation. Dealing with music, in this view, holds a view that balances between actual sensation and conceptualization and representation, between focal and synoptic allocation of attention, and between in-time and outside-of-time processing of the sounds. The former holds track with the unfolding through time; the latter can take some distance with respect to the sounding flux by dealing with music merely at a level of representation that is not dependent on the inexorable character of the unfolding of time.

6. Conclusion and perspectives

The role of the *musical experience* has for a long time been marginal in existing musicological research. There are psychological studies and music reception and cognition studies, but musicology as a discipline is still waiting for a comprehensive and theoretically grounded framework that explains the idiosyncrasies and commonalities of real-time musical sense-making. There is, however, a considerable body of older theoretical writings that have dealt extensively with the topic of having an experience. These writings, however, did not yet receive much attention in musicological research as they dealt with experience in a rather general way. This holds true, also, for this contribution, which describes the musical experience in a rather theoretical way.

It is interesting, therefore, to look for empirical findings that can support the claims. Much is to be expected here from the ecological approach and from music and brain studies. The *ecological approach* to musical sense-making, in particular, has a lot of operational power. It considers psychology as being continuous with the natural sciences and has been elaborated in depth by the Connecticut Tradition (Center for the Ecological Study of Perception & Action at the University of Connecticut) (see [98, 99]), which aimed at identifying general principles at the ecological scale of action and perception within an interdisciplinary framework. There is, in addition, a growing body of neurophysiological research from the growing field of *music and brain studies* which offers a vast body of empirical grounding for the theoretical framework that is related to having a musical experience (see [100] for an overview).

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Many of these disciplines, however, have been working in isolation with only little connections to the domain of music. As such, there is a need of an *interdisciplinary* approach that brings together contributions from different fields that are all related to the process of dealing with music. Such a common field is not yet established as an official research community with institutions, official journals, and academic positions. There are, however, some emerging research communities which focus on a kind of common paradigm revolving around four major claims: music as a sounding art, the process of dealing with music, the role of the musical experience, and the process of sense-making while dealing with music.

All of them are exemplary of the pragmatic turn in musical semiotics with a major shift from a nominalist tradition in semiotics to a realist position that takes the real experience as a starting point. It brings us to old medieval discussion about nominalism and realism: should we conceive of musical entities as mere words that are the products of abstraction by our intelligence (nomina) or do they refer, on the contrary, to real material things (realia)? The discussion seems to be a hot topic in current research. It is challenging as it brings together philosophical and empirical claims, revaluing and broadening to some extent the old dreams of Leibniz and Descartes to realize a kind of all-encompassing science (mathesis universalis). The same idea, moreover, has been taken over by more modern thinkers as Carnap, Morris, and Tarski, who argued for a universal framework that would bring together all sciences in their search for a common problem consciousness. It is arguable to think that music, as a temporal and sounding art, could be helpful in bridging the gap between the conceptual approach of propositional semantics and the dynamic-vectorial approach that is typical of the deictic approach to cognition [101, 102]. Much research, however, is still to be done.

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Section 4

Organizational Semiotics and Computer Visualization

Semiotic Analysis of Computer Visualization

Vladimir L. Averbukh

Additional information is available at the end of the chapter

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Abstract

The purpose of this chapter is to discuss the semiotic approach to form theory of computer visualization. Such theory should be the foundation of design, development, and evaluations of visualization systems. The "direct" semiotic analysis of visualization is defined and the scheme of the analysis is considered. This analysis reveals "who is who" in the process of the visualization semiosis and helps in design and development of the real visualization systems. The analysis allows to describe the problems arising at developments of specialized systems in terms of the semiotics and showing how this analysis can serve as a tool for the visualization systems design. It is important to analyze the sign nature of the human-computer interface and the visualization. Such conceptions as computer metaphor, metaphor action, and metaphor formula are defined. The properties of metaphors are analyzed with a view to possible usage of metaphors for specific applications. The properties are considered by the example of the hierarchical sequence of the natural Room-Building-City (Landscape) metaphors. Also the properties of the molecule metaphor are considered in the context of software visualization systems. In conclusion, some approaches to the theory of computer visualization are outlined.

Keywords: computer visualization, semiotic analysis, visualization metaphor, entities of metaphors, analysis of metaphors

1. Introduction

This chapter connects our previous research studies on semiotics approaches to computer visualization theory and visualization metaphors. It is an extended and revised version of Ref. [1].

In 1987, the special issue of ACM SIGGRAPH Computer Graphics Journal was published. The issue was devoted to the definition and description of computer visualization. The description computer visualization as the independent discipline summed up the great practice of Computer

Graphics since the beginning of 1960s. In this issue, the main conceptions of the new discipline were defined. The visualization is considered as a method of computing. It transforms the symbolic into the geometric, enabling researchers to observe their simulations and computations. Visualization offers a method for seeing the unseen. The goal of visualization is to support the analysis and interpretation stages in framework of the computer modeling cycle. One can consider three main directions in research studies and developments for the computer visualization domain. That is — computer graphics (hardware and software including mathematical and algorithm components), software engineering, and human factors. Our interests lie in the human factor subdomain. The process of human dealing with visualization consists of three stages "*Perception→Cognition→Inter pretation.*" In the frameworks of semiotics, processes of interpretation are considered.

Computer visualization contains three main subdomains: scientific visualization, information visualization, and software visualization.

It is shown that the human-computer interaction and visualization have a semiotic nature. The conceptions of a visualization language and a figurative (visual) text described on this language are considered. The computer metaphor is considered as a basis of the visualization language. The semiotics analysis of computer metaphors allows to evaluate known metaphors and to search new ones for specialized visual systems. Thus, the semiotics analysis can be an important tool for the visualization systems design and development.

Semiotics, dealing with sign systems and with practice of their functioning, may be considered as tools for descriptions of theories of HCI and computer visualization just as mathematics is tool for description of physics theories.

The obvious semiotic nature of the human-computer interface and visualization allows to reveal the sign systems that determine interactions, visualization, and communications. Human-computer interaction in this connection may be described precisely as sign process. Visualization may also be described as sign process similar to the human-computer interaction. Processes of human computer interaction and visualization contain user interpretation of visual and dialog objects as their essential part. In turn, the process of sign interpretation is researched in frameworks of semiotics. That is why one may consider semiotics as the base of theories of HCI and computer visualization. If human-computer interface and visualization have the sign and language nature, then each interface and visualization system contains the language as its core. The language in this case is understood as the systematical description of entities under consideration, methods of their representation, modes of changes of visual display, as well as, techniques of manipulations, and interaction with them. The language (or rather a base sign system) is built upon some basic idea of similarities between application domain entities with visual and dialog objects, i.e., upon a computer metaphor (that is interface metaphor and visualization metaphor).

Semiotic analysis is an important tool for the visualization system design and development. Below we consider the "direct" semiotics analysis of the visualization that reveals "who is who" in the process of the visualization semiosis. It allows to describe the problems arising at developments of specialized systems in the terms of the semiotics and showing how this analysis can serve as a tool for the visualization systems design. Further, metaphor properties are considered to analyze the possibility of the metaphor use for specific applications.

2. Related works

The development of the "semiotics" approach to the theory of computer visualization and human-computer interaction started in the 80th years of the twentieth century. The statements of the classical semiotics were used to describe visual sign processes in connection with a computer graphics and visualization [2–6]. Using the semiotic engineering of human-computer interaction is described in this chapter [7, 8]. The design principles for information visualization based on a combination of algebraic abstract data type theory, semiotics, and social theory were suggested in reference [9]. In many articles, the semiotics of graphics and visualization is considered from the perspectives of dating back to 1980s [10]. This approach involves the study of individual sets of signs and pictographs that are often associated with cartography. However, modern visualization systems depict huge volumes of data possibly without a natural or familiar imagery. These set of displays may be considered as a visual text, which corresponds to visualization languages. The semiotics research studies of visualization languages are the basis of our approach described in Refs. [1, 11–13]. The description of visualization language is important to evaluate the already-existing systems so as to analyze decisions in the phase of design and development.

The concepts of a visualization language and a visualization text depicted on this language are considered. The concept of pictorial (graphical) text was used to describe the petroglyphs and ancient illustrative pictures depicted some narratives. Interpretation of such texts is possible only if the "readers" of the text have an external information [14]. If the graphical texts are considered, then one may consider corresponding graphical languages. They are rich and complex languages, based on natural imagery. It is static languages of fine arts, communications, illustrations and advertising, and dynamic languages of cinema and animation. Similarly, we can define graphical texts associated with computer visualization. The examples of those visualization texts are:

- isolated displays (static pictures);
- dynamic logically related shot changes with the inclusion of interaction, which may define the logic of the change of the conclusions;
- animations also with the inclusion of interaction.

In turn, we can consider the concept of languages of computer visualization. In this case, the language is understood as the systematical description of entities under consideration, methods of their representation, modes of changes of visual display, as well as techniques of manipulations and interactions with them. The language (or rather a base sign system) is built upon some basic idea of similarities between the application domain entities with the visual and dialog objects, i.e., upon a visualization metaphor.

We consider the notion of visualization language from the perspective of semiotics as unity of lexicon, syntax, semantics, and pragmatics [15, 16]. Let us use to describe the notion of visualization lexicon for the ideas from [17] where some formalized models of visualization are proposed for the case of parallel performance data. Among others, such entities as *performance view* and *performance display* are considered. We use the synthesis of these notions to describe visualization languages.

Generalized view of visualization system is defined as a visualization abstraction containing specifications of visual objects, their attributes, their relationships, possible dynamics, and methods of interaction. Thus, view design provides valid picture changes and animations, and interactions with visual objects. View may be understood as a technique of data depiction, a kind of a visualization procedure. A visualization system realizes linking view "arguments" with real data and supports an output to graphics. Resulting pictures (*displays of a visualization system*) are represented visual abstractions. A set of displays considers as a visual text corresponding to a visual language. The same views may be used in a variety of visualization systems and therefore constitute elements of lexicons of different visualization language. The set of views of the visualization system defines its visualization lexicon.

Syntax of a visualization language may be considered as a set of rules describing: (a) relationships of visual objects; (b) possible dynamics of visual objects; and (c) techniques and results of interaction with visual objects of the view. Rules of display changing may also be part of the syntax of a visualization language.

Semantics of a visualization language is set by goals and tasks of visualization. Most importantly that semantics is specified by goals and tasks of computer modeling which data are under analysis and interpretation during the visualization system.

Pragmatics of a visualization language is also related with goals and tasks of visualization and modeling. Pragmatics is determined by meaning, which can draw users of visualization systems. Visualization metaphor is considered as the basic idea of likening between interactive visual objects and model objects of the application domain. Its role is to promote the best understanding of semantics of interaction and visualization and also to determine the visual representation of dialog objects and a set of user manipulations with them. Visualization metaphors form the basis of views of specialized visualization systems.

The notion of computer metaphors (interface and/or visualization metaphor) is rather popular in the scientific literature after research studies of Kuhn [18, 19]. Studying of the literature on problems of a computer metaphor allows drawing some conclusions. One of them—there is a certain consensus on the computer metaphor theory. First of all this consensus consists of the recognition in cognitive approach to the metaphor theory as the base of the theory of interface metaphor. This approach is linked with names Lakoff and his colleagues [20, 21]. The cognitive approach to a metaphor considers a metaphor as the basic mental operation, as a way of cognition, structuring, and explanation of the world. Second, the Peircean semiotics is applied to user-interface metaphor [22]. Our approaches to problems of computer metaphors are described in Refs. [1, 23–25]. Also, some new ideas will be considered below.

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3. Semiotical analysis

The sign process (or semiosis) is considered on the five-term relation between a sign, its meaning, its interpretant, a context where the sign meets, and, at last, a sign interpreter. The sign causes the interpreter to certain reaction or predisposition to it (interpretant) on a certain kind of object under certain conditions (in some context).

The human-computer interaction and visualization, necessarily, have a semiotic nature. The sign nature of visualization allows to reveal sign systems, determining interactions, visualization, and communications. There are relationships between the visual representation of an object, that is, relationships between a signified (a denotatum) and a visual sign. A user or an observer (an interpreter) in determined context recognizes the idea caused by visualization that is the interpreting idea (an interpretant). They are all relations described semiosis (the process of interpreting signs or the sign process).

A set of classical semiosis "roles" in human-computer interaction should be broadened. There is another process actor — the author of the message. The sense intended by the "author" may differ from the interpretant that is the ideas understood by the interpreter.

We consider the "direct" semiotics analysis of visualization that reveals "who is who" in the process of the visualization semiosis. It allows to describe problems arising at developments of specialized systems in terms of the semiotics and showing how this analysis can serve as a tool for the visualization systems design.

First of all, it is necessary to pay attention to the pair "sign-denotatum." Revealing of denotatum and a corresponding choice of a sign is the important problem of the semiotics analysis. Note, that in any concrete case of visualization there are "nonsign" aspects. Not everything is reduced to sign forming.

There are some simple examples (see **Figures 1** and **2**). Suppose we need to represent the progress of a simple process. One may use the conventional technique to represent—to draw a usual 2D graph. Here the process is the denotatum, and the whole of graph is the sign. If further the task to represent the change of the progress of a process, then change the direction of the graph simply and obviously indicates the change of the progress of a process. In this case, the denotatum is the change of the progress of a process and the sign is the change of the graph direction (but not the whole graph as in the previous case). For more complex cases, one may use the more complex (and more interesting) technique of visualization, for example, to animate the process basing on its natural imagery. But, in this (animation) case, one has to construct the more sophisticated and complex sign to represent the same denotatum (the change of the progress of a process).

Let us consider the next example that is the simplification of real specialized system of scientific visualization for the model of pollution of the environment. In the beginning of the system development, the task on visualization provided the real imagery of pollution and animation—the smoke from factory chimneys is diffused in the town air and the dirt from the factory tubes is diffused in the town pond. This animation may be interesting for regional authorities, factory managers, and environment defenders. That is originally the process of

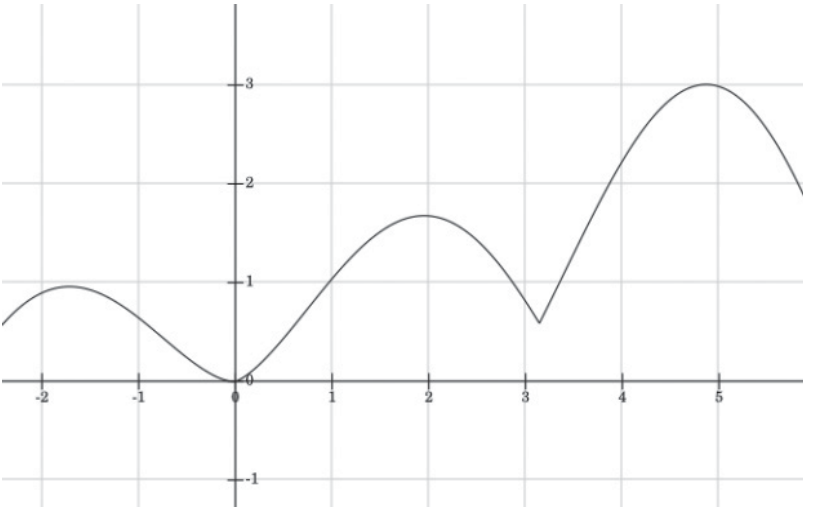

Figure 1. Sample of the plot of a function.

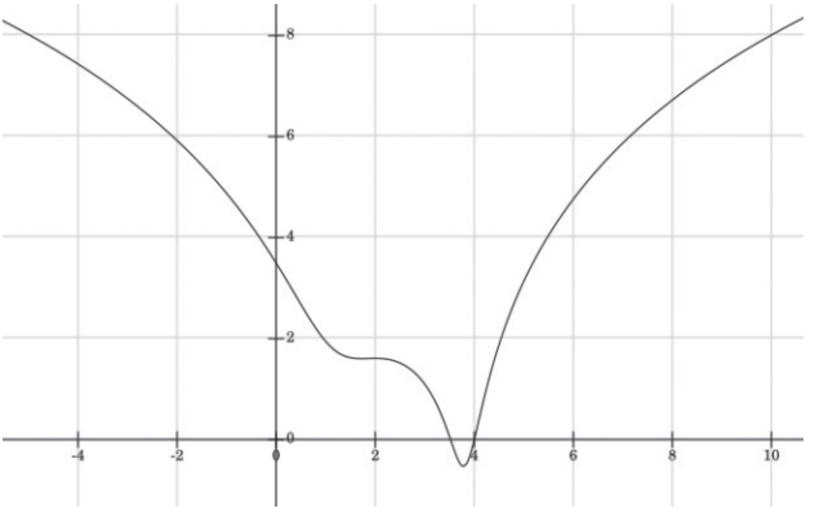

Figure 2. Changing of the direction of a process.

pollution that was considered as a denotatum. The realistic animation has to be the basis of sign representations. Note that in this case the realistic animation is not too suitable to depict the process uniquely. However, analysis revealed that the main problem of this mathematical and computer modeling resided in the reconstruction of values of emission rates basing on available information. Thus, the denotatum and the subject of visualization were not in the least process of pollution of the environment but some properties of the same mathematical model. The use of an abstract imagery to visualize the model is not surprisingly. Just we used the 3D surface to depict the model. In particular, isolines showing equal pollution loads are the sign for the process of pollution (see **Figure 3**).

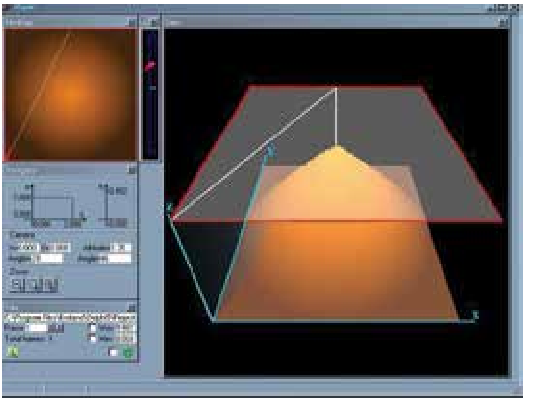

Figure 3. Visualization for modeling of environment pollution.

Another real example is the simulation of excitative process in cardiac chambers. At once, note that, in this case, the excitative process in cardiac chambers is the denotatum. Experts suggested the scientific metaphor to represent pathways of myocardium as the set of interconnected cells. These cells may send signals to each other.

The model depicts myocardium and simulates the excitative process in cardiac chambers by means of simple animations. Basing on this animation we succeeded to visualize the simulations such pathologies as tachycardia and extrasystoles. The simulation of the cardio disorders was realized by means of the system parameterization. In particular, time intervals corresponding to different states of the cardio cells were varied. Such parameters as preparedness to receive/transmit; process of receive/transmit; unpreparedness to receive/transmit were under user's control. The presence of pathology was depicted by types of hesitation. Really dangerous pathologies are chaotic animations. The stable (even not norm) animation is a sign out of the deadly condition. Three-dimensional (3D) model of the heart generated at the first stages of development was rejected because, first, it was inadequately for chosen scientific metaphor and, second, visual perception of 3D animation was difficult for users. Flat representation in this case turned out to be more accurate and winning in terms of user experience. Despite a number of restrictions, the model completely satisfied the expert requirements. In this case, the sign indicating the presence of simulated pathology is the type of oscillation. The heart itself, which is not a matter of designation, does not need in visualization in this case (see **Figure 4**).

Consider the following examples related to the algorithm visualization. Algorithm visualization and animation systems are considered as education means but they may be used as instruments for algorithm evaluation and debugging. Let's ask a question—what is denotatum in the case of algorithm animation. It will be recalled that in the frameworks of theory of visualization the conception of "algorithmic operation" is considered. Algorithmic operations are such operations of the algorithm that are important to understand the program's semantics. For example "compare" and "exchange" in a sorting algorithm [26]. That is, in the case of algorithm visualization, its base operations may be considered as denotatum rather than the algorithm itself. (As we know algorithm is rather complicated conception.)

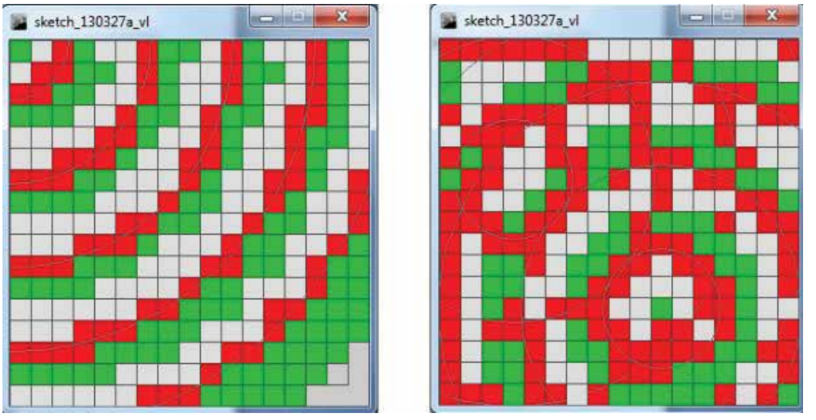

Figure 4. Normal (left) and pathological (right) variants of excitative processes in cardiac chambers.

Starting in the 1980s of the twentieth century, a number of algorithm animation systems were developed. In these systems, the designation was conducted by creating dynamic images that demonstrates the behavior of the algorithm. Here visual dynamic images are considered as signs. In the "classical" systems of algorithm animation only "exchange" operation was depicted when sorting algorithms were realized. "Compare" operation seemed as self-evident for users-observers of animation. In the 1990s, we have researched some problems of representation of both operations in sorting algorithms. On our opinion, the value of variable is preferable to depict by the size of bars. Whereas the color for that end may be used only in certain cases. Some approaches for visualization of "compare" operation were suggested. For example, a harpoon (or an arrow) was used for this purpose. A "harpoon" is moving up from the end of current (lower) object to compare next objects. If the "harpoon" collides with other object then it becomes lower, and the former current object goes up one step (see **Figure 5**).

There are also a number of other successful examples of algorithm animation systems, but majority of these animations deals with sorting and graph algorithms. Sometimes systems depict and animate the process of program execution rather than algorithms.

Considered examples of revealing of a denotatum at semiotics phase of the visualization design show that answers two questions that are important:

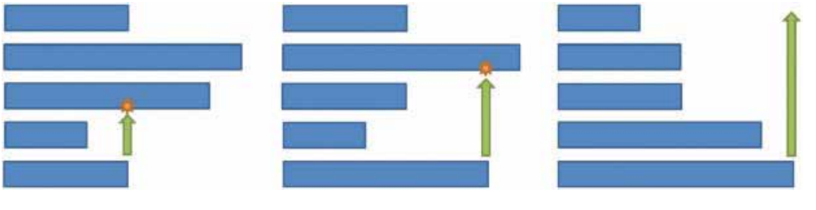

Figure 5. Animations of sorting algorithm using "harpoon" for depicting "compare" operation.

- “what are the objectives of visualization?”
- “what are the subjects of visualization?”

The answer to the second question as one may see needs the special analysis; it is not trivial but sometimes it is unknowns.

Searching methods of the denotatum representation and designation is connected with the conception of a computer metaphor.

4. Computer metaphors

Informally, the visualization metaphor is understood as mapping from an application domain to the visual world. The visualization metaphors have to help in understanding the complex and abstract concepts and in clarifying the relationships between objects. Metaphors are used to define the activities of computer systems users and to depict forms of her/his vision and operations on program objects. Theoretically, any visualization is metaphoric. Whereas in the literature, the traditional methods of data visualization and new (metaphorical) ideas are often opposed [24, 27]. The semiotics analysis of computer metaphors allows to evaluate known metaphors and to search new ones for specialized visual systems. Thus, the semiotics analysis is an important tool for the visualization systems design and development.

The metaphor essences consist in interpretation and experience, the phenomena of one sort in terms of the phenomena of other sort. Metaphorization is based on interaction structures of source and target domains. During process of metaphorization, some objects of target domain are structured on an example of objects of target domain and there is a metaphorical mapping (projection) of one domain onto another. That is the metaphor can be understood as a map from source domain onto target domain, and this map is strongly structured.

Cite an example of a classical metaphor LIFE IS A JOURNEY, where LIFE is target domain, and JOURNEY is source domain. Some structures of JOURNEY (beginning, ascent, descent, end, etc.) are considered in the given metaphor as a basis for the description of life structure. Image-schemas are image-like reasoning patterns, consisting of a small number of parts and relations, made meaningful by sensorimotor experience. There are a CONTAINER schema (things that have an inside, an outside, and a boundary), a PART-WHOLE schema (something can be seen as a whole or as its constituent parts), a LINK schema (two or more things have a link between them), a SOURCE-PATH-GOAL schema (or sometimes, just a PATH, which goes from a source along a path to a destination). There are an UP-DOWN schema, a BACK-FRONT schema, and so on. Schemas are gestalts—structured wholes—that structure our direct experiences. Image-schemas may in fact be the kind of structure, which is preserved by computer metaphors [20, 21].

One can define a computer metaphor (interface and/or visualization metaphor) as an operator from concepts and objects of the application domain under modeling to a system of similarities and analogies generating a set of views and a set of techniques for interaction with and manipulation by visual objects. Computer metaphor is considered as the basic idea of likening between interactive visual objects and model objects of the application domain. Its role is to promote the best understanding of semantics of interaction and visualization and also to determine the visual representation of dialog objects and a set of user manipulations with them. Visualization metaphors form the basis of views of specialized visualization systems whose design is the important part of whole design the "human factor" aspects of these systems.

A set of requirements imposes on source and target domains during the selection of metaphors for visual interactive systems. Among them, there are such as *similarity of properties of source and target domain objects; "visualizeness" (in a broad sense) of source domain; habitualness (recognizability) of its objects; rich structure of interrelationships between objects*.

The concept of habitualness and recognition in the specialized visualization systems should be connected mostly not with everyday realities, but with potential user activity in that sphere for which the interactive system is created. In general, computer metaphors may refer less as to exact matching of reality than conversely may need in additional "irreal" (or "magic") opportunities. "Magic" in the computer metaphor means that "metaphorical" interfaces and visualizations that do not imitate prototypes from real world. The presence of "magic" attributes in a metaphor means that its target domain has properties nonexistent in the source domain. "Magic" in metaphors is closely related to the conception of intuitively usable interface. The "correct magic" of the interfaces and visualizations has to be based on this principle of intuitive usage. Understanding of the magic is interlinked as of cultural background of potential users as of context of using interfaces and/or visualizations. In connection with this context, one should be paid attention to the requirement of the metaphor naturalness. There are a variety of approaches to appraisal of its role. Some authors consider as metaphor such as only those where source domains have based on everyday realities. Really such metaphors, for example, Mosaic, Information Wall, Fish Tank, gain widespread acceptance in interfaces and in information visualization systems. But no less frequently then "natural" (real life), the "quasi-natural" (habitual for a given domain) imageries are used in visualization systems. There are such examples as the techniques of molecule depictions in chemistry or biology. Also, one may consider the visual formalisms as some kind of metaphors. Such visual formalisms as flow charts, data flows, Petri nets, etc. are actively used in diagrammatic visual programming languages. The visual formalisms have abstract imageries but these imageries are interpreted monosemanticly by users-specialists.

We consider the metaphoricalness of any visualization. In our opinion, in the general case, there are no "metaphorless" visualizations of computer models and program entities. The survey of the corresponding bibliography shows on "pictureness" of all metaphors and accordingly on metaphorness of any images in computer visualizations. Per se every computer visualization may be considered as a metaphor because it associates model entities and images and represents one by another for adequate user interpretation. One may show the community of metaphor design and usage in all subdomains of computer visualization. In the case of visualization metaphors, the transition to some world of visualization, where imageless objects obtain their visual representations, takes place. The process of metaphor generation (metaphorization) first of all includes (may be implicit) analysis of target domain of the

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future metaphor. The hierarchical structure of object interrelations of target domain and their properties is revealed on a basis of the metaphor objects and its properties. At the following stage, a source domain and its main object are searched. Criteria of a choice are criteria of metaphor quality.

First, the main object of a source domain should have the properties, similar (closed) to properties of metaphorization object. The structure of these object interrelations and its properties should be *similar* to structure of interrelations of object under metaphorization and its properties, at least on the first level of a structural tree. Second, a source domain should be visualized. That means that the nature of the *source domain* should be like, that its objects have dimension, extent, length, form, color, or other visual characteristics. For example—a metaphor of the railway for the functional description of operational systems.

5. Metaphorical domain

The metaphorization is based on the interaction structures of the source and target domains. During the process of the metaphorization, some objects of the target domain are structured on the example of objects of the target domain, and there is a metaphorical mapping (projection) of one domain onto another. Moreover, not all objects are selected (and not even all of their properties, or structure elements), but only those that are the most interesting for us. The analogues of these objects are searched in the source domain (in frameworks of structures, the qualitative properties, etc.). Further, the following operation takes place. The objects of the target domain together with the object from the source domain are located now in the common "metaphorical domain" or more exact in doing so this "metaphorical domain" is generated. In this domain, the investigated object now starts to function. It is possible to consider, that it is already a new object of a new domain. The metaphorical domain gets autonomy from the domains generated in it. Many properties of its objects only mediately are connected (if at all are connected) to the properties of the source domain objects. By means, the projection of some characteristics of the target domain onto the source domain its own logic of development of metaphorical domain appears. So, for example, the use of the scientific metaphor of an electromagnetic field its intensity is studied. But it is obviously absent on a field of wheat.

There are the questions: what are the nature and the structure of the metaphorical domain; how its generation is produced? First of each metaphor generates some sign system, that is the integral sign set, in which exists the internal relations between the signs somehow that map the relations between the designates. Our metaphorical domain as a matter of fact is a sign system. The understanding of a metaphor as a sign system gives us the basis for the evaluations of the metaphors offered in the concrete cases. If the used affinity (comparison or a set of comparisons) matches the systemness requirements, then we may speak about the existence of a useful metaphor. If not, if the conditional changes of the source domain objects are connected with the changes of the objects from the target domain poorly, then such comparisons usage cannot help us to understand an investigated the situation better. In case of a metaphor, the generation of a sign system is possible to consider as the adaptation of two metaphor operators, the basic:

> *"Let A be similar to B"*

and the additional operator:

> *"The following attributes/elements/characteristics of A are selected for assimilation to the following attributes/elements/characteristics of B."*

Here A stands for a source domain, whereas B stands for a target domain.

6. Metaphor action and metaphor formula

Let us define the concept of "*metaphor action*" to describe the [potential] results of metaphor uses. This conception allows to analyze structurally specific computer metaphors. In turn, the analysis is necessary to understand causes of the successes of one and the failures of another visualization and interface metaphors. Further, the analysis of the logic of metaphor searching and choice enables to formulate the evaluation criteria for the "human factor" aspects of visualization systems.

The concept of "*metaphor action*" is connected with answers to the following questions:

- *"How can this metaphor assist to represent the information?"*
- *"How can this metaphor assist to interact with data or to manipulate them?"*
- *"What properties of metaphorical objects (that is visual and/or dialogue objects generated by the metaphor) take place?"*
- *"What actions or ideas are arisen from the process of the user interaction (including observations of pictures) with metaphorical objects?"*

It is possible to construct a "formula" of the metaphor actions. The metaphor "formula" includes simplified descriptions of the source and target domains, an idea of likening using in the metaphor and the results of metaphor actions.

Note that the computer metaphors do not need to obtain the completeness and precision of similarities. Therefore, in formula (as in a metaphor), only a limited set of required objects is described.

In the general case, metaphor formula is as follows:

> **Source domain***: description [+ set of the objects participating in a metaphorization]*
>
> **Target domain***: description [+ set of the objects participating in a metaphorization]*
>
> **Idea of likening***: {object of Source domain_1} = {object of Target domain_1}*
>
> …

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{object of Source domain_n} = {object of Target domain_n}

{operations over objects of Source domain_1} = {operations over objects of Target domain_1}

…

{operations over objects of Source domain_n} = {operations over objects of Target domain_n}

*[**Magic idea**]: the description additional, often impossible in reality, but useful properties of new objects and/or operations over them.*

*[**Result**]: the description of resultant (metaphorical) domain with a set of objects and operations over them.*

The purpose of our analysis is to reveal the structures of the successful metaphors and to build the basis for the comparison and evaluation of metaphors. Such concepts as "metaphor action" and "metaphor formula" are considered to construct the basis of analysis. We begin our analysis with one of the most popular "desktop" metaphor. Originally, this metaphor was offered for the office automation systems, but then it was expanded for the general case of the interface for operating systems. "Desktop" metaphor in the 90th years of the twentieth century became the most frequent practice. This metaphor is in many respects a basis of the modern visual interfaces. The success of the "desktop" metaphor, undoubtedly, is connected not only (and not so much) with the natural figurativeness of icons those are [not always] clear to users, but with logicality and systematicity of all activity in the frameworks of visual environments based on this metaphor. The "desktop" metaphor generates the unfussy sign system that is the base of the corresponding metaphorical domain.

In the case of desktop metaphor, the formula may be written as follows:

Source domain: The desk with folders containing documents (documents are structured, but folders may be disordered);

Target domain: The office automation system;

Idea of likening: "Folders with papers" = "structure of the data, a set of files";

"Opening of a folder" = "demonstration of file structures and/or files";

"Processing of documents" = "execution of functions, by means commands of the visual language."

Result: The direct access to the data structures by means of the manipulations of icons placed on the screen; calls of some [user] predetermined functions by means of the visual dialog language. The early versions of Microsoft Windows use the extended version of this metaphor.

Addition of source domain: The desk is combined with the control panel where starting buttons are placed. Besides the "magic" idea is added: all actions within the framework of system are made by means of **double click** on icons.

Result: icons those can represent the data structures and the programs calls.

The data structures and programs are executed in the same way corresponding to the classic von Neumann computer.

There is also one more idea: opening of the new windows when program execution begins. One can speak about carrying out of the "metaphorical" interface domain constructed on the basis of the desktop realities. However, not every entities of the real desktops (the source domain of the metaphor), which are richer and poorer than the metaphorical objects in the same time, were equally useful in the new metaphorical domain. Often icons moving on the screen are needed only for grouping and for the convenience of the concrete user. The images of folders do not play a main role in the users' actions with operational system and frequently they are not placed on "desktop." But the major value (not having analogues in initial area) double "click" using for program starts has obtained. Usually the double "click" results is an opening of new window, and, in the case of Internet-browsers windows are opened in almost a literal sense. As the result, we have the logical commands system of the visual (iconic) language, based on the set of icons and "Double-Click" operation.

7. Properties of visualization metaphors

Objects of the new metaphorical domain, the relationship between them and the possible actions in this domain have a number of properties, which we call metaphor properties. The success or failure of visualization systems depends on many factors. One approach to the evaluation of visualization involves the examination of properties of visualization metaphors. We analyze the properties to consider the possibility of metaphor using for specific applications of software visualization. It is important to understand what objects may be represented with one or another metaphor. We need to analyze the possibility of the visualization metaphors (more precisely—the views based on the visualization metaphors) to represent large and huge volumes of data and details required to understanding the program's operations. The positive effects of a 3D display and virtual and augmented reality environments are possible in these cases. Therefore, it is important to analyze possible applications of metaphors in the frameworks of visualization systems using modern computer graphics environment, in particular the virtual reality environment. For all this, we need to describe how to verify the suitability of metaphor for solving problems under consideration.

Note that such metaphor properties such as "ability to contain any objects inside itself", "restriction of a perception context", "closeness", "inclusion in structure", "presence a structure inside", and "naturalness of a metaphor." These properties are connected with using within the framework of metaphors such basic image-schemas, as CONTAINER, UP-DOWN, and BACKFRONT. These image-schemas and other visual characteristics are the base of depiction techniques in many visualization systems. We will analyze the metaphor properties by the

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example of the hierarchical sequence of the natural boom-building-city (landscape) metaphors and the molecule metaphor. These metaphors are used in a variety of information visualization and software visualization systems.

8. Properties of room metaphor

In the beginning, room metaphor was considered as an extension of desktop metaphor. In this case, data and system control objects were placed inside 3D room space. Objects in the room link to specific information (see **Figure 6**) [28]. Furthermore, room metaphor is used to depict objects of software visualization systems and systems of visual programming.

The room metaphor possesses the following properties:

1. *Ability to contain any objects inside itself*. The room not only represents the separate object but is also the container for others ones.
2. *Restriction of a perception context*. The objects inside the room are considered in the separation from "external worlds."
3. *Closeness*. There are no any additional elements to use the room metaphor (excepting possible inner objects).
4. *Inclusion in structure*. It is possible "to build buildings of rooms," that is to consider the set of rooms. Therefore, the room may be an element of construction of some complex construction.
5. *Naturalness of a metaphor*. The room is the natural metaphor, with the presence of the corresponding objects in the real world. This property makes intuitively understandable all properties described above. There are no additional analogies and unnatural images. The functionality and characteristics of the real objects are transferred in the virtual world with only minor extended understanding.

It is possible to consider various ways of objects locations inside a room using the container property. The information may be represented by the type of the objects without considering

Figure 6. Data vault based on the 3D room information space metaphor [29].

their location. One-type objects may be represented by their location in the room. It is more natural to place the visual objects onto "walls" of the room. Also, it is possible to use for the information representation the location of 3D objects indoors. Certainly, one may use both methods together and additionally forms and colors of objects. The collection of rooms may represent a set of program classes. It is possible to observe the dynamics of the program execution "on the inside" by using the special form to the depict kinds of the program constructions. The color in the room may be determined on the base of the contents of the "room-function" (see **Figure 7**).

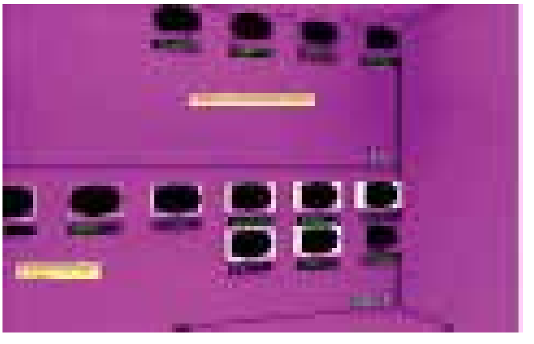

Figure 7. Example of room metaphor realization to represent the links of program elements [30].

One may consider a set of different types of rooms. In this case, the connection between the rooms may represent the structural relationships in the complex object. It is also possible to provide a predetermined, strictly defined location in the room space (wall, skyscraper, etc.). However, such arrangement can represent less information about the rooms forming the structure. The dynamical change of the characteristics of the room may be an additional source of the information. It is possible to use the animation at all rooms. In addition, the animation may affect not only the change in space, but also other characteristics of the room: object colors, sizes, shapes, etc.

9. Building metaphor

In its turn, building metaphor may be considered as an extension of room metaphor. As a rule, visualizations based on this metaphor were represented a structured set of rooms and other accommodation. This metaphor is used to represent in information visualization (see **Figures 8** and **9**) and software visualization systems (see **Figures 10–12**). There is interesting (although rather old) example of building-like metaphor in the case of software visualization. In avatar system, virtual reality was used for performance analysis of parallel systems. The user was inside a "room." The performance analysis data are depicted on its "walls" and "floor." The user could be moving between "rooms" in some paths (see **Figure 13**).

Building metaphor possesses the following properties:

Figure 8. Visualizing a "building" containing the query result [31].

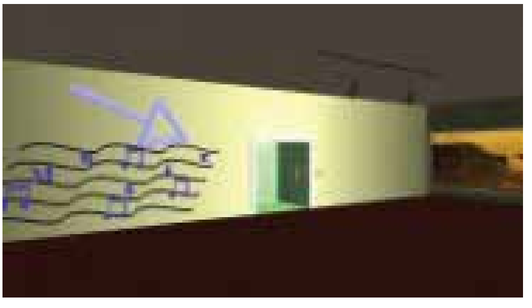

Figure 9. Inside the "building" [31].

1. *Ability to contain any objects inside itself*. The building is the container for others objects. In comparison with the room metaphor, the building metaphor possesses bigger "depth." This metaphor suggests not so much the presence of some visual information objects as the presence of containers with the objects.

2. *Restriction of a perception context*. Everything that is placed inside the building is perceived as connected in a whole, affinitive through some characteristics.

3. *Closeness*. The building metaphor inherits closeness property of the room metaphor in the sense that in the frameworks of this metaphor it is not required external objects, however, the internal filling of the building is very important.

4. *Inclusion in structure*. This property is similar to the corresponding property of the room metaphor. It is possible to construct the city including single building or collecting them in structures (city quarters).

5. *Presence a structure inside*. It is necessary to distinguish the use of the building metaphor and the multiple arbitrary structured uses of the room metaphors. The building in this sense has quite fixed structure in the kind of a location of "rooms" on "floors," and also a set of variations in the structure of each floors, for example, available general "corridor"

between them in the hotel metaphor, in the strict location of rooms of rather up-down neighbors, etc.

6. *Naturalness of a metaphor*. The building is also the natural metaphor. There is an analog for it in the real world. The metaphor does not associate additional analogies and unnatural images.

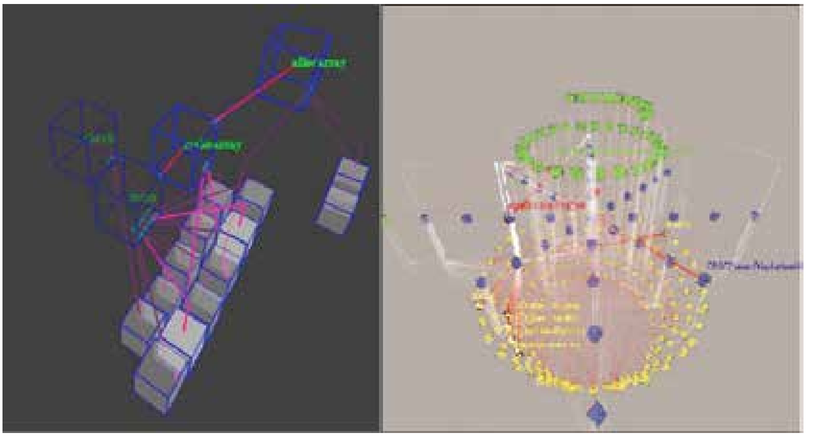

Figure 10. Call graph visualizations based on building metaphor [30].

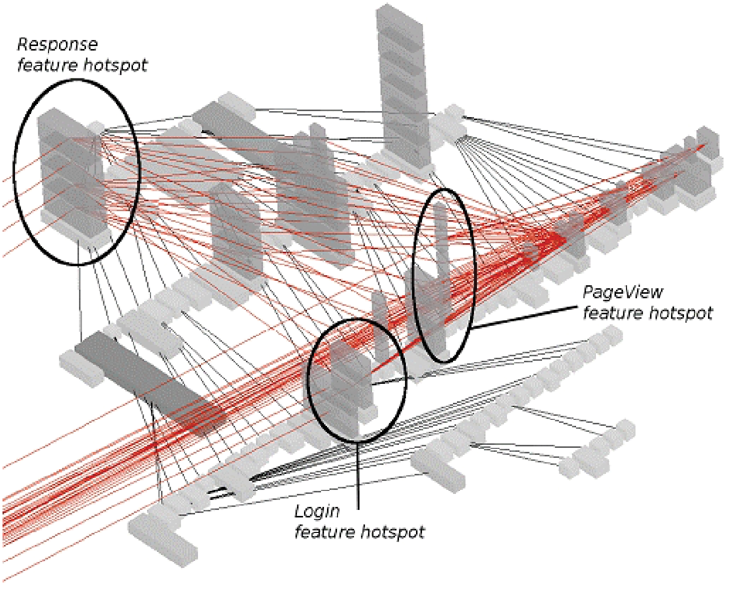

Figure 11. Building metaphor using in software visualization system.

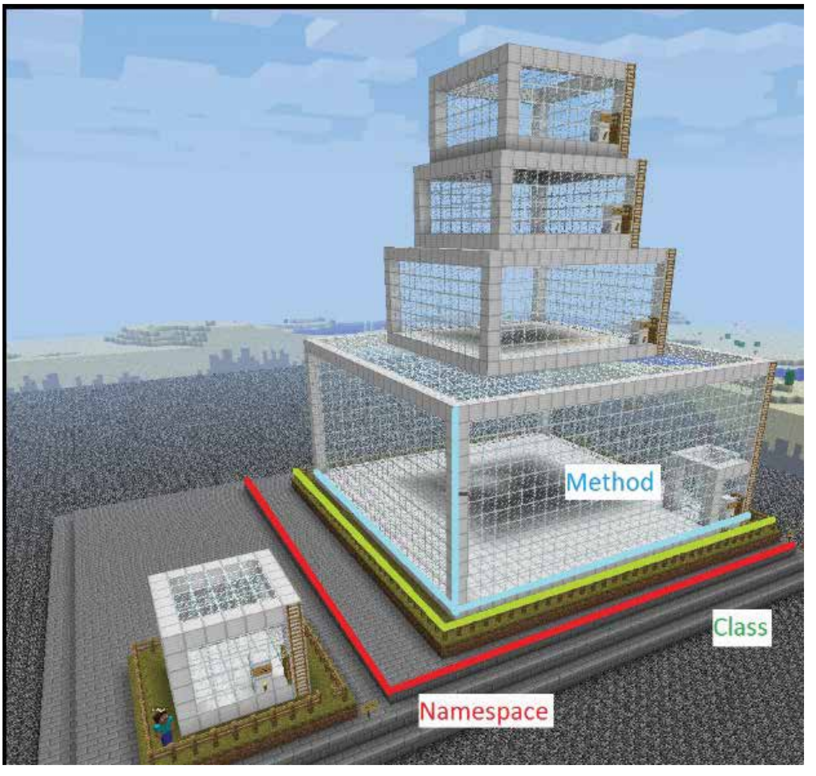

Figure 12. The depiction of program code [32].

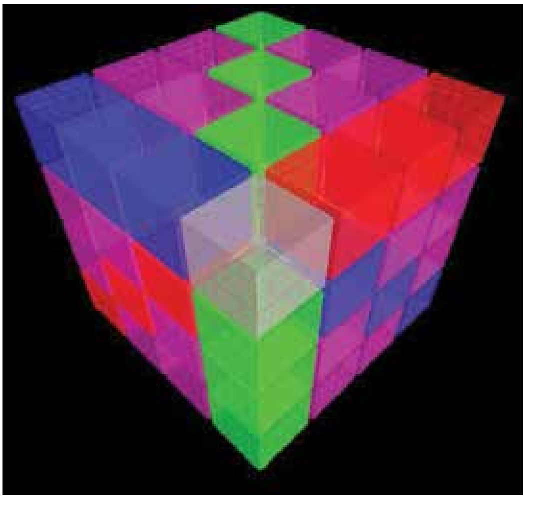

Figure 13. Scatercube—the 3D extension of 2D scatterplot and scatterplot matrix [33].

10. Properties of city and landscape metaphors

City and landscape metaphors are well-known beginning the 90th of twentieth century as in information visualization as in software visualization systems. For example, the city-like metaphor was used to visualize hierarchical graphs (see **Figure 14**). As early as 1993, the landscape metaphor was used to represent a corpus of documents (see **Figure 15**). Note that ideas of information landscape are very popular in information visualization [34–36]. Relationships between the individual objects (e.g., articles) are identified using citations, descriptive terms, or textual similarities. Objects are then clustered using a force directed placement algorithm to produce a terrain view of the many thousands of objects (see **Figures 16** and **17**). Also city and landscape metaphors are actively used in software visualization. Urban streetscape may represent the progression of the program system development [37] (see **Figure 18**).

City metaphor and similar landscape metaphor (and their modifications such as industrial landscape metaphor and factory metaphor are popular in software visualization systems to represent execution traces and call graphs of parallel programs (see **Figures 19**, **21** and **22**). Note the interesting idea united the metaphor of hierarchical edge bundles and city metaphor. In Ref. [40], the adaptation of the existing two-dimensional (2D) hierarchical edge bundles technique to represent relations in a 3D space on top of city metaphors is described. This visualization technique inspired by the 2D hierarchical edge bundles technique is converted into 3D hierarchical attraction points, which affect edge paths across the city visualization. In this way, edges are grouped together, resulting in a more understandable visualization of relations (see **Figure 20**).

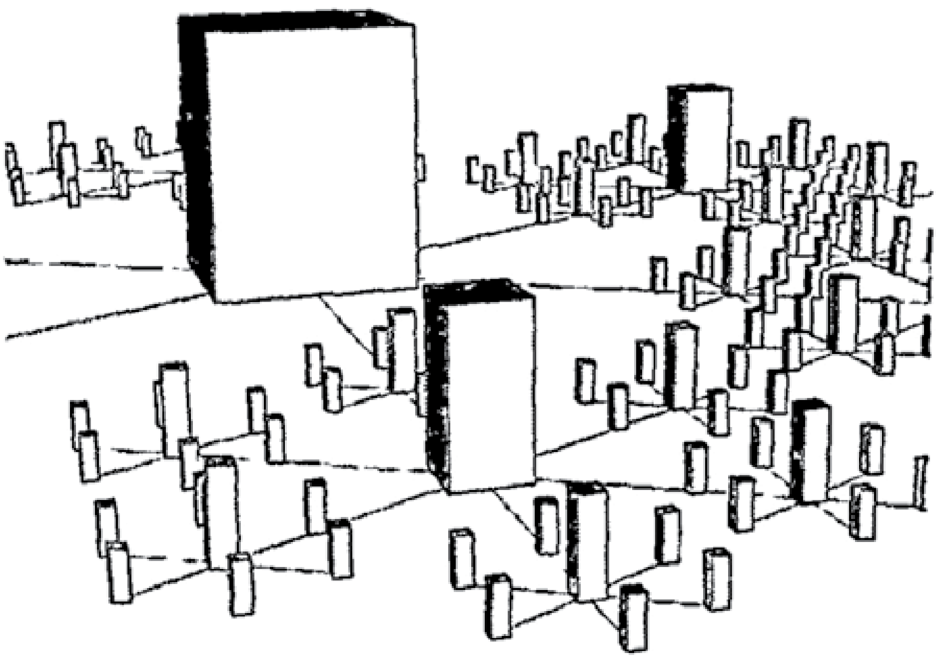

Figure 14. Viewing details in the cityscape-visualization of the tree [38].

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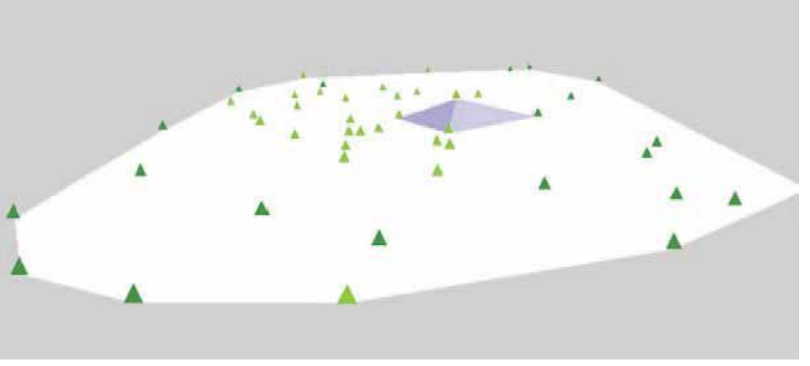

Figure 15. An information landscape bead system, depicting articles from an HCI conference (CHI’91) [39].

One may consider the following properties.

Unlimited context

The user context is not limited artificially in *City* and *Landscape Metaphors*. As a result, additional user’s efforts are required to identify needed objects among many others. At

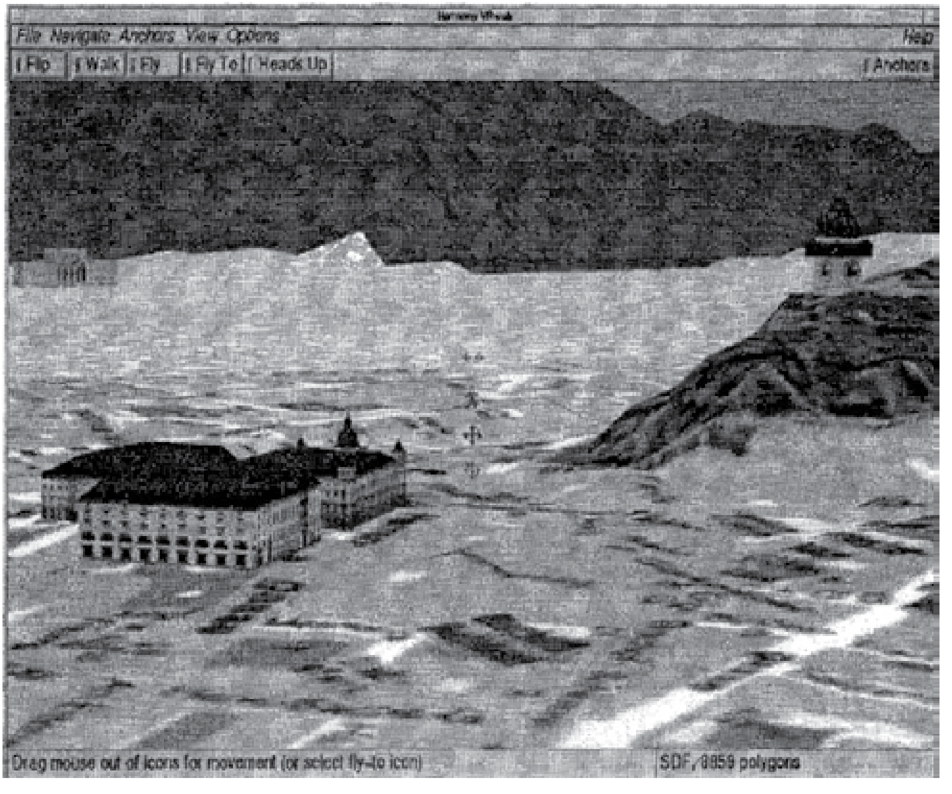

Figure 16. Harmony's VRWeb 3D Viewer [34].

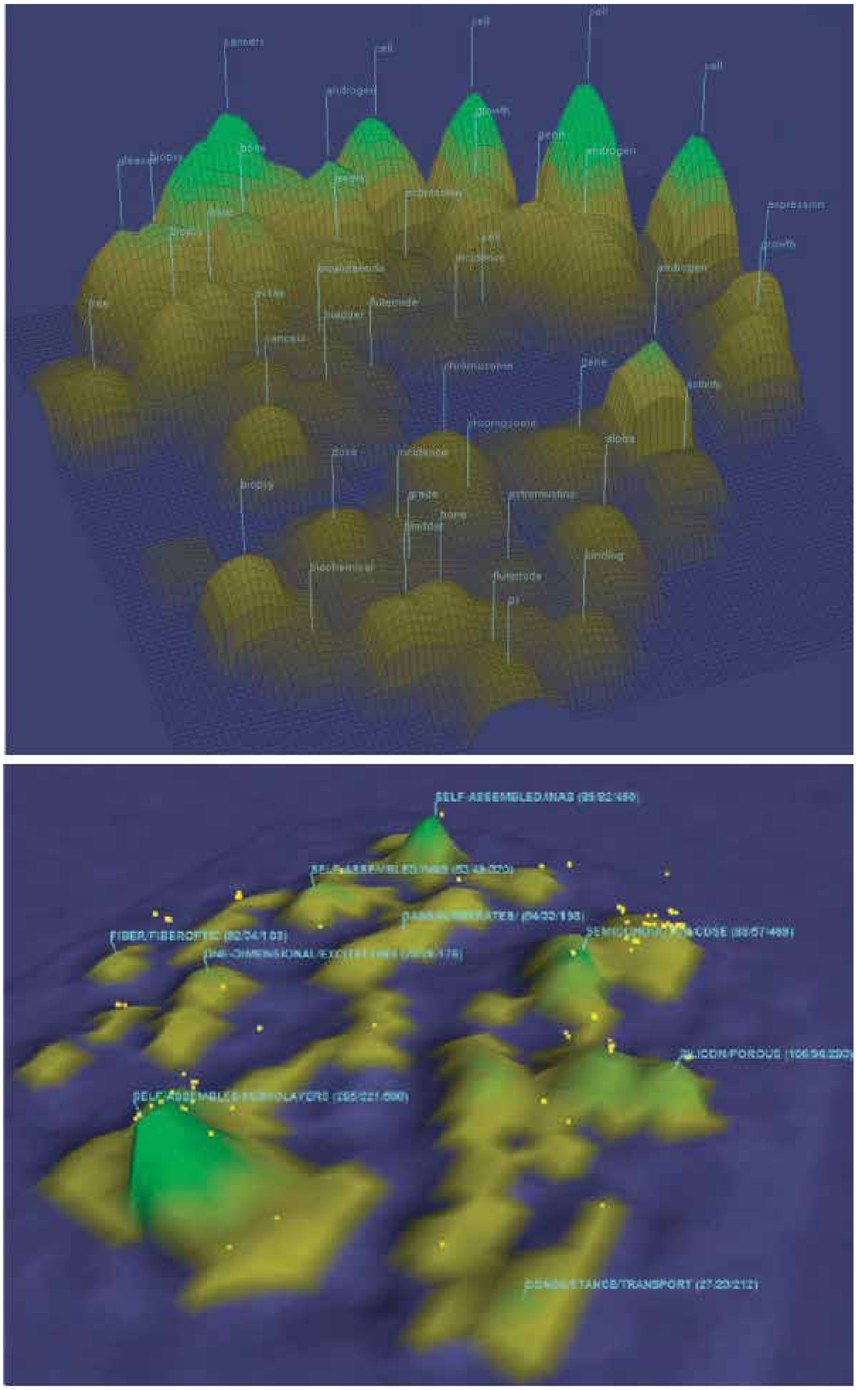

Figure 17. Screenshots of ThemeScapes (up) and VxInsight (down) information landscapes [37].

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Figure 18. Depiction the program system development [37].

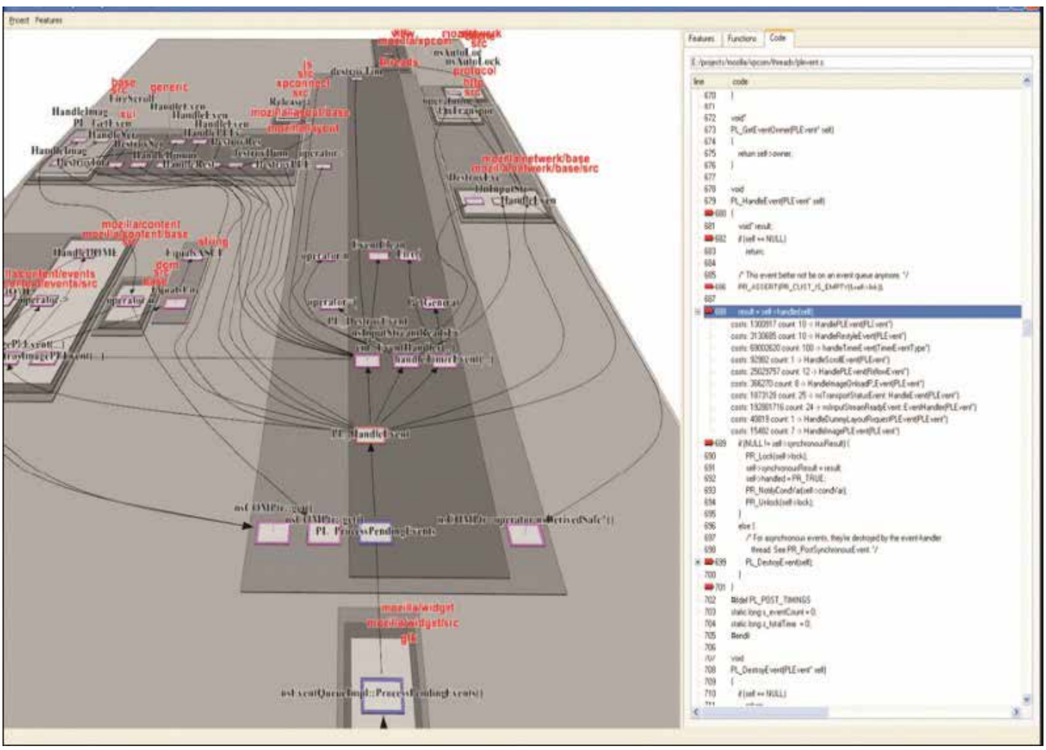

Figure 19. Complex graphical view and textual code view of call graphs based on factory metaphor [41].

the same time, the *unlimited context* allows a quick look at the entire "picture" and quickly identification of key elements.

Naturalness

It is known that naturalness of a metaphor reduces efforts on the resultant image interpretation.

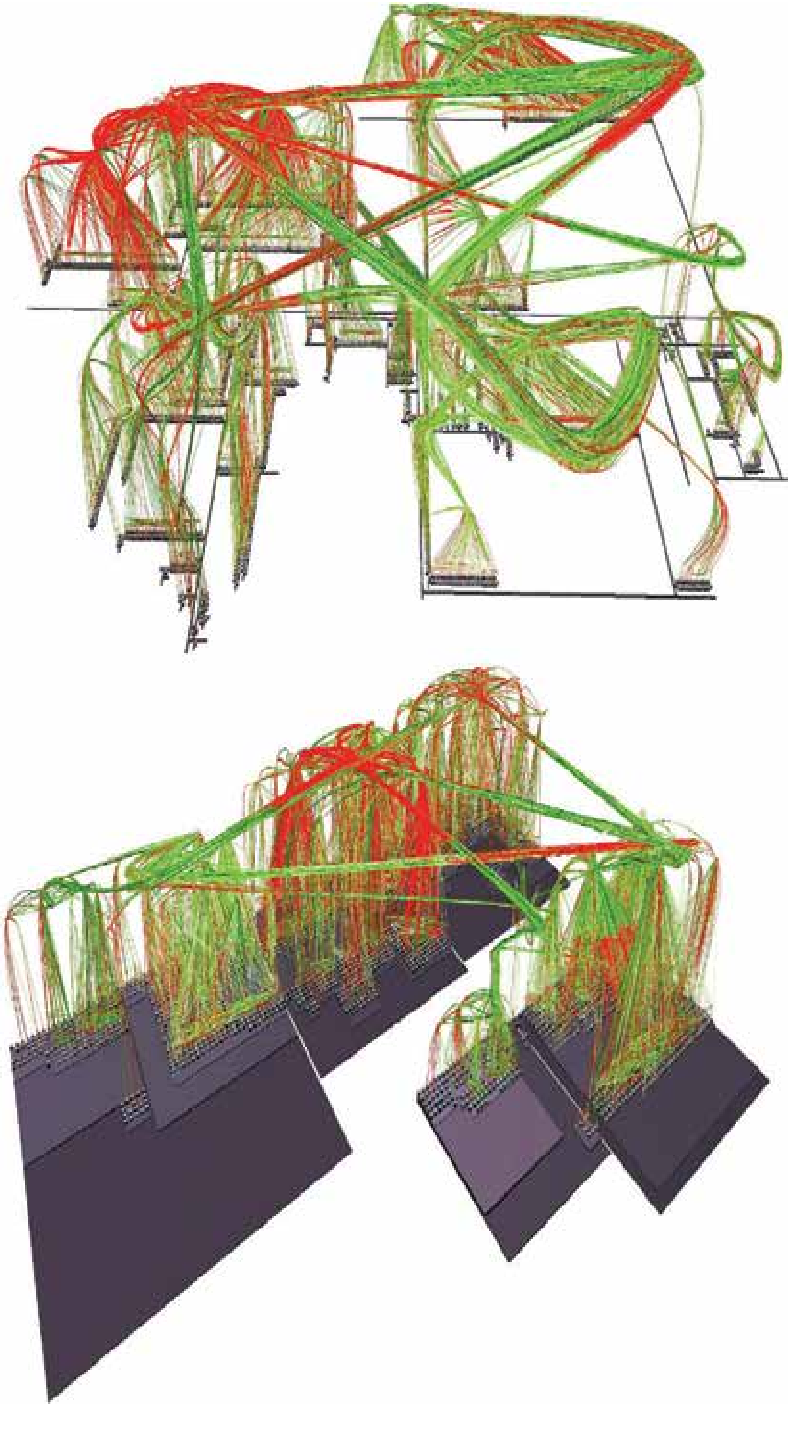

Figure 20. Visualization of dynamic call relations on an execution of JEdit, Java JRE classes included. 2710 classes, 10,870 edges representing 4,632,680 calls [40]. Up: Relations on top of the nested layout of the software city metaphor. Down: Relations on top of the street layout of the software city metaphor.

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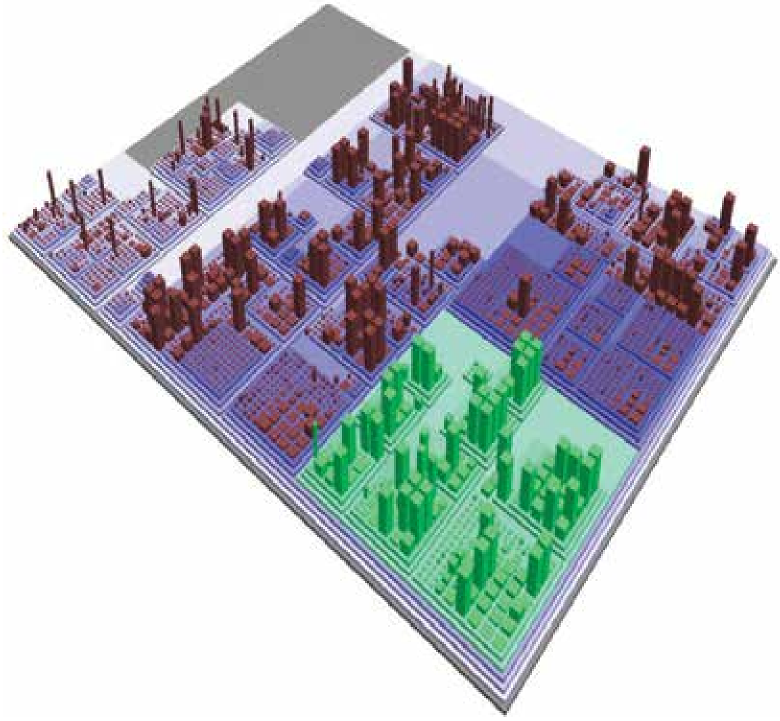

Figure 21. The example of city view of the software system [42].

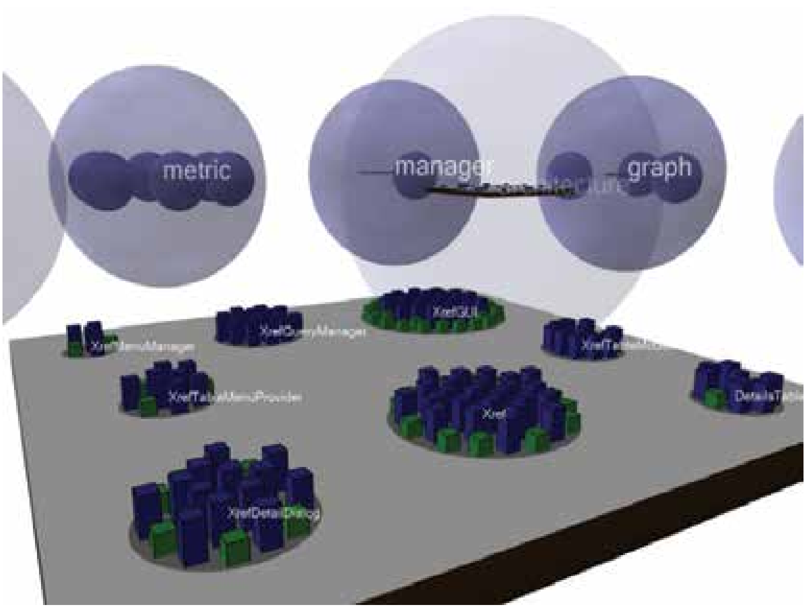

Figure 22. The example of landscape view of the software system containing packages, classes, methods and attributes [43].

In the cases of *city* and *landscape metaphors* not only naturalness of spatial orientation, but also naturalness of navigation takes place. In case of a city metaphor, the method of navigation is defined by the metaphor itself.

Organization of inner structure

Metaphors suggest the existence of an inner structure. In case of a *city* metaphor, this structure is dictated by the metaphor itself, and it is defined rather rigidly—there are buildings, quarters, streets, and districts. In *landscape* metaphor, a structure choice is nondedicated. In this case, one may say about landscape nesting.

Key elements

Metaphors suggest a representation of large volume of information, and in most cases, this information is rather homogeneous in visual sense. Users need the key elements to interpret this information. If we want to use a metaphor to reveal specific features and/or exceptions (for example bugs in programs), these elements have to be depicted by easily distinguished image-keys. One may design some key elements in frameworks of city or landscape metaphors. In these cases, some forms of guidance signs or markers may be used as key elements.

Resistance to scaling

These metaphors are stable in the case of increase in information volumes. Moreover, applications of city and landscape metaphors are reasonable only in the cases of large information volumes. In the cases of *city* and *industrial landscape* metaphor transport corridors help to design software visualization systems. Transport corridors may be used as means to represent control flows, data flows, and other relations between program constructions or parts of program complex.

Note that unlike in the case of landscape metaphor, the choice of city metaphor strongly limits the set of possible views. Thus, city and landscape metaphors may form base to represent considerable volumes of the structured information with identifications of specific interest cases that is necessary in the systems for performance tuning and program debugging for parallel computing. Additionally possibility to fly over a city/landscape creates prerequisites to easy navigation. Flight with changes of height allows to carry out scaling and zooming. Interpretation of the graphical displays based on these metaphors seems to be simple.

11. Properties of molecule metaphor

Now, let us consider the properties of molecule metaphor that also may be used to visualize call graphs of parallel programs (see **Figure 23**). This metaphor may be used in software visualization, for example, to visualize dynamic object relationships in Java programs. The metaphor of a chemical molecule is used to aid comprehension and to help in reducing the size of the object graph [44] (see **Figure 24**).

Figure 23. Call graph visualization based on molecule metaphor [30].

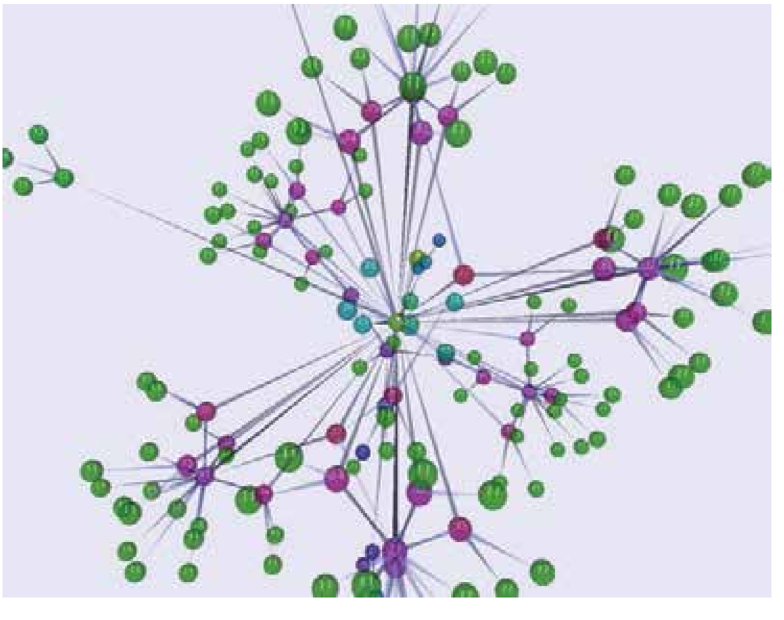

Figure 24. The main cluster from the object diagram [44].

Three-dimensional visualization techniques may improve the quality of graph structure perception. Suggested idea is to search analogies with natural objects. Let us place in nods-functions (which is usually represented like spheres) an electrostatic charge [30].

Connections between nods are replaced by elastic interaction. Let's name the metaphor "a molecule metaphor" because at the given approach the visualization similar to the structure of benzol molecules. Thus, there are two types of interactions: springy between bound nods and electrostatic between all other nods-"atoms." The electrostatic interaction may reflect temporary features of the calling functions, then springy—a number of calls. The consideration of the "molecule" energy allows us to construct the effective drawing algorithm for about thousands of objects. The displays meet the symmetry criteria. Animation (molecule rotation) allows exploring graph structure better. Color may be used for accentuation of interesting features of visualized graphs. The molecule metaphor is constructed on analogies to natural objects [24]. There is an interesting example of using landscape metaphor for visualization of molecular similarities [45].

Physical particles metaphor substantially similar to molecule metaphor may use in software visualization [46] (see **Figure 25**).

The metaphor supports the selection of key elements for example, by coloring or size changing of the molecules elements and changing of thickness of communications between them (key elements). Moving and navigating in pictures related to molecule metaphor may be

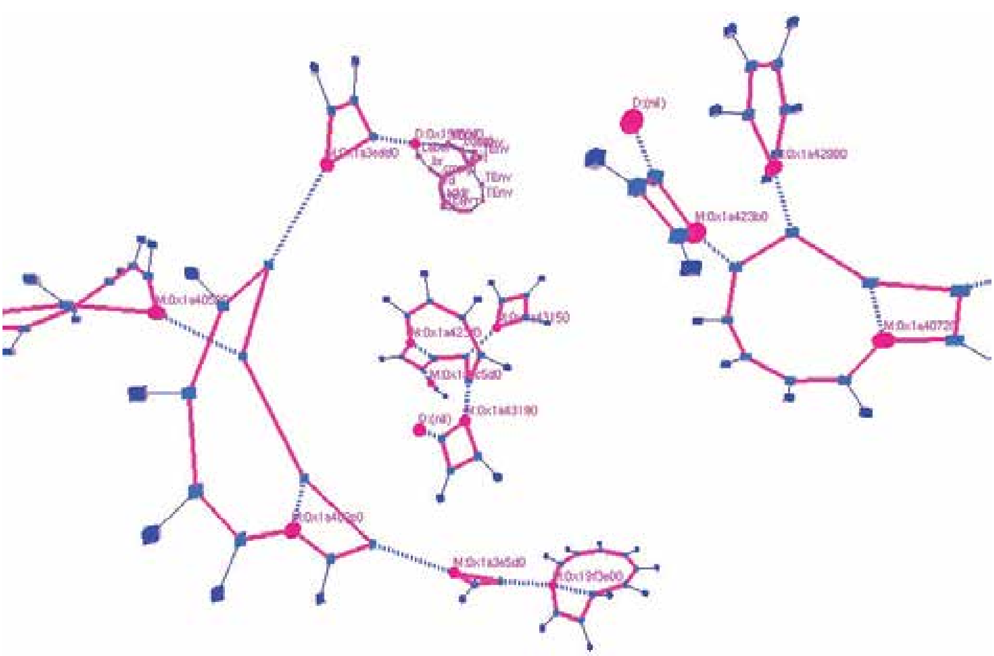

Figure 25. Compilation graph visualization based on physical particles metaphor [46].

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performed by flying around molecule. There is the experience of visual "entering" a separate "atom" and viewing internal visual information inside a single sphere [46]. It is possible to implement similar "entering" spheres in the frameworks of virtual reality environments (organization of inner structure) (see **Figures 23** and **25**).

Note that in general, the use of virtual reality enhances the visualization based on *building*, *city*, *landscape*, and *molecule* metaphors.

12. Context, interpreter, and interpretant

According to semiosis, a metaphor defines techniques of designation and an imagery of visualization. Also, a metaphor defines a context of interpretation. Interpretation of visualization (and also interactive manipulations) based on given metaphor reconstructs (or creates anew) a set of user's cognitive structures in which the picture of the phenomena is represented. A process of interpretation is exactly the generation of representative cognitive structures on bases of the visual images. This process is inverse or more exactly dual to visualizations.

Process of visualization, in turn, is considered as construction of visual (geometrical) images on the basis of abstract representations of objects. These abstract representations are the model of objects under researches, the phenomenon, or the process, somehow connected with the user's cognitive structures that describe these entities.

The context is defined as a metaphor, and an individual of the interpreter. The interpreting context defined by the metaphor is revealed in the individual of the user of visual systems—the interpreter of the sign visualization process.

The answer to a question "who is the interpreter of visual texts?" defines that part of a context which depends on the interpreter. Against this background user modeling is very important. One can consider user models of various levels, for example, the general model of visual perception, or by contrast the concrete model of user manipulations with the concrete input device. Now, the research domain of user modeling is "under construction." For obvious reasons, researches related to modeling of users of mass interfaces (such as educational or informational systems, e-shopping, and social network sites) are carried out most actively. Also, there are interesting researches on modeling users of specialized visualization systems, for example, systems based on virtual reality.

As already noted, the meaning of "visual texts" implied by a developer of the visualization system (an author of the text) can be significantly different from the meaning obtained by a user of visualization systems (an interpreter of the text). Thus, in many cases it is impossible to determine accurately the content of interpretant in computer visualization systems. For the design of visualization systems, it is necessary to consider possibility of meaning distortion, appearance of "descriptive artifacts," partial or full misunderstanding of senses implied in visual texts. Development of the user model and its analysis has to help with an explanation of similar negative occurrences, or (better) have to prevent them. On the other hand, there is possibility of some positive occurrences connected with partial determinacy of *interpretant*. These situations are frequent at the first stage of development of some specialized visualization systems when there are not fully understood, the algorithms and methods to implement them, and often there are not clearly defined the mathematical models themselves. The successful metaphor, well designed and developed views of one or another scientific abstractions often allow the user who really understands an essence of the phenomena under researching, to find more valuable meanings, more than interpreted information in the resulted picture, than the designer of visualization supposes. Thus, indeterminacy or partial determinacy of interpretant (if to consider it from the designer point of view) can occur in those cases of computer modeling, when a new, hitherto unknown knowledge about a given application domain are gained.

13. Design of visualization

In summary, let us describe our approach to the semiotics design of visualization systems. Design of visualization itself is the part of the process of the development of specialized visualization systems. This process includes among other such stages as search/choice/designing of visualization metaphors. The next stage is the design views, based on these metaphors. We define a view as the abstraction of a graphic display, containing specification of visual objects, their attributes, their interpositions, possible dynamics, and ways of interaction. After determination "*who is who*" in visualization in terms of semiosis let us translate resulting scheme of semiotics analysis into the language of visualization design for specialized visualization systems.

The first point of our scheme concerns the recognition of denotatum (designatum) in semiosis. For the scheme of design of visualization systems, this point corresponds to such questions as "*what is the goals of visualization?*" and "*what is the subject of visualization?*" Thus, the definition of denotatum is related in the process of visualization to the definition of the objects of special interest, their states, features and specifications, as well as moments of transition from one state to another. Note that the same set of model objects can be visualized in a few views by different methods.

The next point is associated with the search for methods of signification for the denotatum, that is, with the choice of sign.

For the design of visualization systems, it is important to understand that whole graphical display (a picture) rarely appears as a sign. It is necessary to determine, which elements of the image should (and can!) be recognized, understood and interpreted by the user specifically as such. It is known that the choice of imagery for the view is primarily dependent on the visualization metaphor. Moreover, the metaphor sets the context of interpretation.

The context does not exist by itself. In principle, it is subjective, as it bases on the senses of the interpreter. In this regard, let us make one more remark. Signs (or more exactly the text) are interpreted only by those who can do it, who has the necessary knowledge. For example, a hunter "reads" animal tracks in the snow forest clearing and reconstructs exactly the events what happened there. And an inexperienced person cannot do it. Hence, another important question in the design of visualization stage is the following: *"Who is the interpreter of visual texts"*, *"what experiences and what knowledge he has?"*

As already mentioned, there is another important (if not the most important) actor of the design process—the author of visual text (that is, the designer of visualization). She/he should have knowledge of the application domain, allowing precise identification of the main objects of interest to be visualized, and understand what type they are. However, there is an example of the visualization environment, which may independently choose by certain criteria a way of visual representation from a set of the available ones. This environment should be belonging to the class of cognitive visualization systems. Here, the current author of the visual text is the computer program; therefore, it is difficult to say about the presence of some primary, preembedded sense put in the visual text. In the meantime, a user of this system does the analysis successfully and interpretation of pictures, getting new (hitherto unknown information) from presenting graphical displays. Note, once again, that the problem of the source of the interpretant in the visualization process is still not fully explored.

Due to the projection on the process of visualization design, the scheme of semiotic analysis is a useful tool for the design of visualization systems of various types. It was successfully demonstrated their ability to create new visualization techniques.

14. Conclusion

Semiotics approach to the description of visualization does not isolate us from other approaches. On the contrary, the fact that signs have to be recognized, understood, and interpreted, requires the research studies of the perception of signs and their recognition among the other elements of the pictures. These issues are studied in the framework of Gestalt psychology. There are the well-known publications on Gestalt design of human-computer interaction and visualization [47–49]. However, their results are not always taken into consideration by system designers.

Another approach to research studies on visualization is connected with psychological studies. In the report [50], it was noted that the goal of visualization is to leverage-existing scientific methods by providing new scientific insight through visual methods. Visualization should form (or facilitate to form) holistic mental models and as a consequence to create insight. The occurrence of insight is considered as one of the main criteria in evaluating the visualization quality [51].

Ideas of Brushlinskiy [52] on insight are important in connection with analyzing user experience of systems of computer visualization. Insight is regarded as an event, in which an individual "immediately formulates the basic thought has arisen." Also "noninstant" insight is considered. The process of solving a task lies in revealing the relations between its elements, its conditions, and demands. The individual solving a task is performing analysis via synthesis. New characteristics and relations of elements of the tasks are laid out and synthesized with each other, until the solution is at last found.

Cognitive visualization is aimed at helping the researcher to see all elements of the task at hand, to evaluate their relations with each other. One may say that a search for a solution by a user of scientific visualization system largely matches the activity of a researcher busy with a scientific problem, and that may include both instant and noninstant insight. According to Brushlinskiy, in the latter the thought is being formed during several seconds before one's eyes (it is not originally available and is actually formed, not simply formulated). Study of activity of a researcher analyzing and interpreting data with the help of visualization is a major task, which would allow raising the efficiency of computer modeling as whole.

The process of visualization means building a visual image upon abstract ideas of an object. These abstract ideas constitute a model of an object, a phenomenon, or a process researched, which relates to representational cognitive structures of a user, that describe this entity [53]. Visual images representing an entity being modeled serve to create or restore the cognitive structures upon it. The task of visualization is to obtain a visual image, by means of which a mental image (idea) of the object in question may be correctly restored. On the basis of those preliminary structures, the set of views for the visualization system is designed. On the other hand, the specific visual images representing the modeling entities provide for the formation or reconstruction of an updated version of cognitive structures. Generation of *representational cognitive* structures basing on visual images supports interpretation processes.

Consideration of computer visualization and visual human-computer interface in terms of visual communications is another source of analysis techniques and experience. The analysis of visual communication may be also performed from a perspective of semiotics.

It is very significant the problem of formalizing the visualization theory. There are different approaches to the formalization basing as on semiotic as mathematical analysis methods. The problem of the mathematical formalizing the visualization theory basing on category theory and semiotics was posed and considered in the important chapter [54]. In Ref. [55], formal approaches to evaluation of visual texts and visualization effectiveness are considered. Effectiveness of visualization is defined as a multivariable function. The parameters of this function are partial derivatives of visual text by its informative characteristics. Visualization metaphor may be considered as persistence mapping analogous to denotational semantics using in the programming domain. Also, persistence mapping may be defined throw little varying of visualization parameters.

The formal approaches are one of further directions of our researches.

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Chapter 7

Developing Building Information Modelling for Facility Services with Organisational Semiotics

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Additional information is available at the end of the chapter

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Abstract

Built environment provides infrastructure and space that supports users' activities through facility services. Space provides the context in which services are constructed. Facility services management is facing challenges in information management that requires vast and heterogeneous information from design to operations of a building across various service systems. Building information modelling (BIM), an object-oriented modelling technology seeks to integrate information throughout the entire lifecycle of a building project. However, BIM is limited to meeting the needs of information arising from operation and management of facility services, and the requirements for BIM development are yet unclear. Though BIM building semantics can be enriched, but mainly focusing on building fabrics for design and build. BIM does not support the consideration of building operation activities and the context of building in-use. From a semiotic perspective, the lack of address in pragmatic and social aspects of a building project limits BIM as a through-life solution. This research deployed semiotics, a theory of signs, to analyse and develop BIM from an information system's point of view. Organizational semiotics is a sub-branch of semiotics, which offers a set of methods that can enhance BIM to link building fabrics to facility service activities.

Keywords: BIM (building information modelling), FM (facility management), OS (organisational semiotics), habitat

1. Introduction

The fragmentation within the construction industry is reflected in information and knowledge loss and process discontinuity during a building lifecycle. Such a gap between design/build and facility management (FM) results in an expensive and time-consuming process for data compiling and exchange into FM. Furthermore, a low level of interaction between specialist and facility teams transferring design intent and rationale, causing inefficient and ineffective FM. Building information modelling (BIM) is introducing a new form of information processing and collaboration for designing, constructing and operating buildings [1]. BIM has advantages in facilitating design and construction in the way of precise objectified description with 3D representation, and more dimensions such as 4D with time scheduling and 5D with cost estimating are integrated. BIM is also an entirely different approach of representing a building, which models an asset in digital form enabling those who interact with the building to optimise their actions and resulting in a greater value for the asset in the whole life cycle. The study of BIM for FM is an emerging area. A BIM-based FM model is a relatively new concept under exploration. Most research in the area has focused on enriching attributes of building components and their counterparts as building objects represented in BIM models from a design-and-construction perspective to describe building elements.

The challenge has generally been the capacity to provide information pertinent to managing facility service systems and to integrate operational information and construction information. Such capacity-making data more meaningful for decision support as 'intelligence' lies behind the services [2]. Facility services are operated and delivered according to personal preference and organisational policies in the form of rules or norms relating to allowed and desired behaviour of intelligent service systems [3]. Those features not only require integration of building information, technical engineering knowledge and understanding of the service process, but also the semantic and knowledge-based building information model with service processes. This research gap calls for BIM's development not only focusing on technical aspect, but also concerning social and organisational aspect of building spaces.

BIM has clearly shown value adding to design and construction. However, the current development of BIM is still largely centred on enriching building fabrics, whilst the links between building fabrics and facility activities are yet less addressed. An as-built model is more regarded as an FM model that is developed and applied in O&M (operation and maintenance) practice. But from the literatures we have learned that as-built models seem to contain information more in relation to repair and maintenance services, but less in addressing other services. Furthermore, there is little research linking BIM to FM service processes in a built environment. The context of use of a building is less addressed, hence services related to engineering information and knowledge are not reflected in BIM yet, which causes building information to be dissociated from the facility service delivery process. FM services deliveries are organised information-rich activities involving interactions between building systems, facility systems and user activities within organisations in a built environment. Thus, the requirements for developing a FM model are not only technical, but also rather social and organisational.

Within the background of BIM representing a paradigm shift in the AEC/FM industry globally as introduced above, this research is motivated by a problem of BIM development that arises in supporting the facility services management and accordingly meeting information requirements for services' operation and delivery. Consideration of BIM as a through-life solution for information management, there is a need of appropriate theories and systematic approach to develop BIM for connecting the D&B (design and build) and O&M (operation and maintenance), which enables FM managers to better understand how a building is operated and optimised.

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Semiotics [4], as a well-established discipline of signs, offers a comprehensive theory to understand the nature and characteristics of signs and information system [5]. A sign is something, which stands out to somebody in some respect or capacity [6].

Organisational semiotics (OS), a branch of semiotics, facilitates the understanding of organisations as information systems through using semiotic methods. An information system can be interpreted and examined by organisational semiotic framework [7] at six semiotic levels, which are social, pragmatic, semantic, syntactic, empirical and physical levels. A building as a sociotechnical environment and its virtual representation as BIM is a complex sign system that allows stakeholders to utilise, interpret and interact with. BIM can partially overcome identified semantic and syntactic issues in FM [8]. However, BIM has yet to support business process with the consideration of building activities and the context of use [8–10]—i.e. lacking pragmatic and social aspects from a semiotic perspective, which limits BIM as a through-life solution. Therefore, the major research question is addressed in this study: can organisational semiotics (OS) be used to bridge building information modelling (BIM) making a focus of building fabrics and facility management activities concerning with the service management.

The next section is organised in three parts as followings: first, the theory of habitat and organisational semiotic framework are adopted to analyse a building from a semiotic perspective, addressing the features identified for a habitat, which provides interrelated contexts for facility services management. Second, the following section deals with specifying service-related information requirements based on the analysis of the habitat. The last a summary is provided.

2. Theoretical foundation: a semiotic perspective to service-oriented built space

This section makes the suggestion to the research question. The process of constructing the solution is by obtaining a general and comprehensive understanding of the problem and followed by a theoretical analysis. Buildings are regarded as special and complex products that provide functional spaces enabling people to live, work and achieve their goals. So, a building can be featured as a sociotechnical system. The research regards a building as a complex sign system. BIM is used to model such sign systems from a semiotic perspective. Semiotics, the discipline of signs, provides a solid theoretical foundation for stakeholders' understanding of the characteristics of sign-based and service-oriented built environments. Semiotics offers a series of theories and approaches to underpin this research for deriving information requirements and modelling facility services from a semiotic perspective.

2.1. The theory of habitat

A built space can be treated with the notion of 'habitat' [11], which is depicted by three types of habitats from a semiotic perspective. The term 'habitat' originates from biology, and it is defined as an area that has all that is needed for survival of a species.

The habitat was introduced as a design metaphor by May et al. [12] to study the requirements arising from information systems become embedded in the physical environment.

For a built environment, Andersen and Brynskov [11] define a habitat as an environment that supports and mediates the activities of its inhabitants, presents a set of affordances. A habitat is described from three different features: physical, informational and pragmatic dimensions.

The physical habitat is made of physical space with a defined layout and boundaries over time, i.e. three physical dimensions plus time. The physical habitat is tangible such as a kitchen in a house or an office. People can do their work in offices such as reading, writing or typing and so on, and the physical habitat addresses how interactions between space and users are dynamic over time. For example, a new facility can be installed if it is required for users' activities. A moveable partition wall in between two rooms can be moved to expand spaces if users require a large space for their activities. Different activities can be arranged in the same room over time such as a meeting or a lecture occurring in a multi-purposed designed meeting room. Furthermore, physical habitats can be nested. A given example is a train: the train as a whole is a habitat for travelling activity (embarking, showing tickets and disembarking), but as a part of a train, the compartment is a habitat for work activities. Regarding the built environment, an office building contains spaces with different functions.

The informational habitat is a well-defined combination of information and media that support certain inhabitants' information and communication needs. The informational habitat is essentially semiotic by nature and involves a process of communication and interpretations. The informational habitat provides signs available to participants in the activities through the use of digital and non-digital signs. Informational habitats are distinguished between the representing part and presented part. The representing part is an access area where the inhabitants have access to the information, while the reference area is the object of the information. For example, an exit sign is understandable to users as it clearly indicates the way out.

From Bynskov and Anderson's description, we know that pragmatic habitats concern the social aspect of a space, i.e. inhabitants have their expectations and intensions of using a space, which is closely associated with users' activities. The potential activities exist as different stakeholders' goals and expectations, or regulations and rules that result in certain behavioural patterns. In addition, inhabitants may need to have knowledge and skills for using facilities and taking part in activities in a built space. For example, in a hospital, inhabitants such as doctors and nurses have their knowledge and certain activities that will occur in their workplace. Their activities are also governed by organisational norms. Furthermore, the members of a potential pragmatic habitat are the inhabitants, who could be people, as well as digital agents that have capacities to perform and meet requirements. For example, HVAC equipment could be a digital agent that can condition a room when needed.

2.2. A semiotic perspective to the habitat

In operation and maintenance stages of a building, built spaces support users' activities through facility services. Thus, the value of the built environment is realised through the services it offers and interactions that it mediates and enables for people. The built environment provides users an infrastructure and space in which service contexts are constructed. Service is a rather abstract concept; however, facility services can be presented and understood properly if whole building context is considered. The three types of habitat as effective approaches to identify the building contexts are associated with facility services.

The OS framework provides an approach that systematically concerns the use of signs. From a semiotic perspective, a building or a habitat in this research is a complex sign system that has its meanings. By using the OS framework, we can analyse the aspects of such sign systems and their effects on facility services. For this research, the result of analysis can guide us to derive information requirements for modelling services in a built environment. Based on the theory of habitat, the habitat can be further extended and characterised by a combination of physical, temporal, technical, informational, empirical, syntactic, semantic, pragmatic and social aspects, which are all associated with the representation of facility services (**Figure 1**).

Spatial flexibility affects services, too. Two spaces can be combined into one large space by removing the partition wall between them. The change expands the space's volume so that it can contain more people to do something that a small space is not able to offer, e.g. a gathering or a party that simply requires more space. Such change enables more spatial affordances. Consequently, facility services may change correspondingly to meet the requirements arising from the new functions. For example, ventilation's capacity increases to provide more fresh air, and fire evacuation routes may change to meet the regulation. Equipment and devices, as well as furniture arranged in a built space, also indicate certain services. For example, medical devices installed a differentiate ICU (intensive care unit) and a general ward that have different specialist services. In a flexible meeting room, chairs can be rearranged to fit the type of meeting. They can be lined up for a presentation, or placed in a circle to promote discussion. It is worth mentioning that devices and equipment that belong to service systems are a technical aspect of a habitat. These objects provide technical context for services.

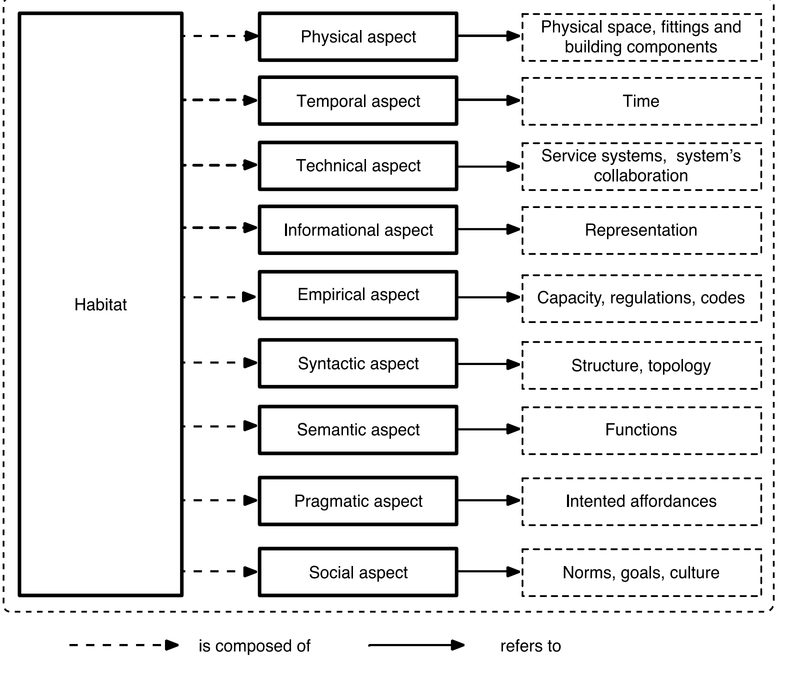

Figure 1. Habitat deconstruction from a semiotic perspective.

A habitat is also characterised by the temporal, which is closely bonded with a physical space. The time change over a built space affects services as well. Lighting configuration may be different for a building between working-time and off time from energy conservation or security perspectives. A high level of space utilisation in a workspace is defined as a space used for the maximum possible amount of time. Second, a built space is usually managed and used over time. For example, a meeting room is managed according to schedules. Building systems are configured to serve a built space in line with space schedules (e.g. work-hours and off-hours, or daytime and night-time). Facility service management often takes into account the spatial and temporal aspect (e.g. a seminar room is scheduled with different events that require different services).

The habitat has technical character. A building provides users with various services, and requires many buildings or facility systems to function. The supporting systems including building systems are integrated, which allows interaction and coordination between them so there is interoperability. The IB (intelligent buildings) approach enables various service systems to be managed and controlled in an integrated manner based on a sensor network. With rapid development of control systems and communication networks, occupants are expected to have more control and interactions with enhanced spaces, which are called intelligent pervasive spaces [13], or alternatively defined by Nakata and Moran [14] as 'an adaptable and dynamic area that optimises user services and management processes using an information system and networked ubiquitous technologies'.

The habitat is characterised by informational factors. Building operation is achieved through interplays between the buildings and people. A building is full of signs that provide information for people to interact with. From the layout, decoration and equipment of a room, it enables people to know whether it is an office or a patient ward. There are instructions available for people to understand how to use a building. A simple example is a thermostat or a programmer in a space that might indicate that the room has air conditioning services and the occupant can adjust the temperature manually. Furthermore, the information provided and its perception and interpretation is subject to a person's knowledge. Occupants ought to leave the building immediately when they hear a fire alarm beeping which indicates a fire has occurred, with an exit sign guiding people to evacuate. For some facility services, some building elements may link to other information sources for sense making. For example, a security camera records videos to monitor a certain built area, and the data are stored and linked to somewhere else. The recorded videos are meaningful for securities. A smart metre records building performance figures, and the accumulated data can be useful for performance analysis for facility managers or energy officers.

The habitat has an empirical character. Empirics are a branch of study of the statistical properties of signs when different physical devices are used. In the design and construction area, the empirical level is concerned with building architectural and mechanical designs that need to not only meet design specifications, but also comply with regulations and codes. For example, the capacity of a disabled toilet needs to meet certain standards in dimensions and facilities to assist the disabled for use and convenience. Other parameters of artefacts that empirics deal with may be spatial capacity, designated lighting brightness, lift capacity, HVAC (heating, ventilation and air conditioning) capacity, etc.

The habitat has syntactic features and concerns the rules of composing complex signs from simple ones. In the design and construction field, the syntactic level represents the requirements

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of topology of space and building systems, i.e. the layout of space and the logical relationships between building system elements. For facility service management, the syntactical aspect is crucial for understanding service system composition and each component in the system, such as devices, sensors or the controller's roles and effects. It is important to interpret engineering system diagrams to information models for facility service management.

The habitat is characterised by semantics. Semantics is the study of the relationship or interactions between a sign and what it refers to. The semantic level concerns meanings of built spaces and artefacts present within them. A space needs to be socially and physically defined for its functions and purposes, which are supportive for business activities. Built spaces provide the context in which services are constructed. Such service context concerns in building use are constrained by limitations in a physical space.

The habitat is characterised by pragmatics, and this concerns the utilisation of a specific space in detail, which involves occupancy patterns, services invocation, and norms and regulations in the service process. Occupancy pattern is referred to as the intended use of a space and possible activities. For example, a multifunctional room is designed to have more occupancy patterns that can satisfy various users' needs. In this case, the service systems of the room can be configured for multiple sets of preferences according to its usage. For instance, service attributes of a normal working scenario can possibly differentiate temperatures and lighting levels from a meeting scenario. In this case, the service systems of the room can be configured for multiple sets of preferences according to its usage. Moreover, a particular occupancy pattern may require related services to support users' activities.

The habitat has social character. The built space provides a physical ground on which social spaces are constructed, with the social space constituted by cultural settings, relationships and interactions between people that are dependent on physical spaces. A social space may regulate how people use a built space. Therefore, it may enable or inhibit affordances in a built space. For example, a social space may prevent occupants opening windows when air conditioning is on for the consideration of energy conservation. Building types and organisations occupying the space affect people's behaviours, for example, at a hospital or university. Certainly, there are differences in how people interact with the physical spaces and also the interplay between people, doctors and patients, or lecturers and students. Even the same building type, for example, office buildings, may have different enterprise cultures and correspondingly norms in an organisation that affect interaction between people and built spaces differently. Google's open culture shapes its workplaces unusually with more open planning, and more interesting decoration, which this tech giant believes has a positive impact on productivity and collaborations and inspiration, while other organisations prefer traditional cubicles in their plan.

2.3. Illustration of the habitat

In the last subsection, a habitat is analysed and deconstructed from a semiotic perspective, which contributes to our understanding of the relationship between such enabling built space and services. A habitat is demonstrated as a combination of nine semiotic-layered aspects. Two examples, a seminar room and a hospital ward, are given to illustrate each habitat aspect related to services in this subsection (**Tables 1** and **2**).

Habitats aspects	Description
Physical	Building components, e.g. walls, carpets, windows, doors
	Furniture, e.g. desks, chairs, shelves
	Equipment, e.g. computers, projection screens, projectors
Temporal	Service schedule, e.g. cleaning 6:30–7:00 am; HVAC 8:30 am–5:00 pm
	Room schedule, e.g. meeting 9:00–10:00 am
Technical	Service systems and collaboration, e.g. BMS, room booking and timetabling, services process
	System components, e.g. smoke detectors, fire alarm call points, CCTV cameras, Wi-Fi extenders
Informational	Utilisation of facilities, e.g. signage, service instruction, policies for users
Empirical	Capacity of facilities, e.g. lighting brightness, air conditioning capacity
Syntactic	Department, spatial structure, service zone
Semantic	Services profile, e.g. lighting, HVAC, CCTV, fire protection, parking, room booking, cleaning, catering etc.
Pragmatic	Seminar, users, e.g. lecture and students
	Meeting, e.g. staff, students, visitors
	Gathering, e.g. staff, students
	Invigilation, e.g. students, invigilator(s)
Social	Specific rules for the use of the room and related services

Table 1. The description of habitat aspects for a seminar room as an example.

Habitats aspects	Descriptions
Physical	Building components: walls, carpets, windows, doors
	Furniture: ward beds, wheelchairs, chairs
	Equipment: medical devices
Temporal	Service schedule: cleaning 8:30–9:00 am;
	Room schedule: visiting 2:00–8:00 pm
Technical	Service systems and collaboration: BMS, a hospital ward management system, visual systems, service processes
	System components: smoke detectors, lighting, nursing call points, CCTV cameras
Informational	Utilisation of facilities: signage, service instructions, policies for users
Empirical	Capacity of facilities: lighting brightness, air conditioning capacity
Syntactic	In-patient department, spatial structure, service zone
Semantic	Services profile: lighting, HVAC, CCTV, fire protection, nurse calls, medical gas, car parking, in-patient
Pragmatic	Care and treatment: patients, medical staff, visitors
Social	Medical device management policy, hospital ward management policy

Table 2. The description of habitat aspects for a general hospital ward.

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With two examples illustrated as followings, the semiotic aspects of a habitat pertinent to facility services are summarised as follows:

- The physical aspect of a habitat refers to physical spaces and building components maintenance, which are mostly related to location identification and facility maintenance.
- The temporal aspect of a habitat considers the time of using a room, which affects the time and sequence of service deliveries.
- The technical aspect of habitat concerns.
- The informational aspect of habitat concerns with information or signs, which can a guide and instruct users to operate facilities.
- The empirical aspect of a habitat describes the capacity of building elements including built space, systems, and devices, which may affect service deliveries.
- The syntactic aspect of a habitat describes structural elements in relation to facility services.
- The semantic aspect of a habitat indicates the functions of a built space, which may decide the required services to support intended users' activities.
- The pragmatic aspect of a habitat describes the intended affordances (intended user activities) and related users. The knowledge and skills of users to operate the facilities are also considered in this level.
- The social aspect of a habitat includes organisational policies and norms, which provides reference for the configuration of rules to service deliveries.

2.4. Habitat-centric service information requirements

Service-related information is required in order to support the facility service delivery process. The BIM-based facility service model is aimed at providing information that is potentially consumed by facility management (FM). The habitat provides the context in which the services are constructed. The features identified by the semiotic approaches in the last section have addressed different aspects of a habitat, in which service-related information can be derived. Specific information requirements are presented by analysis of the habitat in relation to facility services. As a result, the BIM-based facility service model can serve as a pre-set service context to assist FM. The context information can be classified, within the scope of the work, into four principle sets, which are user dimension, physical dimension, technical dimension and service dimension. The multiple service-related dimensions reflect the identified factors of FM discussed in the previous subsection. Each dimension is a collection of reference information for supporting FM activities (shown in **Figure 2**). In turn, the habitat sheds light on specifying the information content of each dimension in a FM service context. The interrelation between each service-related dimensions and habitat aspects, as well as dimensional information requirements, is illustrated in the following subsections.

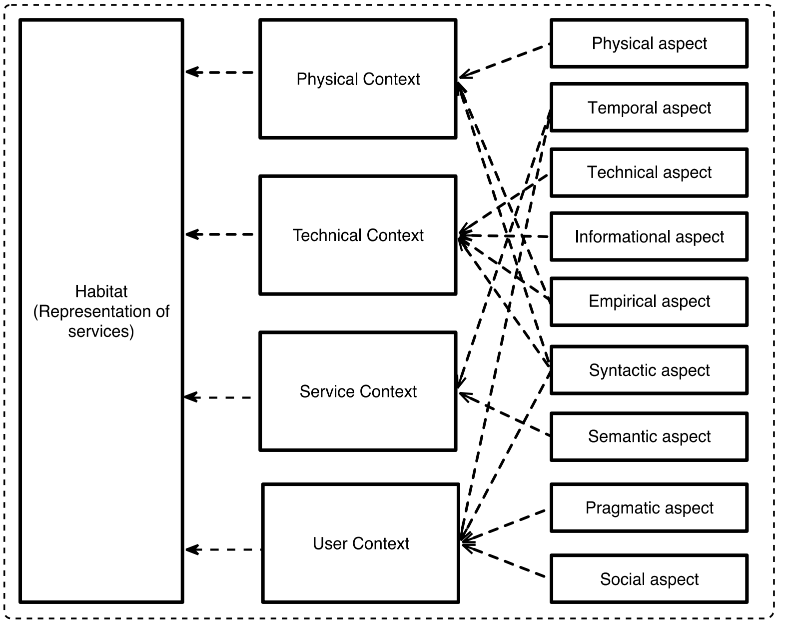

Figure 2. Interpretation of the habitat into categorised service-related dimensions.

2.4.1. User dimension

The user dimension refers to the information related to users' activities of a space. The user dimensional information not only affects how a building is designed in terms of space layout, decoration, furnishing arrangement and building systems, but also is required for multiple FM services systems in their daily activities. A certain habitat (a building type) implies who are the users, their activities or patterns, and their knowledge of supporting intended activities. For example, a hospital's users are mainly medical staff such as doctors and nurses, and patients. In a university building, the main users are faculty staff and students. In the building operation and maintenance stage, users' patterns of their activities affect what and how facility services are delivered.

The content of user dimension is concerned with the pragmatic, social, syntactic and temporal factors of a habitat. The pragmatic habitat constitutes the affordances offered by the habitat and the possible actions or behaviour enabled within the physical habitat [15]. Users' activities in a habitat are defined in the user dimension, considering a space can have multiple functions and can be arranged for different sessions or events over a given time span. Thus, their service requirements for different utilisation of a space can be discussed and linked with defined activities. Users or occupants can possibly have multiple sets of preferences specifically responding to the change in the utilisation of their physical environment. For instance, it is possible to specify different temperatures and lighting levels for a customised personal working environment compared to that for the use of a meeting. In addition, a pragmatic habitat also concerns a user's knowledge or is able to follow informational instructions to use facilities, which is included in the dimension.

However, the affordances that users' activities may be constrained by the social habitat. For example, a norm indicates that a user may not be allowed to open a window when the air conditioning is working for the consideration of energy conservation, although the user is able to open a window that is supported by a physical habitat. A library or a room may not allow food and drink to be brought in. Hence, the pragmatic and social habitat can serve as enabler or inhibitor to users. The social habitat refers to the information related to organisational policies, their objectives and building performance benchmarks in terms of FM services, which can be interpreted and coded as norms to guide service deliveries.

A temporal habitat normally linking with users' activities indicates temporal patterns. The information can be pre-set according to use patterns of a space or a building, which particularly benefit from the configuration of BMS to automatically control building with concerning energy efficiency, or simulation and prediction of energy consumptions of a building. In addition, the information can be available from service systems such as the booking or time schedule system, and to be linked with a particular space in BIM-based information model.

A user can be an organisation that occupies a building or a group of spaces; or an individual person who occupies a space; or a group of people who share a space together. The syntactic habitat for the user dimension concerns organisational structures. The information is required for the configuration of a number of service systems such as space management, move management, as well as considering controlling norms for BMS. An individual user's profile may include the user's name, organisation (department), occupation and personal preference of a service and so on. An organisational profile may include name, business type and organisational policies. With user dimensional information being developed and stored in a BIM model, designers and engineers can specifically configure facility management systems such as BMS to deliver services according to users' preferences for specific activities in a built space. User dimensional information requirements are demonstrated in **Table 3**.

Dimension	Habitat aspects	Specified dimensional information
User dimension	The social aspect	Benchmarks that measure services concerning organisational objectives
		Norms that can be coded into FM systems and processes to control service deliveries, which are derived from organisational policies, objectives and rules, or building regulations
	The syntactic aspect	The hierarchy of an organisation, e.g. organisation—department—group—person
		Priority of implementing norms for service deliveries, e.g. organisational rules > group preference > personal preference
	The pragmatic aspect	Sessions (user activities) based on spatial functions, e.g. meetings, seminars, events
		Users who are associated with a specific profile, e.g. organisational rules, policies; personal preferences; or a person's role or occupation with indicating appropriate knowledge or skills to conduct activities
	The temporal aspect	Temporal patterns related to users' activities in a space

Table 3. User dimensional information requirements in the habitat.

2.4.2. *Physical dimension*

The physical dimension is about information related to physical spaces and building components. It mainly deals with the physical character of a habitat. According to Anderson and Brynskov's definition, the physical habitat consists of the physical layout and boundaries with the available physical artefacts [13]. The physical dimension describes a built space by three physical dimensions, its position in a whole building, and building components attached to the space such as doors and windows. Furthermore, the physical dimension is also concerned with building materials and fittings that fit building functions. It is worth mentioning that system devices and equipment are categorised into technical dimensions, which are addressed as the technical factor of a habitat.

Representing spatial structure also involves syntactical character of a habitat, which indicates physical relations between spaces. Building components are constructed as objects to represent their counterparts in the buildings in the BIM model. It is recognised that representing the physical character of a habitat is widely applied and required for a wide range of FM services, particularly important to the repair and maintenance service. We can conclude that the physical dimension is often the focus of an as-built model and can be compiled from the as-built model. A facility service model is built upon this as-built model, which is extended to represent a habitat by adding other identified service-related dimensional information. Other service-related dimensional information can be linked with a physical space by defining relationships between objects with BIM intelligent object modelling technology. The physical dimensional information is presented in **Table 4**.

Dimension	Habitat aspects	Specified dimensional information
Physical dimension	The physical aspect	The space and its boundaries, e.g. walls ceilings Other building elements within the space, e.g. doors and windows, or other elements defined in relation to a specific service e.g. repair and maintenance
		Furnishing and layout, e.g. desks, chairs, or appropriate types of furniture
	The syntactic aspect	The spatial structures, e.g. building—floors—spaces
	The empirical aspect	Spatial capacity, e.g. area, regulated or designated accommodation of people

Table 4. Physical dimensional information requirements in the habitat.

2.4.3. *Technical dimension*

The technical dimension refers to the information about descriptions of service systems and constitutive devices. A building itself is not only an aggregation of spatial elements but also an assembly of building service systems. On the system level, the technical dimension concerns building services' system topology and system coordination, which addresses the relationships between devices and systems, respectively. Building systems' components are

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modelled to connect with each other in an as-built model to show their physical relationships. In service models, a building system topology indicates logical relationships among devices and instruments, which indicates their impacts and roles in a system. Service systems' key components with input/output functions such as actuators, sensors, or metres are modelled to show their logical connections and functions in the systems. Technical dimensions deal with technical and empirical character, as well as the syntactical and informational character of a habitat. The technical dimensional information is presented in **Table 5**.

Dimension	Habitat aspects	Specified dimensional information
Technical dimension	The technical aspect	System integration and coordination, for service delivery to facilitate user activities, e.g. defined service processes
		Device functions, e.g. input/output protocol for real data exchange, virtual addresses
	The informational aspect	Service instructions to users, e.g. exit signage, audio and visual alarms, visual or textual guidance to facilitate user activities
	The empirical aspect	Device and equipment capacity, e.g. lighting brightness, ventilation air flow and volume
	The syntactical aspect	System topology, e.g. service zone, loop, circulation

Table 5. Technical dimensional information requirements in the habitat.

2.4.4. Service dimension

The service dimension refers to information about facility services related to a certain user activity or occupancy pattern in a space. The service dimension deals with the semantic and temporal aspect of a habitat. According to the review, we understood that the facility services can be various including building services such as HVAC, lighting and fire protection services, but also other 'soft' services such as car parking, a room booking service, energy management and so forth. In the context of building operations, a space may have multi-functions, which afford different activities that are in need of specific services to support. Which services are designed and required for a building needs to be defined in the design and commissioning stage. For example, an office may offer lighting, HVAC service and video conferencing service in a meeting session, as well as fire or security service in an emergency event.

Service dimensional information helps to define and configure service profiles for an integrated FM service system to manage a building in use with timetabled sessions. Specific services can be grouped and linked to a space with concerning use patterns of it. In addition, supporting system and devices can also be defined to link different services in a building with smart IP-based sensor networks. Furthermore, a service (e.g. maintenance, cleaning) may be required to link with physical artefacts including components and devices if it is necessary. A facility service such as a cleaning service is needed as one form of maintenance for the entire building fabric during the operational life of the building. The doors, windows or floors and rooms will require cleaning from time to time. Building information models can be a fortified database of a building to represent building elements or space that requires cleaning. More than that the data attached to the elements can provide dynamic information of the cleaning status and static information about cleaning specifications and requirements.

Service dimension also includes basic descriptive information such as service contractor, service supplier and service requirements, or specific service operator, manager for a particular area of zone to demonstrate such an abstract concept, according to facility manager's requirements. Different services defined in the service model may have various services. In BIM-based modelling technology, those information may be presented as spatial attributes attached to a space object. A space object is represented with containing dimensional information in a habitat to meet different service requirements. HVAC service uses space to represent sensor and controller's location and occupiers' preference of the space. Timetabling service uses the space with its room schedule. Space management service is to define where staffs are located. In maintenance service, space is used to indicate a geometric space in a spatial topology. For example, the operation of BMS requires information such as room location and room schedule, as well as user's preferences, which can be pre-configured during design or commissioning phase. The service dimensional information is presented in **Table 6**.

Dimension	Habitat aspects	Specified dimensional information
Service dimension	The temporal aspect	Time schedule of a room for invoking services, e.g. a meeting
		Time record of an emergency event, e.g. fire event
	The semantic aspect	Facility services that are required to support a specific user activities e.g. the service profile of a room
		Descriptive information includes Service supplier, contractor, requirements and so on

Table 6. Service dimensional information requirements in the habitat.

2.5. Discussion and conclusions

The purpose of this chapter is to define a theoretical foundation for understanding and analysing a building, which is treated as a sociotechnical sign system. This chapter has set out to investigate service-oriented habitats from a semiotic perspective. Organisational semiotics is suggested as the appropriate theory to bridge the gap between building fabrics and FM activities for BIM concerning with the FM service management. Analysing and deconstructing the built environment into multiple service-interrelated characters (the physical, temporal, informational, technical, empirical, syntactic, semantic, pragmatic and social) from a semiotic perspective contribute to the derivation of information requirements on the basis of treating the built environment characterised as a service-oriented and sign-based habitat.

To the field of BIM for FM, the Habitat-centric approach is used to develop a domain-specific information model that specifies the nine habitat aspects linking to four types of FM service-related information. These are user dimension, physical dimension, technical dimension and service dimension, to satisfy information requirements for facility service management.

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Theoretically, this novel approach, inspired by Organisational Semiotics, systematically associates physical aspects with the pragmatic and social habitats considering user activities in a built space. Practically, it enables BIM as an integrated data model to support various facility services and system integration and collaboration between them in daily FM operations. Specifically, the BIM-based facility service model with integrated information can be used to demonstrate service classes with their attributes and relationships, as well as service process with norms. The model contains required information to configure separate service systems or serve as an integrated data model linking with real data model from different sensors to assist decision making to prioritise building performance with a consideration of user activities. Through the modelling development, the facility service model provides a service-oriented approach to connect and identify necessary building elements based on facility service deliveries. Specific elements or different habitat factors can be identified in relationships within a facility service delivery process, for example, occupiers, devices, space, process and norms.

Each building element linking with facility systems can check the relevant habitat information to the service process. For example, for a teaching space such as a seminar room, not only the spatial scale and use rules can be checked to assist booking system (user number constraint or catering constraint), but also the available teaching equipment in a space can be listed, if specific equipment needs IT (system) support for configuration before the teaching session. BMS systems cannot only check room-booking timetable data linked the space in the service model for any scheduled information for energy conservation, but also can request norms from the service model as instructions to deliver HVAC, lighting or other services to satisfy specific users' requirements. Repair and maintenance service can check maintenance information on the devices to make sure the device is operational when it is in use. The users' profile can be checked if they have required knowledge or certificate to operate facilities in some situations, e.g. invigilation requires trained invigilators. The use cases can be defined and extended according to specific building projects and FM systems requirements.

The facility service model though is intended to address pragmatic and social habitat to demonstrate facility services, compared with as-built model, physical aspect of a habitat is also included. The habitat factors are interrelated and a relationship between building fabrics and human factors is essential to enrich and describe facility service from an engineering and practical perspective. Furthermore, the Habitat-centric approach can also be applied in an iterative BIM development process of integrating service-related information including building fabrics and human factors. The BIM-based facility service model will keep developed until required information is complete to fit FM system during a whole lifecycle of a construction project.

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Grounding Functional Requirements Classification in Organizational Semiotics

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Additional information is available at the end of the chapter

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Abstract

An information system has its requirements rooted in organizational policies and behaviour, the complexity of which is governed by the hierarchy and the dependencies of the activities within the organization. This complexity makes requirements analysis for an envisioned information system an intricately challenging task. The absence of well-defined body of knowledge clearly specifying which requirements must be looked for further deepens the challenge of requirements analysis. Though requirements are broadly classified as functional and non-functional, a special concern is required for functional requirements as the information system is expected to meet the behaviour of the organization. We explore the role of organizational semiotics in extracting and analysing functional requirements for an envisioned information system. We also report the results of supervised learning to automatically extract the functional requirements from the existing available documentation.

Keywords: organizational semiotics, requirements engineering, functional requirements, business rules

1. Introduction

Software Engineering has come a long way after its inception in 1960 with the famous NATO conferences [1, 2]. The discussions in these conferences are credited with bringing discipline to the activity of software development and laying down the foundations of this field by relating it to mathematics. There have been further developments and innovations in an attempt to realize the goals of systematic, disciplined and quantifiable approach to software development. The earliest proposed waterfall process model for software development evolved towards iterative process models and is now being replaced by the latest agile methodologies. In addition to process models, programming paradigms have evolved from procedural approach of structured programming [3] to object-oriented programming [4]. However, the goal of a systematic, disciplined and quantifiable approach is still far away. A key role in realizing this goal is played by the requirements, that is the main input to the (engineering) process of software development. Realizing the crucial role of requirements to the design and development of the software, requirements discovery and analysis activities came to be recognized as 'Requirements Engineering (RE)' with the publication of selected papers on RE in Ref. [5] and establishment of regular conferences on RE by IEEE Society. This helped in organizing and bringing discipline to various process models for RE activities and frameworks for analysing requirements. However, the proposed as well as practiced methodologies to ensure consistent, correct, complete and unambiguous requirements have not exhibited the three defining parameters of an engineering approach, namely repeatability, quantifiability and systematic thought process. An attempt to associate these parameters with RE activities calls for a fundamental question–Is the input to RE activities, that is requirements clearly and precisely defined? This is a difficult question, and the challenges are multi-fold in answering this question. Answering this question requires deliberating following points first:

1. What does clear and precise definition of inputs to RE activities signify?

2. What type of software system are we concerned with?

3. Is the solution or answer to one type of system applicable to another one?

4. What is the validity of the proposed solution or answer to the question on inputs to RE activities, that is the requirements?

The answer to the first point above lies in exploring the definition as well as the taxonomy of requirements. We shall present a brief overview of these points in Section 2. The second and third points are overlapping and very much depend on the requirements taxonomy considered. It has been argued in earlier studies that the solution approach to one type of system may not be applicable to another one whether the concern is related to requirements representation [6] or analysis [7, 8] as the systems may range from mission-critical, safety critical applications to enterprise applications and Web-based systems to mobile applications. The last point presents an opportunity to validate one of the proposed requirements taxonomies by either strongly correlating the taxonomy under study to an established framework or by conducting an empirical study at a wide scale.

In this chapter, we shall focus on the last point of validating the functional requirements taxonomy by considering one of the functional requirements classification proposed earlier [9–14]. Though requirements are broadly classified as functional and non-functional, the vital role played by requirements in the development of information systems motivated us to do an in-depth study of functional requirements. Moreover, an empirical study by Kamata et al. [15] on current RE supports our observation that functional requirements need an in-depth and extensive exploration to refine RE processes and methodologies. We shall follow the validation proposition of establishing correlation between an established framework and the functional requirements classification under study.

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As points 2 and 3 above suggest, considering a wide spectrum of software systems is not feasible. We shall, therefore, take into account functional requirements in the context of information systems that are database-driven enterprise wide applications such as retail applications, financial applications and ERP systems. Such information systems need to embed organization structure, hierarchy, policies, processes and behaviour in the form of software requirements. Organizational semiotics present a feasible solution towards understanding requirements of an information system. We shall explore the role of organizational semiotics in extracting and analysing functional requirements for an information system considering requirements taxonomy proposed in Ref. [14]. The reason for selecting this classification scheme, in particular, is that the authors in their work [14] have presented classification of functional requirements with regard to information system only. Since this chapter focuses on the role of organizational semiotics towards better understanding (extracting and analysing) requirements of an information system, therefore, the work presented in Ref. [14] is the best suited choice. We shall explore the following research questions in this chapter:

RQ1. Do organizational semiotics provide heuristics to identify various functional requirements types?

RQ2. Do organizational semiotic analysis frameworks or methods to analyse an information system bear any direct/indirect relationship with analysing various functional requirements types?

RQ3. Is it possible to automate the process of identifying functional requirements from existing documentation using organizational semiotics?

These research questions will provide an opportunity to correlate the functional requirements classification scheme presented in Ref. [14] with the established organizational semiotics framework, thereby validating this categorization approach of functional requirements. The rest of the chapter is organized as: Section 2 presents a brief overview of requirements definition and taxonomy. Section 3 presents a brief summary of organizational semiotics followed by details for RQ1 and RQ2. Section 4 presents our study on the possibility of automating the process of extracting functional requirements from existing documentation, thereby addressing RQ3. Section 5 finally summarizes the chapter in the form of discussion and conclusion.

2. Requirements taxonomy

As introduced in Section 1 above, the Requirements Engineering (RE) practices in Information Technology (IT) industry are still far from engineering-oriented approach. RE practices need to adopt a more systematic, repeatable and quantifiable approach. In order to support this approach, we need to start with the basic questions—*'what is meant by requirements?' and 'what types of requirements need to be considered for information systems?'*. We are of the view that a fair understanding of the requirements (inputs to RE activities) will prove beneficial in devising RE methodologies with an 'engineering' perspective. 'Requirements' have been described differently by different authors. According to IEEE standard [16], 'requirement' is defined as: 'a condition or capability needed by user to solve a problem or achieve an objective; and, a condition or capability that must be met by a system or system component to satisfy a contract, standard, specification, or formally imposed document'. Sommerville [11] defines requirements as a specification of expected system behaviour, or a specific constraint on the system or a user-level description. Despite varying versions, requirements describe the desired behaviour of the developed system and therefore in order to better understand the requirements of an information system, these have been broadly classified in terms of the expected behaviour.

Requirements are usually classified into two broad categories, namely—*Functional requirements* which specify the properties and the behaviour of the information system that must be developed, and the *Non-functional requirements* (NFRs) which describe the constraints on the system as well as the quality aspects of the system. However, requirements have been categorized at a further granular level too allowing elicitation and analysis of requirements to be carried out efficiently. Earlier, White and Edwards [9] proposed following hierarchical levels from requirements capturing point of view:

1. Operational environment—These requirements include external systems and operating needs.
2. System capabilities—These represent functions, behaviour and non-functional requirements.
3. System constraints—These include system architecture and the regulatory policies.
4. Development requirements.
5. Verification and validation requirements.
6. Specification of system growth and change including expected system changes and possible environmental changes.

The viewpoint put forward by White and Edwards has overlaps in system capabilities and system constraints in terms of non-functional requirements. Sommerville, however, has segregated functional and non-functional aspects of requirements. He suggests the following requirements categories [11]:

1. Functional requirements—These represent statements of service that the system should provide, how the system should react to inputs and also in particular situations. These requirements further represent user-level goals and the system goals.
2. Non-functional requirements—These represent constraints on services or functions offered by the system such as timing constraints and standards. NFRs further represent product level, organizational level and external interface constraints.
3. Domain requirements—These represent the features that reflect the domain and can be functional or non-functional.

Recently, Chung and Leite [10] and Slankas and Williams [13] have explored further granular levels of NFRs, and their extraction—both manual and automatic. Similar such

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studies in the context of functional requirements have been carried out by Ghazarian [12], and Sharma and Biswas [14]. Ghazarian has studied nearly 15 Web-based enterprise system projects from the point of view of identifying atomic functional requirements. His study reveals 12 classes of functional requirements, namely: (1) data input, (2) data output, (3) data validation, (4) business logic, (5) data persistence, (6) communication, (7) event trigger, (8) user interface navigation, (9) user interface, (10) external call, (11) user interface logic and (12) external behaviour. Sharma and Biswas [14] have applied Glaserian Grounded Theory approach [17] on requirements specification documents from five information systems to identify seven categories of functional requirements, namely: (1) entity modelling requirements, (2) user interface requirements, (3) user privileges requirements, (4) user interaction requirements, (5) business workflow requirements, (6) business constraints requirements and (7) external communication requirements. Of these two available classification schemes—by Ghazarian [12], and Sharma and Biswas [14]—we have selected the latter one for our work because while studying these two schemes, we observed that the taxonomy of functional requirements as proposed by Ghazarian [12] is close to the solution domain (developed code) and not the problem domain (requirements specification) of information systems. RE is the only phase of software development that deals with both the problem space and the solution space of the envisioned software system [18] as this phase only bridges the gap between 'as-is' system and the 'to-be' system. Nevertheless, the starting point of any software project is the problem space, from where the requirements of an information system are drafted. Therefore, we selected the functional requirements taxonomy proposed by Sharma and Biswas [14] for our study.

We are interested in validating whether the functional requirements categories proposed by Sharma and Biswas [14] are meaningful and useful by grounding them in organizational semiotics framework. We shall do so by exploring first two points from our research questions—(1) RQ1: Do organizational semiotic suggest heuristics that can help in identifying the proposed functional requirements types? and (2) RQ2: Do organizational semiotic analysis methods to analyse an information system bear any direct or indirect relationship with analysing various functional requirements types? We shall explore these points in the following section. Before discussing these points, the following section presents a brief introduction to organizational semiotics.

3. Organizational semiotics

The crucial role played by requirements in the development of information systems has resulted in proposing various approaches to correctly identify and analyse the requirements for the information system. Granular classification of functional requirements is one such possible solution. We have presented this solution approach in detail in Section 2 above. Semiotic analysis framework is another possible solution that has been applied to understanding and analysing requirements of an information system by several authors like [8, 19–24]. In this section, we shall study the relationship between these two approaches, and how one of the former approaches (classification of functional requirements) is rooted in the latter approach.

Organizational semiotics deal with the study of organizations using the concepts and methods of semiotics, where semiotics are the study of signs dealing with generation, transformation and communication of signs that people use for various purposes [25]. Organizational semiotics study is based on the fundamental observation that all organized behaviour is affected through communication and interpretation of signs by people, individually and in groups. Organizational semiotics analysis method, referred to as Methods for Eliciting, Analysing and Specifying Users' Requirements (MEASUR), proposed by Stamper [26] and further enriched by Liu [24, 27] has evolved into semiotic methods or framework for information systems. A radical, subjectivist stance has been accepted as the basic philosophy for developing this set of methods and tools for information systems development. The introduction of subjectivity is required when the context is of information system development as there are multiple stakeholders of an information system, each having varyingly different viewpoints on requirements of that information system. A brief overview of these methods for analysing information systems is presented in Section 3.1, followed by the discussions on first two RQs in further subsections.

3.1. Organizational semiotics for information systems

Organizational semiotics consider an organization as an information system in which information is created, processed and used. It tries to understand organizations in terms of its semiotics—signs, texts, documents, sign-based artefacts (contracts) and communication between stakeholders [28]. The goal of organizational semiotic study is to find new and insightful ways of analysing, describing and explaining organizations. Semiotic method for information systems, MEASUR provides a framework for planning, developing and maintaining information systems. It comprises of three key methods for analysing information system to be developed for an organization. These three key methods [24] include as follows: problem articulation method (PAM), semantic analysis method (SAM), and norm analysis method (NAM).

PAM can be applied at the initial stage of an information system development when the requirements, gathered for the system to be developed, are at a very abstract or high level with a lot of vagueness and ambiguity in the organizational context. PAM can help in better understanding the organizational structure and the scope of system to be developed. The techniques employed by PAM include as follows: (1) *unit system identification* to illustrate a particular course of action and agents involved in that action, (2) *stakeholder identification* to identify relevant groups or parties and their interest in an organization's products and services, (3) *collateral analysis* to structure problem situation into a central course of action and surrounding or collateral activities, (4) *system morphology* to clarify three basic functional areas (i.e. substantive, communication and control) of a socio-technical or a business information system; each of these components can, in turn, be treated as a unit for continued analysis, and (5) *valuation framing* to reveal the cultural behaviour of the stakeholders involved in the information system.

SAM emphasizes focusing on one articulated unit system or focal problem and suggests that analysts should encourage stakeholders or business users to describe their requirements within the scope of that focal problem. The required functions of the system are specified in

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the form of an ontology model. This method is directed towards a focal action, and the agent responsible for carrying out that action. The relationship between these two is captured in the form of simple and well-formed formula (wffs) as:

- <agent-term> <action-term>

These wffs are then presented in the form of ontology models for visual representation that assists in visualizing the relationships between various agents and their actions in an information system.

SAM is followed by NAM which provides a way to specify the agents' patterns of behaviour in the business system. A norm specifies conditions in which an action may (or should/must or must not, etc.) be performed by some agent. These norms act as conditions and constraints; they govern agents' behaviour, normally in a prescriptive manner to decide when certain actions will be performed. Norms, in conjunction with the semantic model, clearly define the roles, functions, responsibilities and authorities of agents.

The organizational semiotic analysis methods, as discussed above, do offer heuristics in terms of lexical patterns for extracting requirements automatically from the available documentation instead of manually going through the existing available documentation and then finding the requirements. Manual intervention cannot be completely ruled out at the time of requirements gathering from documents or eliciting from clients. Nevertheless, some form of automated assistance would be of help to analysts or requirements engineers. We present such lexical heuristics from organizational semiotic approach in the following subsection.

3.2. Heuristics from organizational semiotics for identifying functional requirements

Organizational semiotic analysis approach applies to the complete process of information system development [24] including the requirements understanding and analysis as well. Liu has established the point that Requirements Engineering (RE) is a process of semiosis by identifying the concepts required for sense making of requirements specifications. Liu indicates that requirements specifications are the 'signs' corresponding to the actual requirements having origin in the business domain under study. These actual requirements formulate the 'objects' in semiosis process. The 'interpretant' is the agreed understanding of the sign, that is the requirements specification between analysts or requirements engineers and business users as other stakeholders. MEASUR methods consider organizations themselves as information systems and social norms as unit of specification. These methods are manually applied to an information system under study. We extend this idea and propose heuristics based on MEASUR methods to identify functional requirements from existing documentation. The existing documentation could be in the form of Request for Proposal (RFP) document or organizational structure and policies document, or may be some regulatory document. RFP is usually identified as the first reference document for software requirements, providing an insight into business rules and organizational activities. Referring to any of these documents, we can identify functional requirements by using the heuristics based on MEASUR methods, as described below:

1. Possible candidates for unit systems and focal problems/actions include verb phrases present in the form of participle, and the verb in base form ending in 'tion', 'scion' or 'cion', 'al'. Though not all such verb phrases would be unit systems actually, nevertheless, these serve as heuristic to automatically extract possible unit systems from the existing documentation. These candidates correspond to 'use-cases' in RE terminology.

2. Nouns or noun phrases are possible candidates of stakeholders, agents in the information system. These correspond to entities (classes in object-oriented paradigm) in RE terminology.

3. Statements having these keywords—'communication', 'message', 'queuing message', 'send message' qualify for external or user interface communication requirements.

4. Verbs and verb phrases qualify for actions performed by actors or agents. These phrases serve as heuristic to find user privilege requirements, business workflow requirements, and business constraints requirements.

5. Norm analysis patterns serve as the heuristic to identify business workflow requirements. These patterns are generally represented as [29]:

- If <condition> then <consequence>

Behavioural norms may have more specific form depending on the complexity of behaviour as:

- Whenever <condition> if <statement> then <agent> is <deontic operator> to do <action>

Though Liu and Dix [29] have proposed above-mentioned two norm patterns, but the expression for norms can take several other forms. We have observed following patterns describing norms in an organization through manual study of requirements documents:

- In case <condition> then <consequence>
- <Consequence> provided <condition>
- When <condition> then <consequence>
- Once <condition> then <consequence>
- Only <condition> <consequence>
- In order to <consequence to hold> then <condition>
- <Condition> in order to <consequence to hold>
- <Condition> must (hold) <consequence with infinitive clause>

The organizational semiotic approach does not offer any heuristic to identify graphical user interface (GUI)-related requirements. We have used the above-mentioned heuristics to identify five categories of functional requirements (excluding GUI-related requirements) as proposed by authors in Ref. [14] for employee self-service (ESS) module of HR management project developed at our industry partner's end. Since the project had started following agile approach, therefore the development team could not collaborate for the entire

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project with us, and therefore, we confined our experimental study to this one module only. Following the heuristics described in the points above, we carried out lexical search and started tagging the user management module's proposal document for the presence of verb and noun phrases. The proposal document for this module was a small document running into pages only. We found 14 unit systems following first heuristic and presented these to the development team for validation. They observed that we found four false unit systems and that we could not identify three unit systems. These three unit systems did not follow the lexical pattern of first heuristic. Of the four falsely reported unit systems, two were actually attributes of an information content, and one was related to the style of writing the document. The author of that document had a peculiar style of writing every use-case by mentioning—'Provision to …', and the presence of word 'provision' led to ignoring other unit cases. Following second heuristic, we found 31 candidates for agents—of these, only three candidates are in the role of 'actors' (entity modelling requirements)—this observation was in agreement with the development team working on ESS module. However, the team pointed out that the heuristic is not sufficient to detect abstract concepts.

Such challenges are always there with lexical heuristic approaches, but we believe that more and more experimentation will enable us in refining the heuristics and the solution approach to automate the process of extracting functional requirements from the existing documents like proposal document in our case. For the sake of clarity and brevity, we are not presenting the observations for other heuristics. To summarize, our overall observations using the above-mentioned heuristics were approximately 60% close to the requirements identified by the development team. This percentage is sufficient to infer that heuristics can serve as guiding tool for functional requirements extraction and that functional requirements classes and organizational semiotic heuristics are closely related.

3.3. Organizational semiotics analysis framework v/s functional requirements

An in-depth study of organizational semiotic analysis framework, MEASUR indicates a strong and direct correlation between the framework's analysis methodologies and, the types of functional requirements [14] (except for GUI-related requirements) considered in this chapter. We summarize the relationship for each functional requirement as below:

1. Entity modelling requirements—These requirements represent the domain model of the organization. The domain-relevant concepts are modelled as entities while implementing the information system for an organization. PAM of stakeholder identification helps in identifying agents and stakeholders of the system. These, in turn, correspond to entity modelling statements from the reference documents for an information system. This method defines roles in six different categories, thereby making it easier to identify the stakeholders. These six categories are as follows: actor, client, provider, facilitator, governing body, and bystander. For example, consider the following requirements statement:

   RS1: The system shall only allow a user with an authorized official (AO) role to create a new submission.

The stakeholder identification method in PAM analysis helps in identifying *user* as agent, and *Authorized Official (AO)* as role name. Following entity modelling requirements premises, RS1 has four possible concepts—system, user, authorized official (AO), and submission. Analysing RS1 manually indicates that though there are four concepts but modelled entity is 'user', whose role is that of 'Authorized Official (AO)' and 'submission' is an affordance for 'user'. We observe stakeholder identification results in an enriched information while entity modelling requirements yield in a superset of information from stakeholder identification. It can be observed that there is no conflict between the resulting entities/concepts from two methods; one has enriched details while other has more number of concepts. Thus, it verifies that there exists direct relationship between stakeholder identification of PAM and the entity modelling requirements.

2. User interface requirements—These requirements represent the presentation layer of the information system, that is the graphical user interface used by the agents to interact with the information system. All those statements that describe the layout of information on interface or flow of information from one level to another interface level belong to the category of user interface requirements. These requirements remain undiscovered by MEASUR methods, and therefore, these requirements do not bear any relationship to organizational semiotic analysis approach. Nevertheless, it can be observed that this approach can gain from granular classification of functional requirements to enrich its identified set of requirements. A sample of user interface requirements is illustrated below:

RS2: Any entity/text on the user interface that is a link should be in blue font and underlined.

There is no direct analysis method in organizational semiotics framework, MEASUR, to identify user interface requirements like RS2. But, the requirements identified using this framework can be further enhanced by adding GUI-related requirements for which this category of functional requirements define identification criterion.

3. User privileges requirements—These requirements describe various roles played by the business users in an organization and the privileges associated with those roles. PAMs of stakeholder identification and SAM analysis method together correlate in terms of identifying privileges associated with different roles in an organization.

Considering RS1 again, for example,—this statement on one hand contains entity modelling requirements, and at the same time, it describes role of 'Authorized Official (AO)' who has the privilege to create a new submission. SAM analysis (considering the focal problem of submission) adds value to the information obtained using stakeholder analysis technique of PAM—it associates affordance 'submission' to the role of 'Authorized Official (AO)' possessed by agent and 'user'. Thus, we observe a strong correspondence between the outputs of organizational semiotics framework, MEASUR for identifying user roles and functions with the user privileges requirements.

4. User interaction requirements—These requirements describe how an end-user of an information system will interact with the system through user interface. Though MEASUR methods do not mention much about human-computer interaction but system morphology PAMs could possibly relate to user interaction requirements. This method requires exploring the system with the goals of identifying—substantive behaviour of the agents, message passing from one person to another inside and outside the organization, controls

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flow to ensure smooth communication and substantive actions. System morphology (communication and control) method can help in identifying these requirements as in the 'to-be' system, nature of interaction and communication between people in an organization might get replaced in the form of interaction/communication with the system (valuation framing). An example of user interaction requirements statement:

RS3: The system shall allow the user to edit a submission by clicking on the Facility column. The system shall allow the Facility column to be clicked only when the submission is still underway.

The above statement, RS3 describes how a user interacts with the system to edit an affordance, *submission*. System morphology technique of PAM, thus, can help in extracting user interaction requirement. RS3 is designated as an example of this type of requirement as it describes 'how-to-use' part of user interface. That's how system morphology method and user interaction requirements bear a correspondence with each other.

5. Business workflow requirements—These requirements describe business rules, policies and procedures. In turn, these business rules and policies provide justification to the agents' behaviour within the information system. SAM and NAM of semiotics yield in identifying the actions, the agents responsible for those actions, the conditions under which the action would be carried out, and the actions in consequence, thereby giving a complete view of a business workflow requirement. Control technique of social morphology PAM also results in identifying what can be referred to as business workflow requirements. Considering a requirements statement from the famous London Ambulance Service case study [30, 31]:

   RS4: When an operator receives a phone call concerning a medical emergency, he should dispatch a nearby available ambulance.

   RS4 follows one of the norm analysis patterns presented above, so following NAMs, this statement can be marked as business workflow requirements. In this statement, the agent—'operator' is in the role of actor and is responsible for the action of dispatching an available ambulance. Thus, we can infer the observations from SAM and NAM methodologies for analysing information systems agree with the identification of business workflow requirements.

6. Business constraints requirements—These requirements correspond to the constraints on the information system apart from business workflow logic. Such additional constraints may arise because of organizational policy, external regulatory bodies or market regulations in which the organization is operating or possibly, technical constraints. SAM and NAM help in finding business workflow as well as constraint requirements. Business constraints requirements can be distinguished from business workflow requirements by checking the agent of action under consideration. If the agent is in the role of governing body or facilitator, then the corresponding requirement is an instance of business constraints requirement.

   RS5: The user must have Javascript enabled for the message prompts to occur.

   In RS5, the agent—'user'—is in the role of facilitator for enabling Javascript. In this manner, checking the role of agent can help in designating business constraints requirements, thereby indicating correspondence between organizational semiotic analysis methods and business constraint requirements.

7. External communication requirements—These requirements describe interaction of the information system with other systems or agents outside its scope. PAM of system morphology with a focus on communication with external agents (i.e. agents who are related to the system under study but are actually out of its scope) can help in extracting external communication requirements. Following statement is an example of external communication requirement where the database of the system is modified by an external trigger:

   RS6: Updates to the ALMIS database in the system are commonly performed via remote data transfer. Remote data transfer is commonly accomplished using FTP over the Internet.

   Communication and control techniques of system morphology method of PAM indicate the presence of communication with an external agent or bystander, 'remote data transfer'. RS6 presents an example where observations from PAM methodology and external communication requirements are in agreement with each other, indicating a direct relationship between the two.

In this section, we have addressed our first two research questions—RQ1 and RQ2. We have found that organizational semiotics do offer heuristics to identify different types of functional requirements except for user interface-related requirements. This exceptional case can be attributed to the very formalism of organizational semiotics that has its roots in organization's structure and behaviour of its people, that is the scope of organizational semiotics is confined to the problem domain of information systems and not to the solution domain (the layout of the system to be developed). Addressing RQ2, we have similar observation that there exists direct correlation between organizational semiotic analysis frameworks to analyse an information system and the functional requirements types of an information system with an exception for user interface-related requirements. This leads to infer that the functional requirements types (except for user interface-related requirements) as proposed in [14] are grounded in organizational semiotics bearing a strong correspondence with their analysis methodologies—PAM, SAM and NAM. Secondly, the heuristics from organizational semiotics are helpful in automatically extracting various functional requirement types from available documentation, but it has to be followed by manual intervention. The next section considers the possibility of automated extraction of functional requirements from existing documentation (requirements corpus).

4. Automated extraction

In this section, we explore our third research question, RQ3—Is it possible to automatically identify the different categories of functional requirements in the available requirements documents. A major challenge in addressing this point is that of atomicity of a requirements statement. One single statement can have instances of different types of functional requirements. For example: RS1 is an instance of both entity modelling requirements and the user privilege requirements. The fact that the requirements statement can have multiple forms of expressions in natural language worsens the challenge. We have observed in Section 3.2 that lexical heuristics, though provide a solution to extracting functional requirements, are not well-accepted by practitioners as they feel the approach is as good as manual analysis techniques. If the approach can be automated or semi-automated, then the solution would have higher chances of acceptance by practitioners. Machine learning classification algorithms offer a seemingly feasible solution, and we explore the viability of this solution in this section.

Machine learning (ML) is about the construction and study of systems that can learn from the data. A broad classification of machine learning algorithms identifies two types of learning: supervised and unsupervised. Supervised learning makes use of the guiding function to map inputs to desired outputs (also referred to as labels, because these are often provided by human experts labelling the training set). Unsupervised learning, on the other hand, models a set of inputs by grouping or clustering common instances/patterns.

In this study, we have used supervised ML technique considering labelled or annotated documents as input to our study. We have explored Naïve Bayes, Bayes net, K-Nearest Neighbourhood and Random Forest algorithms to identify statements signifying different functional requirement types. Naïve Bayes is a probabilistic classifier that applies Bayes' theorem with strong (naive) independence assumptions. The underlying assumption in Naïve Bayes algorithm is that the presence or absence of a particular feature bears no relationship to the presence or absence of any other feature, given the class variable. Despite this assumption, Naive Bayes classifier proves to be quite effective in a supervised learning setting. Bayesian network, in contrast, makes use of conditional dependencies. KNN classifier classifies objects by a majority vote of its neighbours. Random forests are an ensemble learning method for classification (and regression). A multitude of decision trees is constructed at training time in this algorithm, and the final output class that is the mode of the classes given as output by individual trees.

The common metrics used to check the result of ML algorithms are as follows: precision, recall, accuracy and F-measure. Of these, we have used precision, recall and F1-measure to compare the results of these learning algorithms to find which algorithm suits better for automated extraction of requirements. Precision defines in terms of the fraction of retrieved instances that are correct, whereas recall refers to the fraction of correct instances that are retrieved. Abbreviating requirements statements as 'RS', we define precision and recall for our study as:

Precision = True Positive RS Type/(True Positive RS Type + False Positive RS Type)

Recall = True Positive RS Type/(True Positive RS Type + False Negative RS Type)

Here, 'True Positive RS Type' indicates correct predictions for the category of functional requirements statement. 'False Positive RS Type' statements are incorrectly labelled as belonging to that class of functional requirements. 'False Negative RS Type' statements are the predictions which were not labelled as belonging to an appropriate functional requirements type but should have been.

F-measure considers both the precision and the recall of the test, representing weighted average of these two metrics (precision and recall). F-measure reaches its best value at 1, and the worst score is 0. It is defined as:

F-measure = 2x (Precision × Recall)/(Precision + Recall)

4.1. Requirements corpus

We prepared our data set (requirements corpus) using text version of the requirements documents by copying the documents to text file. We had access to nearly eight requirements documents of varying sizes in terms of counts of statements. We dropped the non-functional requirements section while preparing data set as our evaluation study is focused towards functional requirements. Though atomicity of functional requirements is desirable, but it is not always possible to discretely express one type of functional requirements with natural language expressions. Therefore, we allowed one statement to belong to more than one category of the functional requirements. The lexical heuristics are present in the requirements statement, therefore, in our case, we have composed the feature vector to be presented as input to ML algorithms as requirements statement followed by 'yes' and 'no' indicators for the presence and absence, respectively, of a type of functional requirement. Two sample statements from feature vector are illustrated below for making the point clearer:

- 'The document contains following sections', no, no, no, no, no, no, no
- 'An administrator should be able to perform all the search queries as a normal user.', yes, no, yes, yes, no, no, no

Here, the first sample statement does not correspond to any type of functional requirement. Consequently, it has all 'no' labels. The second statement indicates the presence of entity-modelling requirement, user privilege requirement, and the user interaction requirement. Therefore, this statement has corresponding 'yes' labels to it, and to signify the absence of rest of the functional requirement types, there are 'no' labels corresponding to them.

The task of annotating the requirements statements with 'yes' and 'no' labels corresponding to presence/absence of different types of functional requirements in the statement under study was performed by five human subjects to ensure fairness and unbiasedness of our study. The subjects chosen for the study are research scholars and master students, who have done courses on Software Engineering and Business Modelling. Two of the selected subjects had industry experience too. After dropping the non-functional requirements, the details on the size of the documents studied are presented in **Table 1**.

Manual annotation by different subjects can possibly have lot of variations depending on an individual's thought process. Therefore, manual annotation could be a potential threat to the validity of our results. In order to mitigate this threat, the author of this chapter organized meetings with the subjects and shared the background of the annotation task to be done. The details of the proposed classification were discussed thoroughly as subjects might get confused in closely related categories such as user interface requirements and user interaction requirements. We also performed validity check for annotation by selecting a random sample of 100 statements in one of the initial meetings and labelling this set. We, then, performed peer review of those annotations. The result of peer review revealed that there are not drastically differing views of the rule labelling. Once satisfied with the observations from peer review, we proceeded with our experiments on the annotated requirements corpus.

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Document	Size (number of statements)
Doc 1	208
Doc 2	798
Doc 3	1135
Doc 4	1251
Doc 5	351
Doc 6	1305
Doc 7	900
Doc 8	230
Total	6187

Table 1. Requirements corpus details.

4.2. Evaluation study and observations

We performed our experiments by applying Naïve Byes, Bayes Net, K-Nearest Neighbourhood and Random Forest algorithms to our annotated corpus. Our classification results are based on n-fold cross-validation study as recommended by Han et al. [32]. We have computed precision, recall and F-measure for each of the classifier. In n-fold cross-validation, data are distributed randomly into n-folds where each fold is approximately of equal size and equal response classification. We have used Wekahttp://www.cs.waikato.ac.nz/ml/weka/ tool for carrying out our experimental study. We loaded the files in Weka and converted the annotated statements to word vectors using Weka filter. In the first phase of our study, we used the documents in their original form, that is without any changes to the word form, or applying any filter. The results of the first step of our study are presented in **Table 2**.

The next phase of our evaluation study included filters—we dropped stop-words at the time of data set preparation. Stop-words refer to a list of words that should be filtered out during classification due to either commonality of words or domain-specific generality of words. We have considered determiners only (a, an, the) as stop-words in this work, and we have not observed much of an improvement after applying stop-words as filters. Instead, KNN and Bayes net performance dropped as reported in **Table 3**.

The experimental study that we carried out for automated extraction of functional requirements is just a starting first step towards effectively utilizing ML classification algorithms for classifying functional requirements, and needs to be further worked up further refinements. These results are not very good because high recall has resulted in lower precision and a high precision yielded in lower recall. Bayes net algorithm only has yielded in both good results and good recall. Nevertheless, the results are encouraging in the sense that heuristics also allowed us to be 60% closer to actual requirements (that too with a small document), and ML approach too has nearly 60–70% of correctness in terms of precision and recall.

Classifier	Precision	Recall	F-measure
Naïve Bayes	0.396	**0.717**	0.483
Bayes net	**0.607**	**0.646**	**0.608**
Random forest	**0.747**	0.401	0.481
KNN	0.608	0.585	0.584

Table 2. Functional requirements extraction—10-folds cross-validation study.

Classifier	Precision	Recall	F-measure
Naïve Bayes	0.396	**0.717**	0.483
Bayes net	0.476	0.54	0.483
KNN	0.586	0.492	0.512

Table 3. Functional requirements extraction with determiners as stop-words.

5. Discussion and conclusion

In this chapter, we have presented the role of organizational semiotics in identifying functional requirements for an information system. We hypothesized that organizational semiotics do provide heuristics to identify various functional requirements categories, and there exists a direct relationship between semiotic analysis framework and analysis based on identifying functional requirements classes. Our study reveals that semiotic analysis framework and functional requirements categorization approach (to better understand the requirements) bear strong correspondence with each other and, at times complement each other provided the categorization of functional requirements is meant for information systems. The software systems have a wide spectrum as we have elaborated in the chapter, and one solution or one classification scheme for a type of system may not be applicable to another type. Secondly, our study reinforces functional requirements categorization, based on grounded theory, in context of information system [14] by grounding the classification scheme in an established theory of organizational semiotics.

We believe that our study around organizational semiotics and functional requirements will prove useful in bringing an organized and systematic approach to requirements engineering for information systems. Organizational semiotic analysis approach has slowly paved the way to information systems engineering though with certain gaps in context of information systems, where these gaps can be bridged by deliberating carefully as to what requirements we want to consider while developing an information system. Additionally, requirements analysis methods considering functional requirements categories first may gain from the knowledge of heuristics rooted in organizational semiotics.

With increasing complexity of software systems being developed, it would be worthwhile to develop an automated approach to assist practitioners. We have explored two separate

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approaches towards the purpose—one semi-automated using lexical heuristics and word-tagging, and the second of ML classification. The observations from both the approaches are almost similar (approximately 60%). It is difficult to judge which one is a better solution as this would require more extensive study and experimentation. We intend to carry out this study as part of our future work. Additionally, we intend to improve upon the heuristics from organizational semiotics analysis framework.

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Section 5

Semiotics and Science Education

An Operational Approach to Conceptual Understanding Using Semiotic Theory

Daniel L. McGee

Additional information is available at the end of the chapter

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Abstract

Duval suggests that understanding of a mathematical concept is accessed through the commonality in its associated registers of representation. In this chapter, we present two studies where students in treatment (with a broader experience using registers of representations and comparison (with more limited experience using registers of representation) populations were interviewed to assess their ability to perform both familiar and unfamiliar treatments and conversions. As most mathematical concepts include a range of associated registers of representations, we assess the importance of using a broader range of treatments and conversions among these registers and suggest an operational approach to using these treatments and conversions to gain insight into the understanding of the concept.

Keywords: semiotics, registers of representation, treatments, conversions, conceptual understanding, multivariable calculus

1. Introduction

In mathematics, representations are commonly used from the algebraic, geometric, numerical and verbal registers when concepts are presented and discussed. Movement between and within these registers of representation is well recognized as an important part of understanding these concepts [4]. Duval [1] takes this a step further by defining a mathematical object (i.e., concept) as the commonality of all its associated registers of representation. He goes on to indicate that, as seeing this commonality requires various registers of representation, "a two-register synergy, and sometimes a three-register synergy" (p. 126), is required to understand mathematical objects (concepts). "Synergy" of registers can be considered "simultaneous awareness" of the registers of representations.

Based on Duval's assertion that the understanding of mathematical concepts can only be achieved through simultaneous awareness of associated representations, McGee and colleagues [2, 3] implied, without an explicit presentation, that an operational framework might become accessible by associating the comprehension of a mathematical object with the ability to fluidly move between its associated registers of representations. It was found [2, 3] that promoting the ability to move fluidly across three registers of representation throughout topics of integration and differentiation significantly improved students' problem-solving abilities. McGee and Moore-Russo [4] also found that a similar multi-representational perspective on conceptual understanding appears to positively impact teaching and learning with preservice teachers as well.

This chapter will present an explicit operational approach to using semiotic theory to assess students' understanding and will summarize data obtained from two studies that provide insight into its implications, applications and methodology.

2. Theoretical framework

The semiotic basis for mathematical understanding lies in movement among and within the semiotic registers associated with a mathematical concept. These transformations (movements involving different registers of representations for the same mathematical object) fall into two categories:

- Conversions describe a movement from a representation within a given register to another representation within a different register where both registers are associated with the exact same mathematical concept. For example, moving from the representation within the verbal register, "we start with 20 and increase by 10 each year" to the formula in the symbolic register $y = 20 + 10x$ would represent a conversion.
- Treatments describe movement from a representation within a given register to another representation within the same register where both registers are associated with the exact same mathematical concept. For example, simplifying the formula within the symbolic register $2y = 20 + 4x$ to the formula $y = 10 + 2x$ within the same symbolic register would represent a treatment.

Duval [1] asserts that a mathematical concept can only be understood by seeing that which is common to all of its representations. For example, the number "3" can only be fully understood if we see the commonality of several registers of representations including groupings containing three items, the number 3 on a number line and numerical operations such as "2 + 1," to name a few.

While Duval [1] emphasizes on the need to harness various registers of representation when understanding mathematical concepts, others [2–6] studied the nature of how registers of representation are used. The initial introduction to a mathematical concept most often begins with an established order of representations associated with the concept known as a semiotic chain [2, 6]. For example, when presenting a line, a presentation might begin with the formula $y = 2x + 3$ (symbolic register), proceed to a table of values associated with the formula (numeric register) and conclude with a graph of a line with slope two and intercept 3 (geometric register). McGee and Martinez-Planell [2] found that as a concept is better understood, students would progress toward simultaneous awareness of the concept's representations which would be associated with the ability to perform treatments and conversions that are not in the initial semiotic chain. An example of this evolution is shown in **Figures 1** and **2**.

Figure 1 presents a semiotic chain containing the geometric, numerical and symbolic registers that might be associated with the initial presentation of a mathematical concept. McGee and Martinez-Planell [2] would consider a more procedural understanding to be associated with limited movement among these registers. For example, if we assume that a student can only replicate the two conversions found in the semiotic chain of **Figure 1**:

- geometric -> numeric register and
- numeric -> symbolic register.

Conceptual understanding, on the other hand, would be associated with the ability to perform up to all six possible conversions associated with the geometric, numerical, and symbolic registers:

- geometric -> numeric register,
- numeric -> symbolic register,
- geometric -> symbolic register,
- numeric -> geometric register,
- symbolic -> numeric register, and
- symbolic -> geometric register.

Figure 1. An example of a semiotic chain.

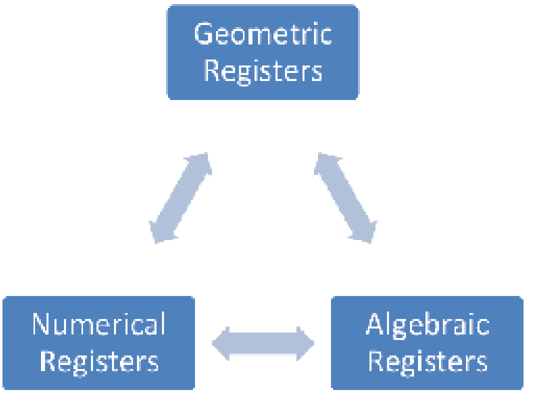

Figure 2. An example of simultaneous awareness of registers of representation.

Figure 2 provides an illustration of what simultaneous awareness of all registers might look like.

The evolution from performing only the two conversions in the semiotic chain shown in **Figure 1** to performing up to six conversions found in **Figure 2** is the basis for the operational approach to conceptual understanding that is outlined in this chapter.

3. Overview of the operational approach and methodology

Our operational approach using semiotics to assess the conceptual understanding of a concept is based on the assumption that a procedural approach to solving a problem without conceptual understanding will likely be restricted to treatments and conversions associated with a semiotic chain (see **Figure 1**). If conceptual understanding is perceived as understanding the commonality of various registers of representation as Duval suggests, then this produces simultaneous awareness of registers that would be consistent with **Figure 2**.

Our operational approach to assessing conceptual understanding can loosely be summarized as follows:

- Identify the semiotic chain or common treatments and conversions that would best be associated with a procedural approach to solving a problem or presenting a concept.
- Create written or verbal assessments that incorporate both familiar and unfamiliar treatments and conversions that involve the same registers of representations observed in step one.

In step two, it should be noted that if there are n representations associated with a concept then there are n–1 treatments and conversions in an associated semiotic chain and $n!$ total possible treatments and conversions that pass among these representations. While certain contexts may make some of these impractical, we would suggest that all $n!$ possibilities should be considered. It should be noted that conversions that present a real-world situation from the verbal register as the target are among our most successful instruments in interviews that are seeking to assess students' understanding. For example, given the representation from the symbolic register $y = 10 \times 2^x$, asking students to find a representation from the verbal register (real-world situation) that could be represented by this formula can provide considerable insight into students' thinking processes.

In this chapter, we present the data from two studies [2, 3] that had previously not observed their data in this context to determine what insight this operational approach might provide into students' understanding. In particular, to what degree is it necessary to be able to move fluidly among familiar and unfamiliar treatments and conversions in order to understand mathematical concepts when conceptual understanding is measured using other standard classroom instruments?

With single, double and triple integrals, the registers of representation can be seen (for single integrals) in **Table 1**. The semiotic chain most commonly used in university classrooms

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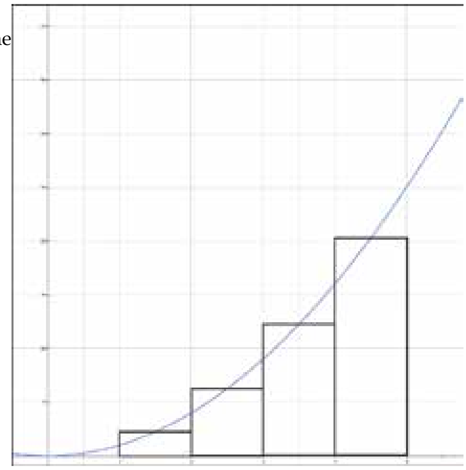
Representation in geometric register for an approximation of the area under $y = x^2$ between $x = 1$ and 5 using four rectangles and the midpoint rule for the height of each rectangle	
Representation in the numerical register for the above approximation of the area	$(1.5)^2 \times 1 + (2.5)^2 \times 1 + (3.5)^2 \times 1 + (4.5)^2 \times 1$
Expanded sum representation in the symbolic register for the above approximation of the area	$x_1^2\,\Delta x + x_2^2\,\Delta x + x_3^2\,\Delta x + x_4^2\,\Delta x$
Sum with sigma representation in the symbolic register for the above approximation of the area	$\sum_{i=1}^{4} x_i^2\,\Delta x$
Sum with sigma representation in the symbolic register for the precise value of the area	$\lim_{n\to\infty}\left(\sum_{i=1}^{n} x_i^2\,\Delta x\right)$
Definite integral representation in the symbolic register for the precise value of the area	$\int_1^5 x^2\,dx$

Table 1. The registers of representation associated with an integral.

that traces the path from a numerical Riemann sum approximating the area under a curve to a definite integral representing the precise area is shown in **Figure 3**: While the precise details associated with the registers of representations as we trace paths to the area under a curve, a volume under a surface and the mass associated with a volume change to reflect single, double, and triple integrals, the overarching semiotic chain can remain the same. Our first study provides insight into the ability of our operational approach to assess conceptual understanding with this semiotic chain when used with double and triple integrals.

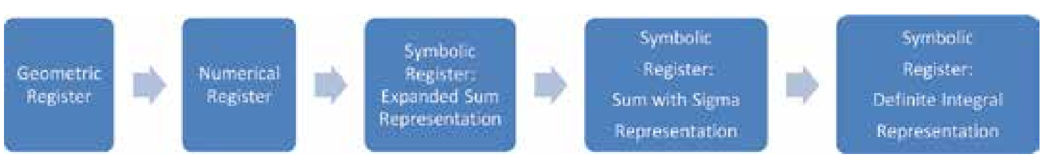


Figure 3. Semiotic chain associated with an integral.

The second study we present involved slopes and derivatives. It was interesting in that more registers of representation were involved and, unlike our first study where a single semiotic chain was most commonly used, instructors used a variety of semiotic chains. **Table 2** presents some registers associated with constant slope, and **Table 3** presents some registers of representation associated with variable rates of change. Instructors invariably presented semiotic chains when discussing slopes and derivatives; however, the semiotic chains varied. For example, some began with a geometric representation, others began with a table of values and so on. While the semiotic chains associated with their presentations varied, we nonetheless felt that our operational approach could be modified to determine whether greater flexibility in performing treatments and conversions could be associated with greater conceptual understanding without assuming a unique semiotic chain as the starting point.

For each study in this chapter, we will look at two demographically similar populations where neither academic nor demographic factors distinguish them: One population studied the topics associated with the study with greater access to a broad range of experiences involving registers of representation and a more exploratory approach that would potentially facilitate less-common treatments and conversions. This population will be referred to as the experimental population. The second population will be referred to as the comparison population, where students had a more procedural background where they sometimes used fewer registers of representation and were less likely to explore less-common treatments and conversions. We will then present outcomes for these two populations involving traditional

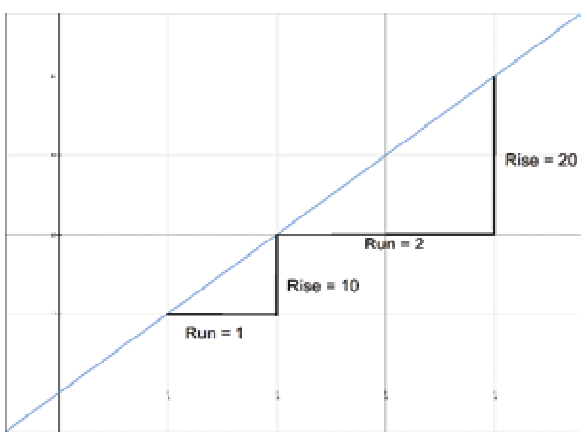
<table>
<tr><th>Verbal</th><th>John earns $10 an hour</th></tr>
<tr><td>Numerical</td><td><table><tr><td>Hours Worked</td><td>1</td><td>2</td><td>3</td></tr><tr><td>Money Earned</td><td>$10</td><td>$20</td><td>$30</td></tr></table></td></tr>
<tr><td>Geometric</td><td>
</td></tr>
<tr><td>Algebraic</td><td>t = hour of the day, $f(t)$ = cumulative money earned up to that hour $m = \frac{f(t_2) - f(t_1)}{t_2 - t_1}$</td></tr>
</table>

Table 2. Common representations of constant slope in different registers.

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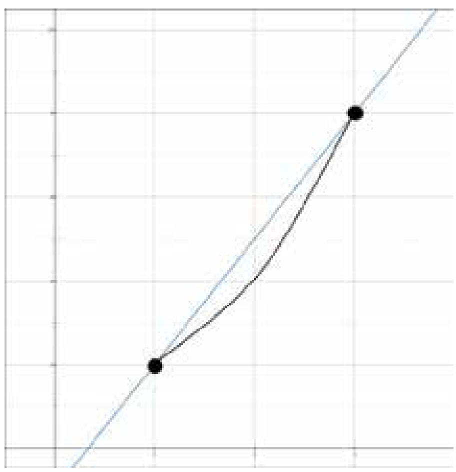
<table>
<tr><th>Verbal</th><th>At 1:00, the height of a river is 2 feet and at 3:00, the height of a river is 8 feet.</th></tr>
<tr><td>Numerical</td><td><table><tr><td>Time of Day</td><td>1:00</td><td>2:00</td><td>3:00</td></tr><tr><td>Height of River (ft)</td><td>2</td><td>4</td><td>8</td></tr></table></td></tr>
<tr><td>Algebraic</td><td>t = time of day, $h(t)$ = height of the river at time t.$m = \frac{h(t_2)-h(t_1)}{t_2-t_1}$</td></tr>
<tr><td>Geometric</td><td></td></tr>
</table>

Table 3. Registers of representation associated with variable slope.

problems that are often seen in multivariable calculus classes and interviews to assess students' abilities to perform treatments and conversions. From these data, we will assess to what degree the ability to flexibly perform treatments and conversions is necessary to conceptual understanding where conceptual understanding is measured by performance-solving standard calculus questions.

4. Results

In our first study on topics from integration, **Table 4** presents the results from interviews of the experimental and comparison populations with treatments and conversions that were not likely to have been seen by the comparison group. With every single treatment and conversion, the experimental group performed significantly better (Student's t-test, $p < 0.05$) than the comparison group. **Table 5** presents the results from interviews of the experimental and comparison populations with treatments and conversions that were likely seen by both populations. The experimental group did better with all transformations and significantly (Student's t-test, $p < 0.05$) better than the comparison group with all treatments and conversions except the conversion of the geometric register to definite integral representation of the symbolic register.

Table 6 presents the results of common examination questions that were considered to be appropriate for both groups and would likely be appropriate for most multivariable calculus classes. The experimental group did significantly (Student's t-test, $p < 0.05$) better than the comparison group on all questions.

In our second study on slopes and derivatives, **Table 7** presents the results from interviews of the experimental and comparison populations. With every single treatment and conversion, the experimental group performed significantly better (Student's t-test, $p < 0.05$) than the comparison group.

Table 8 presents the results from interviews of the experimental and comparison population. In questions 1 and 3, the experimental group performed significantly better (Student's t-test, $p < 0.05$) than the comparison group, and the difference between the two groups was not statistically significant in question 2.

Conversions and treatments	Comparison group	Experimental group
Geometric register to numerical register	42%	100%
Numerical register to the expanded sum or sum with sigma representation of the symbolic register	17%	80%
Sum with sigma representation of the symbolic register to the definite integral representation of the symbolic register	0%	80%
Verbal register to numerical register	0%	50%

Table 4. Treatments and conversions involving less commonly seen treatments and conversions.

Conversion	Comparison group	Experimental group
Geometric register to definite integral representation of the symbolic register	67%	80%
Definite integral representation of the symbolic register to verbal register	17%	80%
Verbal register to definite integral representation of the symbolic register	33%	80%

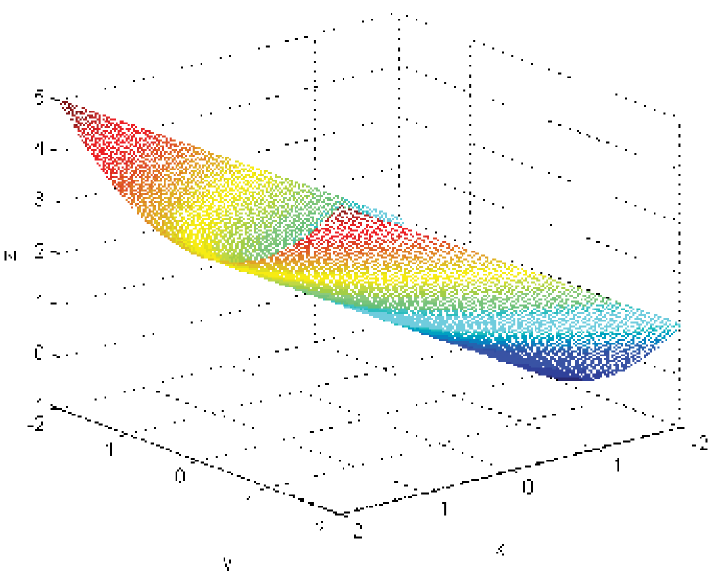
Table 5. Treatments and conversions involving more commonly seen treatments and conversions.

Question	Comparison Group ($n = 68$)	Experimental Group ($n = 36$)
Find the volume over the xy-plane and between the surfaces $y = 0$ and $z = 10 - x^2 - y$.	26%	53%
Find the volume over the plane $z = 1$, below the surface $z = 10 - x^2$ and bounded by the planes $y = 1$ and 5	48%	73%

Table 6. Results on common examination questions for the experimental and control groups.

Treatment/conversion	Comparison group	Experimental group
Geometric register to the numerical register for the slope between two points.	8%	75%
Geometric register to the algebraic register for the slope between two points.	0%	67%
Geometric register to the numerical register for the directional slope on a plane.	0%	50%
Algebraic register to numerical register for the formula of a plane.	17%	58%
Verbal register to the algebraic register for a situation associated with a plane.	0%	67%
Geometric register to algebraic register for a physical plane presented using the 3D kit.	0%	33%

Table 7. Success rates for students in the control and experimental groups on tasks involving conversions between semiotic registers that the control group had not encountered previously.

Question	Control group (n = 32)	Experimental group (n = 36)
 1. If f is represented by the above surface, a. Draw the cross sections $x = 0$ and $y = 0$ b. Identify the signs of the following derivatives where $\vec{u}$ is in the direction of $-\vec{i}-\vec{j}$.a. $f_x(2,2)$ b. $f_y(2,-1)$ c. $D_{\vec{u}}f(2, 2)$	53%	76%
2. If $f(x,y) = \sin(x^2y)$, find formulas for the following: $f_x(x,y)$ b. $f_y(x,y)$	88%	83%

<table>
<tr><th>Question</th><th>Control group (n = 32)</th><th>Experimental group (n = 36)</th></tr>
<tr><td>
<table>
<tr><td></td><td>$x = 1$</td><td>$x = 3$</td></tr>
<tr><td>$y = 1$</td><td>3</td><td>5</td></tr>
<tr><td>$y = 3$</td><td>7</td><td>4</td></tr>
</table>
3. If the function f is represented by the above table:
a. Find the best approximations for $f_x(1,1)$ and $f_y(1,1)$
b. Find the formula for the tangent plane to f at the point (1,1,3) and use it to approximate $f(1.1, 1.2)$
</td><td>37%</td><td>61%</td></tr>
</table>

Table 8. The average scores on common examination questions for the experimental and control groups.

5. Discussion

Our operational approach uses the breadth of conversion and treatment capacity with associated registers of representation as an indication of conceptual understanding. So we begin by checking whether those that are able to navigate less-common treatments and conversions are likely to manifest greater understanding in other aspects of assessment.

Table 4 shows a startling inability to navigate less-common treatments and conversions among students in the comparison group that were taught in a traditional stand-and-deliver manner as compared to students in the experimental group that were in an active learning environment where they were encouraged to explore and make sense of associations between registers of representation. The comparison group had an average success rate of less than 15% performing these treatments and conversions while the experimental group had an average success rate greater than 75%.

Our fundamental question was whether this sharp difference in the ability levels of these two populations with less-common treatments and conversions would be equally manifest with common treatments, conversions and problems. **Table 5** showed that with commonly seen treatments and conversions, the comparison group did far better but still had an average success rate of less than 40%. The experimental group, however, showed only a modest improvement moving from less-common to more-common transformations with an average success rate of 80%. The similar rate of success in the experimental group with both familiar and unfamiliar treatments and conversions would be consistent with simultaneous awareness of registers that we associate with conceptual understanding. While the comparison group did better, there was still a sharp and significant difference between the two populations with the experimental population achieving twice the rate of success than the comparison group.

Using standard classroom instruments with the populations of our first study, the greater capacity of the experimental group was manifest on common examination questions shown in **Table 5** where the experimental group averaged 63% and the comparison group averaged 37%. So the data from our first study would indicate that if we measure conceptual

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understanding by assessing students' ability to perform familiar and unfamiliar treatments and conversions among registers of representation associated with a mathematical concept, our assessment is not inconsistent with assessment of students' understanding using traditional calculus problems.

In our second study, **Table 7** shows a startling contrast between the experimental and comparison groups with the comparison group obtaining a success rate of 4% with treatments and conversions and the experimental group obtaining a success rate of 58%. So, as with our first study, the experimental population demonstrated a far greater capacity to perform treatments and conversions among registers of representation associated with the given topic.

Table 8 shows the results of the two populations in our second study using traditional calculus assessment instruments. With the most procedural question (question 2 on finding derivatives), the comparison population did slightly (but not significantly) better than the experimental population. With the questions that would be considered less procedural (questions 1 and 3), the comparison population averaged 45% and the experimental population averaged 68.5%. These results would once again reinforce that if we use students' ability to perform a broad range of treatments and conversions with registers of representations associated with a concept to assess their conceptual understanding, these results will not be inconsistent with traditional assessment instruments when the traditional instruments are associated with conceptual understanding. Interestingly, we did not find this to be the case, in this particular instance, with procedural problems and processes.

While we have focused on the role of harnessing various registers of representation in understanding concepts as suggested by Duval [1], it is worth noting that students that were successful performing treatments and conversions were over 11 times more likely (34 occurrences for the experimental group vs. three occurrences for the comparison group) to use intermediary registers (that were neither the source nor the target registers of the conversion) than students that were unsuccessful. For example, if one is asked to perform a conversion from a symbolic register (formula) to a geometric register (graph), a numerical register (table or set of coordinate points) is a reasonable intermediary register that is neither the source nor the target of the conversion. McGee and colleagues [2, 3] found the spontaneous use of intermediary registers in problem solving to be associated with student success. So this multi-register approach to understanding is both helpful in terms of providing registers from which one can glean the commonality and to provide intermediary registers which can be useful to solve problems and perform treatments and conversions.

The implications of this operational approach are twofold. As Duval [1] indicated that conceptual understanding lies in understanding the commonality of registers of representations, these studies of our operational approach provide data and insight into the importance that a broad range of treatments and conversions has in student understanding and provide an applied format to further research with this and associated concepts. The second is that this approach provides a context for conceptual understanding that encourages teachers and professors to harness various registers of representation simultaneously when promoting students' understanding.

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Chapter 10

Using Signs for Learning and Teaching Physics: From Semiotic Tools to Situations of Misunderstanding

Alaric Kohler and Bernard Chabloz

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/67429

"Language is the source of misunderstandings."

*The Little Prince, A*ntoine de St-Exupéry, 1943, chapter XXI.

Abstract

This chapter investigates various usages of semiotic objects in science education, such as arrows and graphics. We propose a series of examples drawn from physics schoolbooks, school tasks, and research data to investigate the *semiotic roles* of these objects in their specific context of use, which is to teach physics. It is not necessary to know physics prior to the reading of this chapter: we are analyzing *signs* and possible interpretations. The aim is to illustrate potential situations of misunderstanding related to *semiotic objects*, taking into account a novice standpoint. For instance, the comparison of various uses of *arrows* on a single sketch reveals the diversity of *semiotic roles* played by the same object. It illustrates the need for coordination between *semiotic registers* by the interpretant for a successful mediated communication. The results also stress the particular challenges of such coordination in science modeling. It advocates for more practice of modeling and for students to take a more active part in the process, in order to prepare them to interpret models more easily, and for teachers and students to share more explicit discourses and usages of semiotic objects.

Keywords: physics, science education, modeling, schoolbook, mediation, misunderstanding

1. Introduction

Science education is known for being challenging, and has led to an abundant research literature interested notably in students' conceptions [1–2] and conceptual change [3–5], teaching methods, and approaches [6–12]. The mediation of teaching and learning through language and semiotic tools of various sorts has been largely overlooked [13]. Yet, the few research including language and semiotics in the analysis of teaching and learning bring interesting results, see for instance [14, 15]. In cognitive psychology, most research assume in their method of data collection and analysis, that the interpretation of questions and tasks by students and research participants are nonproblematic [16], and that students' use of language is similar to the teachers' use when referring to concepts, which leads researchers to assimilate students' answers to their own conceptions of knowledge [17]. When assessing students' understanding in problem-solving tasks, for instance, the measured performance is typically indistinctly challenging students' conception in physics and ability to make sense of the question.

This chapter proposes an investigation of a few *semiotic objects* mediating the communication in physics classroom, and show that signs are both facilitating understanding and providing specific pitfalls for misunderstanding. The work presented is a semiotic analysis of teaching material in physics, mainly schoolbooks for college or high school. It may be of interest for educational psychology, science education research, cognitive psychology—in which language and semiotic analysis are often missing—and for suggestion of further research in semiotics.

The research methodology is inductive: starting from peculiar practices experts have grown used to, from writing conventions or commonalities, we propose a set of examples illustrating the fact that signs commonly used in physics can be challenging for interpretation due to various reasons. We proceed to the analysis of possible interpretation, in a fashion that can be assimilated to Artigue [18] and Brousseau [19] *a priori analysis*. One example is the challenging task of coordination between various semiotic registers and objects, which we exemplify in the next section. Another reason is the lack of clues or conventions in the use of semiotic objects which can play different *semiotic roles*. We will address this issue in the third section, taking the example of the *arrow*. In the last section, we will discuss the communicative counterpart of the use of semiotic tools for mediating knowledge, as a risk for situation of misunderstanding to emerge.

2. Coordination of semiotic objects and registers

This first section investigates a few situations where students in physics must deal with *semiotic objects* of various kinds. Duval develops the idea that learning concepts sometimes requires a *coordination of semiotic registers* [20]. He proposes to approach the problem raised by the *change of semiotic register*, typically when dealing with a problem-solving exercise using both a natural language and a formal language such as mathematics, not only as a form of expression but as a task of *coordination*, in the piagetian sense. Duval argues that for reasoning

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with several semiotic registers, these must be *coordinated*. We propose here to extend the analysis of the problem of *coordination* stressed by Duval about *semiotic register* to *semiotic objects*, and to *semiotic standpoints* in order to analyze specific cognitive tasks of interpretation of signs of various kinds within their specific semiotic context. We draw on this contribution of Duval's work, which fits with the piagetian theory, yet his distinction between various types of representation based on *information processing* theory seems problematic for the purpose of our analysis, for the reason raised in the introduction. Moreover, signs are not only used for expressing one's thought—as Duval defines it—but also as a mediator or semiotic tool for thinking [21]. Here is a first example.

2.1. A first example

A physics student in her oral examination tries to remember why a stone dropped from the top of the Eiffel tower is *theoretically* not falling quite vertically [22]. To help her, the teacher lets her draw a sketch and ask her to trace the stone's trajectory on it. She draws a vertical line (reproduced in **Figure 1**).

The obstacle on which the student stumbles over here is about the meaning of *vertical* across the two semiotic registers at stake, i.e., the natural or scientific language in which the question is addressed, and the sketch. The coordination of the drawing of a line and the concept *vertical* is achieved, from the teacher's standpoint, through the relativity of the *vertical* to the center of gravity of the Earth. Hence, an expected *vertical fall* would be drawn on the sketch as a line starting from the top of the tower to the center of the circle representing the Earth. From this coordination, the teacher aims at displaying the influence of the rotation of the earth on this specific *verticality*. The teacher uses *vertical* as a concept, in the sense that concepts are related to a broader set of meaning, and more particularly here to a formal system [23]. It is literally impossible for the teacher to declare a line *vertical* without a reference point such as the center of gravity of the Earth which, together with the falling object, defines the system.

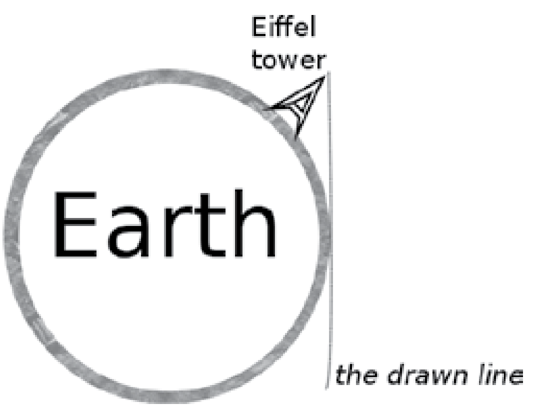

Figure 1. Reproduction of the student's sketch.

From the student's standpoint, however, *vertical* is a standalone notion, which stands for something like "from high to low in a straight line, or vice versa." The coordination between the drawing of a line and the use of the word is relative to this notion of *vertical* which, in terms, poses problem because the conventions of drawing is to consider the top of the paper higher. Conclusively, the students must draw a line from the top to the bottom of the paper (or vice-versa) to make it *vertical.* In other words, the coordination of the vertical line (graphical register) and the vertical fall (natural language register) fails in making a single meaning, what Duval calls a *semantic univocity*. The student failed to coordinate drawing conventions and modeling in physics.

To raise the issue analyzed here, a teacher can simply ask the following surprising question:

"Why is the attraction of the Earth vertical and towards the lower?"

The answer is disquieting, precisely because it is unusual at school: the attraction of the Earth is vertical and towards the lower per definition of *vertical* and *lower.*

The ambiguity is nevertheless not only linguistic: it is precisely the coordination of drawing conventions from which, most often, *vertical* is understood by children as a notion of natural language, and the *vertical* as a concept of physics, which can be represented geometrically or mathematically with a direction and a sense, but only relatively to a gravitational field.

In a piagetian theoretical framework, the coordination is a higher-order process relating operations on objects. Transposed in semiotics, the objects are symbolic—they are *signs*—and the operations are operations in the interpretation of the signs, i.e., operations (co)constructing the meaning for a particular subject. In order to avoid the theoretical reductionism inherent to formal logic, we rely on Grize's logico-discursive operations [24] rather than on Piaget's *logic of signification* [25]. Grize's Natural Logic provides an open-system logic allowing the researcher to investigate operations specific to the tasks under scrutiny, to the interpreting *psychological subject* in his/her particular situation, context, and history. Moreover, when the semiotic coordination involves several registers, it can be described as the coordination between operations of different kinds. Based on this approach, the challenge posed to the student in this first example, while interpreting the physics task, can be analyzed as the coordination between logico-discursive operations transforming the object-class {vertical} and concrete operation transforming the sketch, i.e., |drawing a line|.

2.2. A second example

The following task can be used for inducing to use trigonometry in problem-solving. It is designed for first grade college (high-school) students in *Neuchâtel*, a small town of Switzerland south of which we can see the Alps, but not the sea. The sea is further south, at the other side of the Alps. Here is the problem:

- Evaluate the relevance of the saying: "Raze the Alps to the ground, to let us see the sea!"

Students will come to the conclusion that razing the Alps to the ground is probably insufficient to see the sea, because of the bend of the Earth. An observer should stand higher to have

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a chance to spot the sea side in Genoa. Students can evaluate the constraint for a *Neuchâtelois* to see the sea, and they probably will produce a sketch alike the one reproduced in **Figure 2**.

This task is an alternative version of the first example: students must succeed a coordination of two semiotic registers, a linguistic one for the question in natural language and an analogical one for the drawn sketch.

Here, the coordination of various semiotic registers involves the coordination of semiotic standpoints, i.e., standpoints taken semiotically, a standpoint in reference of a position that is not concretely adopted by the interpreter. In Piaget's famous *mountain experiment*, children are alternatively moving physically to adopt a different *concrete standpoint*, or asked to adopt a standpoint in imagination, semiotically, i.e., through the use of signs such as the drawing of the mountains and a dot representing the standpoint from which to look at the mountains. In this second example, the student must coordinate two semiotic standpoints for his problem-solving:

1. The standpoint of the *Neuchâtelois* who desires seeing the sea;
2. A standpoint from space, looking at the Earth from far enough to see it round, and to imagine the line from the observer to the sea in Genoa, in order to check wherever this line is interrupted by the Earth surface or not.

Hence, in this task, the *coordination of standpoints* is required not only to evaluate the consequences of the bend of the Earth on the horizon of a *Neuchâtelois*, but also for the actual drawing of a sketch as the one reproduced above (**Figure 2**), since the students have to make their own sketch and use it as a *semiotic tool* to solve the problem, not just as a way of expressing the solution. The coordination of standpoints is hence constitutive to the problem-solving, and to (some aspect of) the concept of curvature of the Earth.

This analysis contributes to explain the difficulty of this apparently simple question. As pointed by Mounoud [26], coordination of standpoints remains a challenging cognitive task until late in the cognitive development, and also for adults.

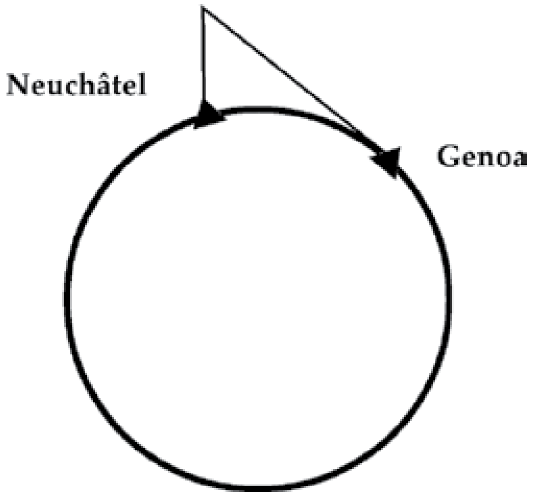

Figure 2. A simplified sketch.

2.3. A third example

The trajectory of the free fall of a thrown object corresponds to (a part of) a parabola (see **Figure 3**, the graphic on the left). Yet, the time graph of vertical free fall also corresponds to a parabola (see **Figure 3**, the graphic on the right).

The challenge for interpretation appears immediately: the drawing of a graph triggers generally a spatial or spatiotemporal representation by the reader, thus both graphs are interpreted as representing a trajectory. Two comments must be done here, to specify the use of a semiotic tool such as a graph by physicists:

1. The *free fall* is for a physicist the movement of a *material dot* in the absence of any other forces than gravity or, in any other case where all other forces would be exactly balanced. Hence, it is not a parachute jump before parachute opening…
2. A *graph* is not a *drawing*—however one can *draw a graph*. This last expression is introduced here provocally, in order to stress the difference between the graph as a mathematical object and the drawing of the graph, its graphical representation which we will call *graphic* here.

In this third example, students need to coordinate the analogical semiotic register of the graphics with the observation of a falling object. Moreover, it is with the coordination of the two graphics—two objects of the same semiotic register—that students may achieve a more complete understanding of the mathematical object *graph.* Hence, the cognitive task requires the coordination between two specific semiotic objects of the same semiotic register: the progressive construction of the two graphics can be displayed with a simulator, in order to support students understanding the parabola as a mathematical object, a semiotic tool, independently to what it represents in a particular use.

The congruence between the two graphics and the observed trajectories of the object "falling" freely is achieved through a common timetable, here, through *synchronization*. This *synchronization*

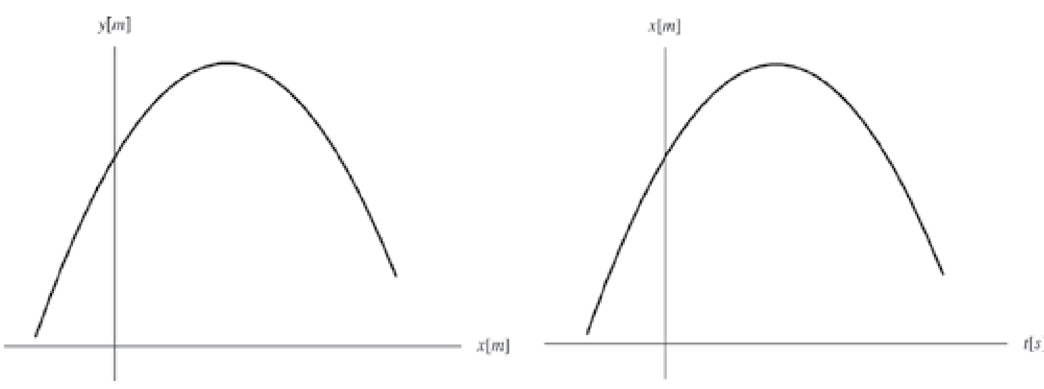

Figure 3. Drawing of the graphs of, on the left, the trajectory of the free fall of a thrown object (x- and y-axis in meters) and, on the right, the position-time graph of a vertical free fall (x-axis in seconds, y-axis in meters).

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is a specific type of *coordinations* of *semiotic objects* which can be supported by the simultaneous construction of the two graphics on a simulator. Both graphics are nevertheless referring to a common *semiotic tool* in mathematics: the *graph*.

2.4. A fourth example

Figure 4 presents an *electrical diagram*, conventional representation of the assembly of various *resistors* and an electricity source of 12 V.

The *resistors* are assembled in series, yet the diagram displays them in parallel. The expected coordination between the diagram and the electrical assembly it represents is a differentiation: students have to differentiate a parallel setting on the diagram and the parallel assembly.

Remark: an usual French translation of the word *resistor* is *résistance*. Thus the French signifier *résistance* is used as a metonymy, since it denotes [24] an object which *has a resistance* as a physical property, which can be measured in order to define the *resistance* with a number—the name of which is taken from the process of opposing resistance to the electrical flow. What a lot of pitfalls for the students' interpretation!

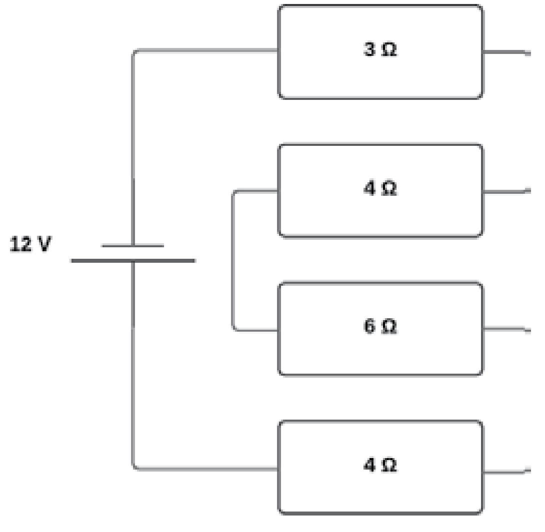

Figure 4. An electrical diagram.

3. This is not an arrow

Diagrams and sketches are complex semiotic objects and play an important role both in the making of scientific models and in supporting students to understand these models and the related concepts. In order to investigate this complexity, we propose here to approach it through the description of the diverse usages and functions played by a specific object commonly met in diagrams and sketches: the arrow.

Arrows are commonly used in physics classroom. Schoolbooks and exercise sheets frequently offer sketches to illustrate the verbal instructions or explanations. In these representations, the arrow is a *semiotic object* aiming at a better communication and transmission of knowledge, and eliciting the cognitive task expected from the students. Yet, arrows are in turn used by students to support their reasoning, or formulate their answers, i.e., as *semiotic tools* for learning or doing physics. The way students will use the arrows as semiotic tools may be influenced by the way it is used to elicit the taught knowledge. In order to investigate this question, we will present examples from schoolbooks and exercise sheets. These examples tend to show that *arrows*, as *semiotic objects*, are neither used in a way supporting a regular and rigorous congruence for the coordination between semiotic registers, neither according to well-established conventions as for the electrical diagram, for instance.

Our analysis of *arrows* as *semiotic objects* is descriptive—it stresses the properties of the signs themselves, such as the sense and direction, the line and/or color of the arrow—and functional. For the functional analysis, we investigate the *semiotic role* [27] played by a specific arrow in its particular context.

The examples presented below are analyzed following two steps.

First, we provide examples where *arrows* sharing the same properties play various roles. The *semiotic role* is differentiated from the *semiotic function* of Piaget, which refers to the general capacity of using signs, symbols, and icons. The semiotic role of a sign, symbol or icon is always specific to the objective of communication or interpretation and is situated historically, socially, relatively to a domain of knowledge (such as physics), etc. It is relatively to the specific objectives of communication in a school context of teaching physics that we will analyze the challenge of interpretation for the learners, when a sign such as an arrow plays several semiotic roles within the same sketch or schoolbook. Novices in physics are confronted to the double task consisting in (1) the assimilation of the semiotic objects themselves in relation to a domain-specific knowledge, and (2) the appropriation of the object as tools to support their learning, reasoning, and to produce relevant answers.

Second, after distinguishing various *semiotic roles* for *arrows*, examples will be provided of a diversity of *semiotic objects* for a particular *semiotic role*. Just like the diversity of *roles* for *arrows* can lead interpretants into difficulties, we argue that the diversity of *semiotic objects* for playing the same *role* may be challenging for whom has to infer the meaning from the regularity and the congruence between *semiotic register*, i.e., the regular association of a specific *semiotic object* with a specific *semiotic role*.

3.1. A first analysis: a single object for various semiotic roles

The analysis shows that a single *semiotic object*—the arrow—can play various *semiotic roles*. **Figure 5** presents a sketch of "simple levers" from a schoolbook for secondary school [28].

This sketch contains two arrows with identical outlines. The first arrow, circled by us in red, denotes the application of a force and represents the sense, direction and maybe the intensity

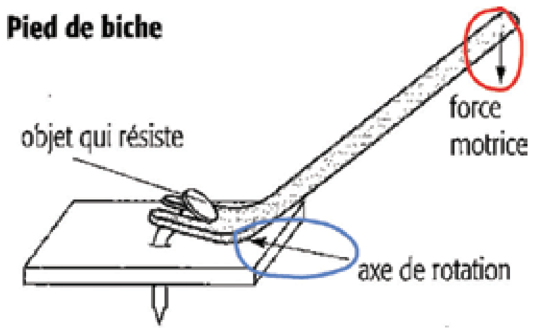

Figure 5. A sketch about simple levers, extract from [28], p. 323.

(yet without any scale) of the vector used for modeling the force. A second arrow, circled by us in blue, points to a location on the sketch and associates a caption "rotational axis" to it. These arrows play two different semiotic roles.

First, the arrow encircled in red indicates some of the properties (and more) of the mathematical object used for modeling the force, the vector: the arrow materializes the application point, the sense, direction and (maybe) the magnitude of a vector. There is a conceptual congruence between the analogical semiotic register to which the arrow belongs, and the linguistic semiotic register to which the vector belongs (mathematical language). Yet, the arrow can only be congruent with the vector for a specific instant of the application of the force. A brief instant later or earlier, the vector modeling the force could be of a different magnitude, direction or even sense, depending on the situation.

In addition, the arrow encircled in blue plays a role of pointing to a location, of guidance of the interpretant's attention. In this sense, the meaning of this arrow is similar to a verbal deictic such as "this one," yet in an analogical semiotic register. It can contribute to a joint attention in the social interaction mediated by the written schoolbook. The arrow encircled in blue is not the only semiotic object used in **Figure 5** to guide the reader's attention: a caption "object which resists" is related to the sketch of the object by a simple line playing the same role. Hence, two different semiotic objects are used in this sketch for a single semiotic role.

Moreover, the "object which resists" applies a force—the "resistance"—on the crowbar, but there isn't any arrow to represent this particular force. In addition to use arrows for various semiotic roles, and to use various semiotic objects for the same semiotic role, there is no systematic use of arrows for a single semiotic role in the sketch: while the red arrow represents a vector modeling one force, no arrows can be found for representing the vectors modeling other forces.

3.2. A second analysis: arrows and movement

In the previous example (**Figure 5**), the sketch does not suggest any change or movement, but rather a static situation. *Arrows* are nevertheless often associated with movement in other contexts, such as the sketch below, taken from the same schoolbook (see **Figure 6**).

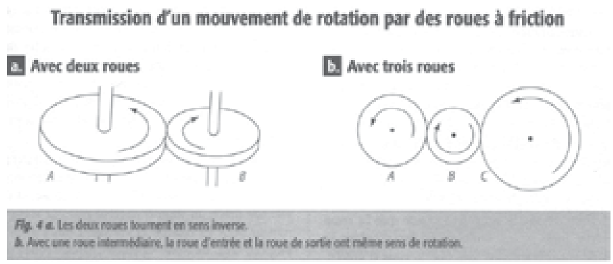

Figure 6. A sketch about rotational movement, extract from [28], p. 323.

In this sketch, the arrow plays a different semiotic role: it allows to represent a movement on a semiotic support (paper) that cannot move or be transformed itself in a way that displays movement (contrary to a luminous screen, for instance, which can be used to trigger the illusion of movement). There might be a difference in the interpretation of **Figure 6** between novice and expert: for the common reader, the arrow may directly represent a movement. With some imagination, the reader may even see the various wheels "turning" in the direction denotated by the arrows. For a trained physicist, the same *semiotic objects*—the arrows—may rather denotate a theoretical object, a concept, i.e., vectors, which are in turn used to model the velocity of the wheels. If interpreted as vectors, the various lengths of the drawn arrows in **Figure 6** raise questions: are they corresponding to various intensities of the vectors of velocity, are they depending on the diameter of the wheels or just random and meaningless? The directions and senses of the drawn arrows are also problematic to interpret as directions and senses of each corresponding vector: the arrows have no direction and the sense would rather correspond to a "rotational vector" perpendicular to the disk than to a vector modeling velocity. Hence, the congruence between the two semiotic registers is difficult to establish with this sketch.

Moreover, the arrows as *semiotic objects*, are more than vectors, since they have a position (on the sketch), while vectors are "nowhere." This particular point may lead students to consider that the arrow *is* the vector—and it is indeed a common misunderstanding. This misunderstanding has obvious consequences on the reasoning, questions, and answers. Moreover, it is meaningless to draw arrows curved if they represent vectors in **Figure 6**: the vector is never curved… this curvature has more to do with the trajectory. These various ambiguities about the arrows of **Figure 6** provides an illustration of the difficulties a novice can encounter when interpreting a sketch in physics where the semiotic roles are undifferentiated: arrows in **Figure 6** could represent movements, velocities, trajectories, vectors or a mix of these. On the other hand, learning physics entails differentiating movement and trajectory. This differentiation made Newton able to set a radically new approach, according to Koyré [29]: a mathematical model connecting forces and movement, and not only prediction of trajectories, which was the concern of medieval physics—in particular for shooting cannonballs accurately.

This analysis shows that the differences of interpretation of arrows on a sketch between novice and expert can lead to specific misunderstandings. When the arrows are interpreted by experts as vectors, logico-discursive objects used to model a physical phenomenon at a chosen instant, they can be interpreted by novices as movement, trajectories or an undifferentiated mixture of the two, leading them to imagine a movement from the sketch while the attention of the expert is on a specific instant, making of the sketch a static representation.

Let us go back on the first example with this new hypothesis and examine how it could work on the sketch of **Figure 5**. Could students interpret this sketch as designating a rotational movement of the crowbar? The caption "rotational axis" may support such misunderstanding. Indeed, learners should not use the convention associating arrows and movement; otherwise, the confusion between force and velocity—often observed by physics students [30]—may be strengthened all the better. The confusion pointed here concerns also the sketch as a whole: if it represents a static situation—which is the case of **Figure 5**—vectors are modeling a motive force at a given instant, and hence there is no movement at all to be considered. Students can nevertheless be tempted to think of such movement, since the effect of the motive force *in reality* is a movement: when one presses on the crowbar, it is for *moving* the nail out of the plank. However, modeling the movement of the crowbar and the nail requires different semiotic means, a different sketch, or more than a sketch.

In conclusion, the fact that the arrow only represents a vector at a given *instant* is crucial for understanding the physics of the phenomena. Using a written semiotic object such as an arrow to represent a model which has kinetic features—possibly better represented by a video document for instance—consists in a reductionism which is impacting differently on the interpretation depending on the objective of the communication. Yet, even when the teacher's objective is to address with a sketch a static situation for which the reduction to an instant is of no consequences, students may interpret the same sketch thinking of a dynamic phenomenon, trying to establish a congruence between the sketch and a movement. It seems therefore important that the use of a sketch comes to the interpretant with explanation about the specific objectives it may be useful for, be it in the communication or modeling.

3.3. A third analysis: differentiating arrows

In this analysis, we present examples of sketches dealing with semiotic challenges with a diversity of arrows. We start with examples providing clues to support the coordination between semiotic registers by the interpretants, and pursue with an ambiguous sketch about *forces*, discussing the question of *norms* for semiotics in physics.

In the following extract (see **Figure 7**) of an old schoolbook [31], arrows are used for pointing to the representation of a scale, on which the reader is invited to read a value (called α).

In order to represent two situations of equilibrium on the same sketch, one without any weight and one with a hanging weight "A," arrows are differentiated: one has a dotted line, the other a full line. This precaution may avert the misunderstanding of arrows as movement, which we discussed above. Indeed, the plurality of arrows may be interpreted as signifying that each arrow only represents a particular state of affair, and not a movement or process.

In this sketch, arrows do not denotate vectors which are used to model forces, but rather designates the orientation of the look of the physicist measuring the force applied by the weights

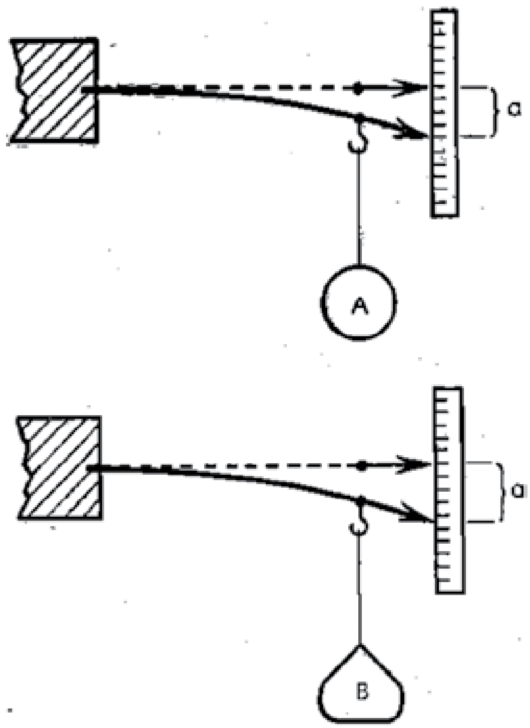

Figure 7. Illustration of the measuring of a force [31], p. 17.

"A" and "B" on a bending stem at the moment of equilibrium. In both cases, the target concept of the communication is the force, yet the approach is different: arrows denoting vectors play a role of modeling, while arrows pointing to a scale play a role of directing the attention or designating a measuring activity.

The semiotics of this sketch relies on a double representation—the representation of two situation of equilibrium—in order to communicate the semiotic role of the arrows as representing static balance of forces. This representation is reinforced with the representation of a *variable* (called α) and by another similar sketch representing another weight ("B"), which suggests a difference in mass with a difference in shape and size on the sketch. In reference to physics, the semiotic role of the sketch, which is to refer to static situations, is better supported than we could show in the first analysis (see **Figure 5**). Yet, the reader needs, for making sense of the measuring on the scale, to understand the process of bending of the stem after hanging the weight at one end which refers to an the asymptotic situation of equilibrium—when the stem has stopped bouncing up and down—which *theoretically* happens after … an eternity!

If arrows all play the same semiotic role of pointing to in this sketch, other roles can be found for the arrow in the same book, and not further than the next page. It will be the example discussed in our third analysis, and raises the question of the coherence of semiotic roles within a schoolbook or, more generally, within physics.

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The following example provides an explicit caption for an arrow. In the first sketch of the chapter on *forces* in a schoolbook [31], one arrow is used to denotate the vector AF (see **Figure 8**).

The congruence between the semiotic registers is explicited in the caption of the figure, next to the sketch, which states: "*Any body is subject to the attracting force of the Earth: its **weight**. The vector $\overrightarrow{AF}$ represents such a force, of an intensity equal to 300 kilogram-force*." The differentiation between the vector and the force is explicitly addressed, by stating that the former "represents" the latter. The congruence between the arrow on the sketch and the vector it denotates is also explicated, by several signs. The naming of both ends of the arrow (A and F) allows to *call* the arrow "AF" and add this signifier a miniature horizontal arrow indicating that "AF" is actually a vector. Moreover, not only the sense and direction of the vector are represented on the sketch with the two ends "A" and "F," but a scale is provided which explicitly makes the length of the arrow meaningful: it is the intensity of the vector, which is expressed in "kilogram-force." Yet, by doing so, the arrow AF gains several properties that exceed the meaning of the mathematical object *vector*. As mentioned before, the arrow AF has something more than the vector $\overrightarrow{AF}$: a point of application. There is no congruence between the sketch and the mathematical model about this point of application, and the drawing of arrows for representing vectors can become tricky, particularly on sketches representing objects in a realistic form, rather than just with a *dot*. More importantly, the point or *dot* F used for calling the end of the arrow has no corresponding meaning in the linguistic semiotic register of mathematics: a vector is only defined with a direction, sense, and intensity. Alternatively, the arrow AF could be representing two dots on an axis of forces in an abstract space, but it would make of A something else than a point of application, and AF would not represent the vector $\overrightarrow{AF}$ anymore. Confusion may occur here, despite the effort to make the correspondence between semiotic registers more explicit, all the more so since the letter "F" chosen for the mysterious end of the arrow may suggest a relation with a *force*…

Sometimes, vectors are insufficient and what arrows provide in addition is needed. It is the case for representing a point of application.

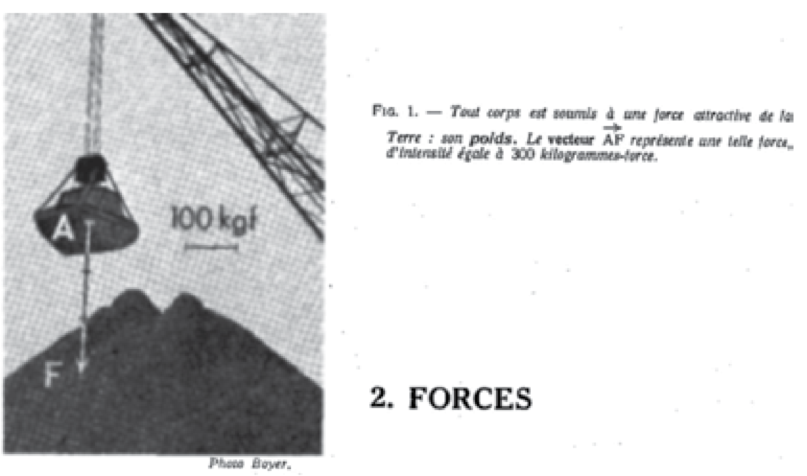

Figure 8. First illustration of the chapter on *forces* [31], p. 16.

In the sketch of **Figure 9**, the authors have used two types of line to deal with the issue of the point of application: the reaction force of the wall is drawn with a dashed arrow, and the two points of application are related with a dashed line across the door which represents the *lever arm*, all the way to the rotational axis of the torque, on which the action and reaction forces are articulated. The semiotics of this sketch supports the link between the Newtonian theory—in the linguistic semiotic register—and the sketch—in the analogic semiotic register. None of these precautions have been taken in **Figure 5**, for instance.

We have seen an example dealing with the *point of application* an arrow denotates alongside with the *vector*. The next example presents a case where the differentiation of arrows remains open to several possible interpretations, and where the caption introduces ambiguity rather than a clue for inferring the meaning of a specific arrow.

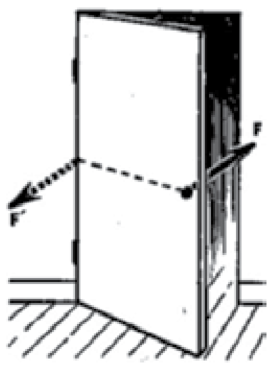

Figure 9. Illustration of a torque [31], p. 49.

In the sketch of **Figure 10**, two arrows are differentiated graphically: the arrows have dotted or continuous lines, and start from two different faces of the object.

The dotted line starting from the center of the base of the object is associated with the caption "friction," while the continuous line starting from the surface of a side of the object (alternatively the right and left side) is associated with the caption "sense of traction." The dotted arrow plays a role for modeling a *force of friction*, the arrows itself denotating the sense and direction (and maybe magnitude) of a *vector*. The localization of the starting point of the arrow may also represent the *point of application* of the force of friction, even if it is here simplified by reducing it to a mathematical dot situated at the center of the base of the rectangle, on the line of contact with the ground.

What the continuous arrow represents is more difficult to infer from the sketch. It could denotate a vector modeling a *pulling force*. Yet, the caption refers exclusively to the "sense of traction," which cannot be understood literally since the direction of the arrow should also be taken into consideration if the arrow denotates a vector, the direction of the vector and the direction of the arrow are congruent. Nevertheless, pairing the sense of movement and forces is typically the common sense a physics teacher opposes: friction forces and traction

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forces may have the same direction and sense, e.g., when holding a sledge slipping down a slope, and friction forces are not always in the opposite sense of acceleration, e.g., when a car accelerates. Since it is inducing such an association or confusion between force, acceleration, or movement by the lack of specification, the sketch of **Figure 10** may support interpretations confusing the concepts of *force* and *movement*, which has consequences on the learner's cognitive tasks of coordinating sketches and concepts, and more generally of reconstructing the concepts with the support of sketches.

Moreover, this sketch also supports the confusion mentioned earlier between the study of static and dynamic situations. **Figure 10** actually represents a stationary situation (i.e., with constant velocity), if the pedagogical objective is indeed to demonstrate that the friction force is a reaction force in the same direction and opposite sense to the traction force. Yet, the confusion between *force* and *movement* introduced by the caption "sense of the traction" supports the imagination of a "story," a process: the object is first immobile, is then pulled—the arrow could even stand for the rope in this interpretation—and thus it moves, braked down by the friction force. In such a representation, the acceleration phase is completely overlooked. The friction force is a friction between the two surfaces instead of a resistance to start moving, while the stationary situation could be standing for both cases.

The graphical differentiation of the two arrows is also operated through the choice of a different starting point for each arrow. The continuous arrow starts from the surface of the object. We have seen the semiotic challenge posed by the graphical representation of a *point of application* of a force, in particular when sketches are representing *objects* rather than *dots*. Following the modeling of objects as mathematical dots, any point of application of a force exerted on an object should be the center of gravity, according to the specific model used here. While we understand that the point of application of the dotted arrow in **Figure 10** is not quite the center of gravity, but the horizontal center on the line of contact with the ground, this leads to confusion when the interpretant tries to coordinate the dotted arrow with the continuous arrow. These arrows represent vectors which only need to be added to each other to be coordinated as a *sum of forces* exerted on the rectangle. But a novice reader could wonder whether he/she must think of torque. When representing a torque, in **Figure 9**, the author of the same schoolbook chooses to connect the points of application of the forces across the door, in order to represent the *lever arm*. Here in **Figure 10**, the sketch is not about torque and such semiotics would be irrelevant. Now, the point of application of the continuous arrow—on the surface of the object—is difficult to justify if the arrow is meant to denotate a vector. It rather supports an interpretation where the arrow designates a rope, a concrete object rather than an *object of discourse* [24] such as a *vector*. The problem identified here can be analyzed in terms of an ambiguous coordination between semiotic registers within the sketch. The sketch uses two different semiotic registers: one represents something; it is *representational* or *figurative*, while the other represents a model; it could be named *modelative.*[1] The rectangle or the line representing respectively the object and the ground are *figurative*, while the point of application and the arrows are *modelative*. It is

[1]In French, the adjective "modélisant" could avoid us to introduce a neologism, here. In English, yet, the lack of adjective corresponding to modelling, the active form of the verb to model leads us to prefer a neologism to avoid ambiguity.

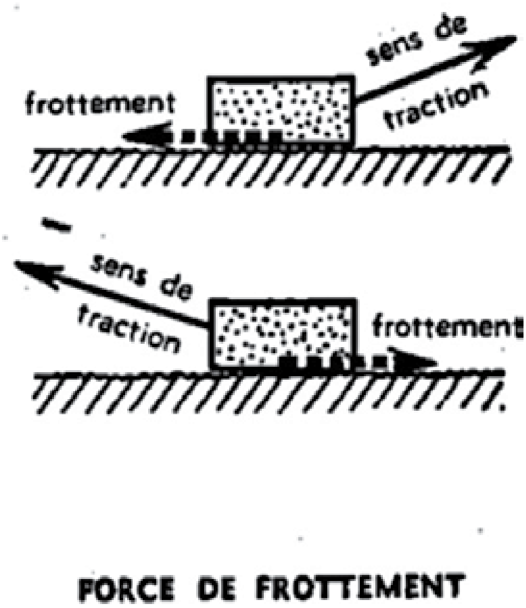

Figure 10. Illustration of friction forces [31], p. 27.

interesting to note that the linguistic register does not always allow to differentiate such an ambiguity: the word *attraction* is also ambiguous, as *attracting* does not mean *making something come* in physics, but rather *pulling* even without any resulting movement.

This analysis would not be complete without considering the effect on interpretation of the arrows that are *not* drawn on the sketch. Since the interpretant, and more particularly the novice, must rely on inferences for meaning making and on what there is on the sketch, the absent arrows may also influence such inferences. Typically, one may interpret arrows as representing forces rather than movement, ropes or anything else, if there is one arrow on the sketch for each of the expected forces to be considered. Piaget shows in his theory how the whole system of operations allows a deeper understanding of each operation constituting such system. We may consider a sketch as a system—at least the interpretant expects the sketch to "work" consistently like a system—and the single operations used for interpreting it as depending on the interpretation of the whole. Following this hypothesis, the fact the earth attraction and the supporting force exerted by the ground on the object are not drawn in **Figure 10** does not support the interpretation of the arrows as forces in this sketch, and would allow them various semiotic roles. If all the forces exerted on the object at a specific moment were drawn on the sketch it would support the interpretation of the arrows as denotating vectors and as modelative of forces and support the interpretation of the sketch as a whole as modelative of a stationary situation rather than of a dynamic, or of a truncated "story."

Hence, not only what is on a sketch may open the possibility for misunderstandings, but also what is lacking. It is not surprising, considering that interpretation relies greatly on inference processes, for which consistency and repetition are important criteria. If a sketch contains four arrows, among which one is ambiguous and the other three are clearly denotating vectors, the ambiguity is easily solved in favor of a consistent use of arrows that grants the semiotic object the same semiotic role within the sketch: the fourth arrow will also be interpreted as denotating a vector. These *a priori* analyses draw the attention on the importance of consistent use of semiotic objects in science education, in order to support the desired interpretation. More detailed is the analysis, more problematic the consistency appears. We will continue to refine our investigation with a last analysis, interested in the differentiation between what arrows are modelative of.

3.4. A fourth analysis: vectors for various physical quantities

In this analysis, we provide several examples to raise the issue of the various physical quantities vectors can model, and to provide illustration of clues that can be used in order to support the interpretation.

The graphical representation of a trajectory "equipped" with vectors for velocity, acceleration and force constitutes a classical example of a sketch with arrows, which we use for presenting, explaining, or using the second Law of Newton. **Figure 11** illustrates a sketch with arrows for three types of vectors mentioned.

The arrows in **Figure 11** are not distinguished according to the various physical quantities that the learner needs to differentiate. The sketch could raise nonsense questions as: "Why is the arrow representing velocity longer than the arrow representing the acceleration?" Meaningless practices could also be grounded on this sketch, such as adding or subtracting vectors modeling different physical quantities. In **Figure 11**, single letter captions have been added for each arrow, which could work as clues for the physical quantity represented by the arrows. As useful as it can be, the interpretation remains subject to the interpretant's knowledge of implicit convention. For instance, "F" generally refers to the sum of all forces applied on the object, rather than to a specific force exerted on the object. This object is here reduced to a dot, consistently with the model: it is not a figurative object, but a modelative object. Moreover, the arrow associated with "F" has its arrow end on the object instead of its starting point, suggesting the idea that the force is "pushing" the object. Generally, the arrows

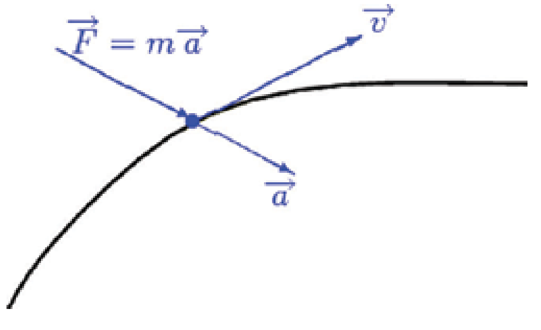

Figure 11. Illustration of a graphical representation of various vectors implicated in Newton's second law [32].

denotating vectors are starting from the object, its center of mass if it is drawn as a figurative object. Yet, once again, a diversity of practices is not rare in science education, and often comes without a word of explanation. The linguistic register seems more consistent with arrows starting from the object, yet vectors are not only modeling properties *of* the object (such as velocity or acceleration) but actions *experienced by* the objects (such as forces). These relations that physical quantities have with the object are not signified by the mathematical expression of the second law—written on the caption "F" of the sketch—and can only be interpreted here from the knowledge of the interpretant.

In the following example (see **Figure 12**), arrows of various colors have been used to differentiate between the various physical quantities the arrows are modelative of.

This trick allows the teacher to address his students with the provocation presented in **Figure 13**: "this is not a triangle"

Figure 14 shows more examples of a color and shape scheme for arrows, depending on whether they are denotating a vector modeling velocity, acceleration, or forces.

The shapes and colors provide a clue for interpreting arrows as denotating vectors modeling different physical quantities (i.e., *force*, *acceleration*, and *velocity*). Yet, there are no explicit criteria for the shape and colors: the author simply mentions that a particular care has been given to these representations. The practice of arrows in the schoolbook nevertheless shows that vectors modeling acceleration have generally a double line and the color red, while trajectories or movements are represented with black lines and arrows. Vectors modeling forces are denotated by arrows of various colors throughout the book.

Figure 15 presents an example using colors, but from another book [35].

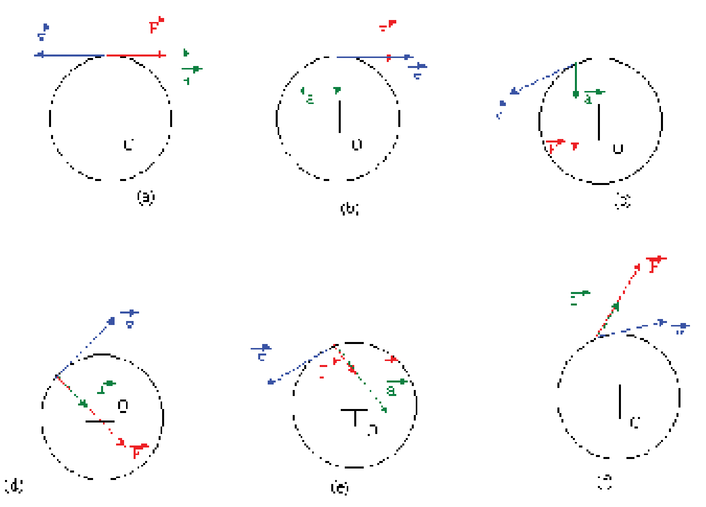

Figure 12. Exercise about vector quantities implied by Newton's second law [33].

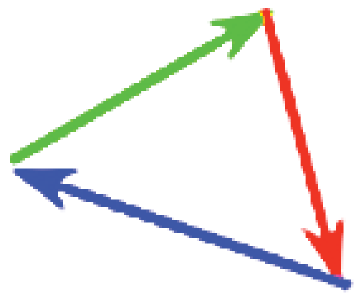

Figure 13. “This is not a triangle”.

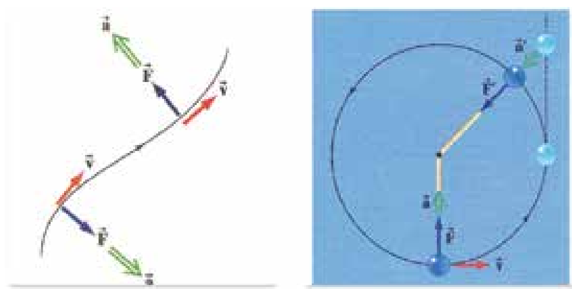

Figure 14. Illustration of vector quantities implied by Newton’s second law [34], p. 121 and p. 152.

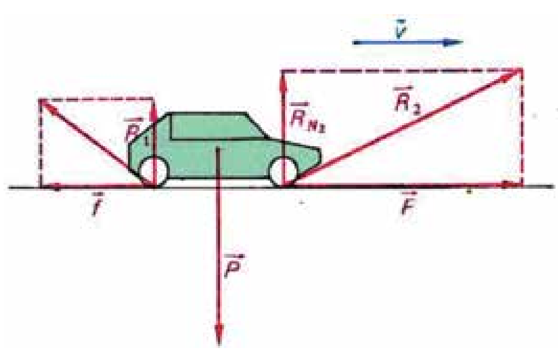

Figure 15. Forces exerted on a car and velocity vector [35], p. 43.

The object is represented figuratively and there is here the problem of the point of application discussed earlier. There is an additional ambiguity due to the oblique vectors R1 and R2, which are not modeling additional *forces* experienced by the car, but the result of a composition of *forces already* represented on the sketch.

4. Discussion and ideas for further research

This brief inquiry about the *semiotic roles* played by arrows in a few sketches mediating communication in physics led us to consider several roles:

(1) a role in directing attention: pointing to a specific location on the sketch, in which the arrow works as a graphical deictic;

(2) several roles in signifying:

  (1) designating a movement ;

  (2) designating a trajectory ;

  (3) designating an action such as pulling or pushing ;

  (4) denotating a vector which, in turns, is modeling several physical quantities, notably:

    (1) a velocity of an object;

    (2) an acceleration of an object;

    (3) a single force experienced by an object;

    (4) a sum of forces experienced by an object.

If it were not for the role in directing attention, for which the arrow does not represent anything, we would be tempted to consider arrows signs with several significations, just like words can have several entries in a dictionary. A "pound" means both a quantity of money and a mass. However, even without this role in directing the attention, analyzing arrows in science education is not that simple. Indeed, the arrow itself, as a semiotic object, has some properties such as the sense and direction, and the length, which are or are not congruent with the corresponding object of discourse in the linguistic register, depending on the semiotic role played by the arrow. For instance, the direction and sense of an arrow denotating a vector are relevant, while the precise direction of an arrow denotating a pulling action on a door is not necessarily congruent with the linguistic correspondent—the force exerted on the door or its movement. Moreover, depending on the particular sketch in which the arrow is used, its length may be relevant or not: when a scale is associated to the length of the arrow and the arrow denotates a vector, its length can be interpreted as congruent with the magnitude of the vector. On a sketch with arrows denotating vectors modeling various physical quantities, however, the comparison of the length of the arrows is meaningless. The direction and sense of an arrow pointing at a specific location of a sketch is also partly irrelevant: it is only the combination of the two that achieve the pointing.

Hence, it appears that the actual coordinations the interpretant can or should do while interpreting sketches in physics depends on the semiotic roles played by the arrows on the sketch, and depends on various other choices made during the design of the sketch.

When the arrow denotates a vector, there is congruence between the arrows direction and sense, sometimes its length, and the vectors direction and sense, sometimes its magnitude.

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Establishing this congruence requires from the learner to coordinate two semiotic registers together: an analogic register used in the sketch, and a linguistic register using mathematical language and, more precisely, a mathematical *object of discourse*, i.e., *vector*. Within the analogic register used in sketches, the analysis has shown that two semiotic subregisters must be differentiated: a *figurative* representation of objects which represents objects as they appear in real, and a *modelative* representation which represents objects according to a specific model, operating specific reductionism following specific and systematic rules (e.g., representing an object by a material dot).

Moreover, some semiotic roles are not exclusive and can be used simultaneously or can be undifferentiated in a particular sketch. For instance, an arrow can indistinctively refer to the direction and sense of a movement and the vector modeling velocity. After all, if nothing is explicated, the coordination of semiotic registers largely depends on the knowledge of the interpretant. Many not-so-well-made sketches work fine for those who know not to look at what could otherwise appear as "mistakes" in the representation.

We have raised the question of the coherence of the clues used to support the interpretant inferences in single sketches. This question can be addressed for physics in general, questioning the coherence of the way arrows are used and how the diversity of usage is associated with clues (graphical differentiation, captions, etc.). Despite an overall convention that arrows are used to denote vectors, more particularly vectors senses and directions, the few examples analyzed here advocate for a rather nonnormative use of arrows in science education. Detailed features such as the graphical rendering of the arrow, the point of application or the way to distinguish between various physical quantities modeled by vectors are not *normed* and vary within a single book, sometimes even within a single sketch. For the book, we showed with **Figures 8–10** that dotted arrows could refer to various types of arrows, and despite a great care to graphical representation in this particular schoolbook [31].

The many challenges and risks of misunderstanding we could stress from a few examples of sketches only, build an overall impression of a *wild language*. The various ways sketches, and in particular arrows in these sketches, are used to mediate communication in the examples analyzed show that sketches are indispensable semiotic tools—some sort of *proto-language*—and yet, the lack of systematic usage and conventions or norms stresses how *uneducated* these semiotic tools are. If it may be some sort of graphical proto-language, specific to physics or even to a chapter in physics, it does not follow the rules of other semiotic tools such as *technical drawing*, *algebra, English syntax*, etc. Sketches we examined remain for most of them unsystematic in the way they use semiotic objects such as *arrows*, and their interpretation depends highly on rules specific to each particular sketch, when there is any. The *wilderness* is not related to a lack of existing means, since older schoolbooks are sometimes better, and there are a number of means to provide the interpretant with clue to support the desired interpretation, which we stressed throughout the analysis.

Future research is needed to elaborate a more systematic semiotics for science education, both for describing existing practices and innovative ideas and for testing various semiotic norms, in order to investigate which ways are making the interpretation easier for specific issues.

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