Ecological Modelling of Information Systems

Christian Flender

Faculty of Information Technology,
Queensland University of Technology,
Brisbane, Australia
c.flender@qut.edu.au

Abstract. Conceptual modelling is central to information systems development. The design of information systems requires appropriate languages to conceptualize interactions between actors. Mostly, design languages are adopted to the application system to be modelled instead of being aligned with the nature of perception of the modeller. Perception and cognition are very different from computations on symbolic representations. Cognitive structures and processes emerge from continous sensorimotor interactions. Action-oriented languages already consider action and coordination in terms of speech acts. However, speech acts can not be foundational as a speech act itself is brought forth or *enacted* in movement, in particular through action in perception. In this paper, it will be argued for non-representational modelling. To address the problems of representations, an ecological approach based on quantum interaction is proposed with respect to both criteria action in language and action in perception.

Key words: Conceptual Modelling, Action-oriented Modelling, Ecological Perception, Enactive Cognition, Quantum Interaction

1 Introduction

Conceptual modelling is central to information systems development. Information systems are embodied in humans and machines, in particular computers and their users, acting in collaboration. The design of information systems requires concepts to make appropriate discriminations and abstractions of the system under investigation. For instance, meta-concepts such as entity, object, event or process are meant to bear semantics so as to combine them toward more complex structures and behaviours reflecting socio-technical phenomena. Generally, concepts are used to judge a present situation similar to a previous one [1]. For example, an artwork may be judged as aesthetic according to some similar experiences made in the past. Nowadays, it is still the case that such experiences are reduced to being mere abstractions or identifiers of an external setting whose existence may be absolute (realism) or never ever deducible from one's own mental representation (nihilism) [2]. Such conceptual representations are said to have a number of (fixed/graded) properties, e.g. color and shape of an artwork, and (definite/indefinite) exemplars, e.g. other artworks treated as similar members.

From this viewpoint, the separation between mind and world is presupposed as concepts account for (Cartesian) dualism in representing something external or denying access to an external world at all. Hence, the meaning of concepts, e.g. the perceived size of an artwork, is meant to be either inherent in categories in the world or arbitrary to our assumably self-enclosed minds.

However, understanding concepts as representations bears the naive presupposition of their ontological nature. For instance, it has been shown that representational concepts work well for analytic categorisation tasks but they fail for associative thought [3, 4]. Furthermore, classical concepts presupposing clear boundaries and fixed properties do not account for instances having varying degrees of memberships [5, 6]. Even for representations as graded structure, i.e. concepts with varying exemplars and properties, there is no chance to distinguish between concepts on the basis of empirical evidence as artificial stimuli builds upon preconception [1]. Furthermore, inappropriate use of probabilities does not fix the problem of concepts being highly susceptible to change. Most of representational languages have a lack of context-sensitivity [7–9]. It is quite obvious that those preconceptions derogate the value of representations with regard to cognitive tasks like predication, combination and similarity measurements of concepts. This is crucial to the design of information systems as the main concepts to be modelled are human actors being autonomous and embodied organisms bringing forth their own domain of significance in action. In the first place, modelling social interactions can not be representational but must account for contextual situations in complex conversational scenarios. Action-oriented modelling [10–16] employs speech acts [17, 18] for modelling pragmatic concepts such as actors, responsibilities, actions and commitments. To start systems development from the level of speech acts simplifies interaction modelling as there is a closer proximity to natural language compared to artificial representational concepts. However, speech acts can not be foundational as a speech act itself is brought forth or *enacted* in movement, in particular through action in perception. [19–21].

Hence, there is a lack of non-representational languages for the design of social interactions beyond simple speech acts. Recent developments in the field of quantum interaction [22–24] are promising as concepts can be modelled as participatory thus closing the presupposed mind-world gap of representations. Based upon an ecological approach [1, 25, 21], this paper outlines first attempts to contextualize concepts toward complex interactions between social actors. Having languages reflecting the context-sensitive nature of human interactions will significantly contribute to more accurate conceptual models [26]. The paper proceeds as follows.

In the next section, representational modelling is discussed from two points of view: classical and graded structure. Classical views build concepts upon set theory and classical logic, whereas graded structure accounts for exemplars of concepts having varying degrees of memberships. In Section 3, action-oriented modelling is introduced. As conversations are reduced to sequences of intentional acts and message exchanges thus neglegting complex associative interactions, in Section 4, ecological modelling is proposed by drawing from quantum interaction and enactive cognition. Ecological modelling accounts for emergent properties arising out of context-sensitive interactions. It is argued that ecological modelling avoids problems of representations and enriches action-oriented interactions. Section 5 concludes the paper and gives an outlook to future work.

2 Representational Modelling

A representation is a physical shape or form that stands for something [27], in case of information systems it stands for a socio-technical system [12], e.g. a business process model depicting human-computer interactions. The modeller as a cognitive agent perceives the real world, demarcates the relevant part of the real world by abstracting away from unnecessary details and finally constructs a model of that relevant part using a set of concepts and rules to combine these concepts. Two types of concepts are distinguished according to their degree of context-sensitivity. From the classical view there exists for each concept a set of defining features that are necessary and sufficient (e.g. [28]). In contrast, graded structure accounts for varying features and exemplars (e.g. [29, 30]).

2.1 Classical View

From the classical view, concepts are denotative or identifiers. They have clear boundaries and fixed properties. Furthermore, concepts bear meaning or inherent semantics. Particular instances can be treated equivalently as members of a class. Classes are specified through classical logic. For instance, consider an artwork as a concept. It may be defined as the conjunction of several concrete properties such as color, shape and size as well as abstract features like beauty. Exemplars treated equivalently as members of this class satisfy the criterion of being sufficiently similar with respect to the artwork's preconception, i.e. the product state space of its properties.

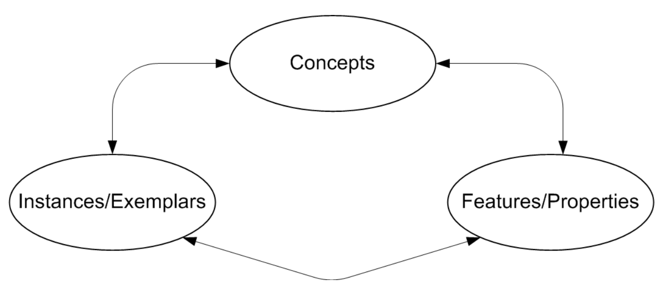

Fig. 1. Modelling Concepts.

Here, there is a presupposed separation between mind and world, internal and external, subject and object. This duality becomes clear if perception is understood as an input-output relation between mind and world, i.e. internal mechanisms recover representations of the external world. This duality is built into conceptual research in the sense that categorisation tasks presuppose defining features of concepts. However, catgegorisation depends less on predefined properties rather than on perception and life activities [1, 31]. Hence, there must be better-worse classification allowing for varying degrees of memberships. For instance, red hair might be a better instance of *red* than red fire or vice verca.

2.2 Graded Structure

Several alternatives to the classical view have been put forth. Amongst others, prototypes represent concepts by as set of, not defining, but characteristic features, which are weighted in the definition of the prototype [29, 32, 33]. Instances are categorized if they are sufficiently similar to this prototype. Exemplar theories represent concepts neither by defining nor characteristic features but by a set of instances stored in memory. New items have to be sufficiently similar to instances in memory in order to get categorized [30, 34, 35]. This is much more flexible than presupposing clear boundaries and fixed properties. However, naive preconceptions of representations do not go away with an increase in varying structure. This becomes clear for the *generation* of conjunctions.

In contrast to analytic thought, intuitive, generative or associative modes of cognition provide access to remote or subtle connections between features that may be correlated but not necessarily causally related [36, 37]. For instance, the guppy effect is a quite compelling example of this shortcoming [38]. Guppy is neither rated as a good example of *fish* nor of *pet*, but it is a good example of *pet fish*. Hence, activiation of *pet* or *fish* alone does not cause activiation of guppy. For instance, consider the Entity-Relationship (ER) notation [39]. Here, composite or joint entities are described by means of the product state space, e.g. the Cartesian product space of *pet* and *fish*. However, the conjunction of both concepts cannot describe the situation wherein novelty (e.g. guppy) is generated. Generally, meaning of concepts is disclosed or brought forth and emerges in action. People do not use language only to talk about events in the external world, they act and communicate *within* the world as social actors [40]. Hence, in the first place, modellers should understand language not for identification purposes but as participatory and context-dependent concepts [31], i.e. actions.

3 Action-oriented Modelling

Participatory sense-making is communication and implies doing things like stating, promising or questioning. Action-oriented modelling [10–16] employs speech acts [17, 18] for modelling pragmatic concepts such as actors, responsibilities, actions and commitments. In action, actors coordinate behaviour. Hence, language is primarily the coordination of intentional acts [41] and not a representation of an external world. For instance, consider the Semantic Object Model (SOM), an action-oriented modelling approach [12]. SOM supports the coordination of actions by means of coordination principles (cf. Figure 2).

3.1 Action in Language

In SOM, autonomous and loosely-coupled actors (objects) coordinate behaviour through intentional acts[1] (transactions). Intentional acts are typed according to the coordination involved. Negotiation specifies initiating transactions (e.g. make offer), contracting transactions (e.g. accept order) and enforcing transactions (e.g. deliver product), whereas hierarchical coordination defines control transactions (e.g. give advice) and feedback transactions (e.g. confirm order). Using actions or intentional acts for requirements specification bears the advantage of describing an information system naturally from an inside view. Actors coordinate behaviour in action. According to Austin (1962), to speak is to act [17]. The theory of speech acts [18] is meant to be a foundation for action-oriented conceptual modelling [40].

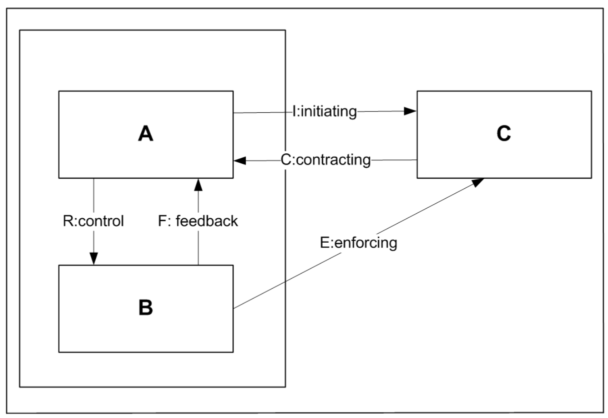

Fig. 2. Modelling Actions.

A speech act consists of four different sub-acts [18]: (1) uttering words, that is, performing *utterance acts*, (2) referring or predicating, that is, performing *propositional acts*, (3) stating, questioning, commanding, promising, etc., that is, performing *illocutionary acts* and (4) causing an effect in hearers, that is, performing *perlocutionary acts*. Actors *do* or *enact* acts 1-3 simultaneously. Most interesting is the relationship between illocutionary acts and propositional acts. Representational modelling languages focus on the propositional content that is a representation of something to which a propositional act refers, e.g. an order refers to an artwork. For instance, object-oriented models [42] or ER models [39]

[1] It is quite obvious that intentional acts reach far beyond speech acts. In the light of intentionality, the mental life of an actor is the temporally extended and dynamic process of flowing intentional acts like perceiving, remembering, imagining, empathizing, speaking etc. It is animated by precognitive habits and sensibilities of the lived body and influenced by communal norms, conventions and historical traditions [27]

would represent an order as an instance of a class or relational type. However, detaching the propositional content from its pragmatic meaning and intended use is a prominent example of misinterpreting language as a representation of the real world instead of understanding it as a concept enmeshed in action, for instance enmeshed in *using* an order [31, 16].

Designing information systems from within their social context avoids misinterpreting language as a detached representation of an external world. Instead, from an inside view, actors coordinate behaviour via intentional acts, in particular speech acts. However, speech acts emerge from recurrent sensorimotor patterns that enable action to be perceptually guided [27]. What is sensorimotor activity and what means perceptually guided action?

3.2 Action in Perception

Social actors are autonomous and embodied agents. Autonomous agents stand in sharp contrast to systems whose coupling with the environment is specified through input-output relations, e.g. finite state machines. Interactions for an agent with its environment are not prescribed from outside but the result of an agent's operationally closed organization and history [43].

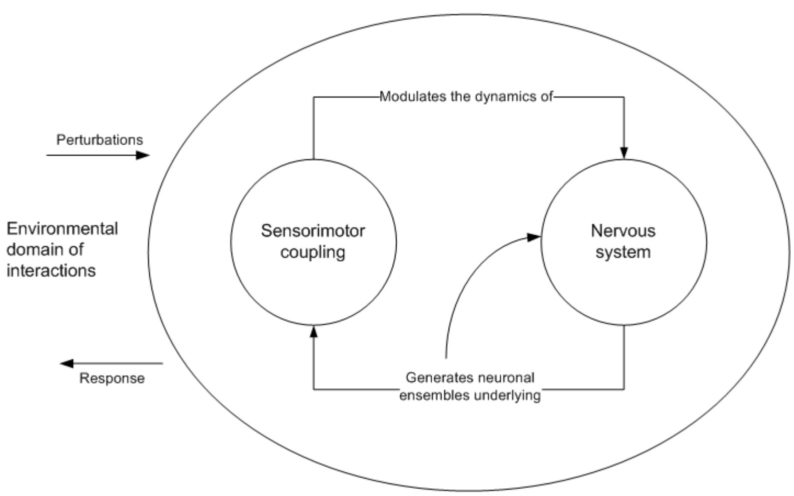

Fig. 3. Sensorimotor Activity as Perceptually-guided Action [44].

Agents are embodied as the nervous system links sensory surfaces (sense organs and nerve endings) and effectors (muscles, glands) within the body, and thereby integrates the organism, holding it together as a mobile unity, as an *autonomous sensorimotor agent* [45]. Hence, perception is no input-output relation between sensory stimulation and motor action rather action is perceptually guided by tuning to certain potentialities or attractors which in turn modulate movement. An appropriate model for perception is touch where actual and anticipated body movements enable the discernment of qualities like shape or form. In perception, objects are not represented rather than virtually accessed through sensorimotor profiles [19–21]. Stimuli is not transduced into internal neural representations and internal cognitive transformation processes recover, through complex computational operations, objective features of the world so as to generate appropriate motor actions on the world [46]. But how does sensorimotor activity give rise to intellectual capacities like speech acts? Intentional acts can be distinguished into presentational and re-presentational [27]. The latter mentally (re-)evokes or brings forth an object which is not necessarily given as present, e.g. speaking, whereas the former, which is a requirement for re-presentation, intends an object which is given as present in its very being, e.g. perceiving. Re-presentation arises in ongoing presentational experiences of one's surroundings. In both cases, presentation or re-presentation, sensorimotor activity is constitutive, and thus an ecological or enactive account of perception and cognition [21, 25] is foundational.

4 Ecological Modelling

So far, it has been argued against representations. Concepts are not identifiers rather than meanings brought forth in action and sensorimotor activity. In this section, an ecological approach is proposed to address the problems discussed. Ecologies reject dualisic preconceptions (e.g. mind-world, internal-external, subject-object etc.) which are nothing else than poles of attention [25]. Instead, it is argued that in social interactions action and movement determine context or relevance of concepts. To realize this insight, we propose to model conversations with quantum interaction while being consistent with enactive cognition. For enactivism [27, 21, 2] context is determined in body movement and object movement. In quantum interaction, action and movement is built into its formalism to generate meaning of concepts.

4.1 Enactive Cognition

The relation between reflective, intellectual or re-presentational acts (e.g. imagining, visualizing, remembering, thinking, speaking etc.) and pre-reflective, unconscious or presentational body movements (i.e. perceptually guided action) is a matter of degree [21]. There is no strict line when movement ends and thought begins. Both require sensorimotor activity. For instance, consider perceptual presence of something strictly unseen (e.g. an occluded object behind a fence) and the nonperceptual presence of an unseen item (e.g. the room next door). Actual and anticipated body movements (bodiliness) affect sensory change and lead to the virtual presence of an intentional object [19, 20]. Although the room next door is unseen movements in relation to the room let one *do* see or *enact* the room. One just has to walk over there. Discerning an occluded object behind a fence as a whole is possible due to the anticipation or expectation of new sensory stimulation in moving to the right or left. But there are also sensory effects produced by environmental changes such as changes in local illuminance or moving objects. Such changes attract attention (grabbiness) and also influence to what extent perceivers are familiar with sensory effects. For instance, color perception is the understanding of ways of how color changes as color-critical conditions change [21].

In summary, perceptual experience is virtual. Features of objects are present as available, rather than represented. Sensorimotor activity has access to environmental settings through continous interactions which are both movement-dependent (bodiliness) and object-dependent (grabbiness). From continous presentational experiences re-presentational capacities such as speech acts emerge which in turn modulate movement. The enormous context-sensitivity necessary to account for this circularity can be modelled with quantum interaction.

4.2 Quantum Interaction

In recent times, quantum formalisms have been explicitly taken out of their domain of origin and applied to conceptual modelling [47, 48, 3, 4]. This is in alignment with enactive cognition. For both concepts and microparticles a property and its negation can be potential (e.g. an artwork is aesthetic or is not aesthetic). According to enactive cognition, meaning of concepts is grounded in the potential ways of how sensory stimulation changes in (actual or expected) movement. The actual observation or doing determines the state or value of a concept and reorganises the dynamic weblike structure it is embedded in. Hence, observations, movements, doings, measurements etc. determine the context that evokes the actualization or *collapse* of a concept's meaning, e.g. the concept of an artwork acquires meaning in the context of actually *using* such an artwork in one or another way (presenting it to an audience, looking at it etc.). It is this interaction between contexts and concepts that is called entanglement. More precisely, a state of entanglement is modelled as the tensor product of two Hilbert spaces, e.g. see [23, 1]. Such a product accounts for non-deterministic effects of context in bringing forth or disclosing new concepts with different properties compared to the entangled spaces it emerged from. No representation, no fixed properties and no clear boundaries are involved. Concepts as much as thoughts are highly dynamic, context-dependent and susceptible to change.

The state space of a concept includes potential (superposition) states and actual (collapsed) states. In Figure 4, the state of a concept is described by a unit vector x and properties by orthogonal projections $P_A(x)$ and $P_{A'}(x)$. The subspace A stands for a context while the subspace A' is the negation of this context. Under the context A the state of a concept x changes or collapses to the projection $P_A(x)$ and under A' it changes to $P_{A'}(x)$. To entangle concepts and meaning the conjunction of two concepts such as *pet* and *fish* is described in the tensor product space $H1 \otimes H2$. The spontaneously generated entity or compound resulting from this entanglement accounts for gain and loss of properties as well as unexpected typicalities of instances as context changes. For instance, it was shown that the emergence of new properties resolved the fish pet problem as introduced in Section 2 [49]. Hence, once context is given (the pet is a fish and the fish is a pet) guppy is categorized as typical for both *pet* and *fish.* This is not the case for classical conjunctions of decontextualizd concepts as guppy is neither *pet* nor *fish* but *pet fish*.

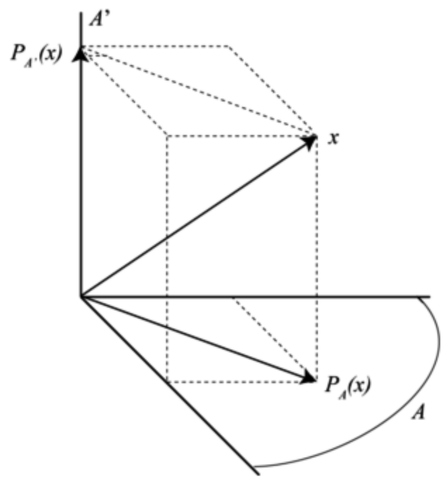

Fig. 4. Determining Meaning of Concepts in Action.

As it has been discussed in Section 3, action-oriented modelling escapes representationalism by focussing on communicative acts. Communicative acts draw heavily on context [50]. Moreover, communication and organization are closely entangled: communication is not something that just occurs within an organization, because organizations themselves emerge in communication [51]. Hence, social cognition is much more complex than simple sequences of speech acts. The social is constituted by its individuals, whereas individuals are constraint by the social. Social and individual co-enact each other [52, 27, 2]. Having briefly discussed the applicability of quantum interaction it is obvious to extend the entanglement of concepts and contexts toward an ecological approach to social interactions. Conversations between actors are constituted in movement and doings which disclose the social context. Therefore, we will devise a semi-formalism to entangle intentional acts (contexts) and their propositional content (concepts) associated with those acts (cf. Section 3.1). In SOM (cf. Figure 2), conversations are modelled as the sequence of transactions or intentional acts. Hence, integrating intentional acts, whether perceptual or cognitive, with the mathematical structure of quantum interaction allows to account for context and thus for the spontaneous generation of meaning in negotiations between autonomous actors. For example, a concept such as an offer has a different meaning in the context of initiating transactions than in the context of contracting transactions. In the initial phase of negotiations offers are without any obligations. However, once commitments are made new properties emerge transforming an offer to an order. Order management occurs in a different context where individualized orders might not just be reducible to their compounds but also need reference to the social context from which they emerged. As the social context changes, concepts acquire new meaning on the fly. Hence, the scope and flexibility of concepts extends toward complex networks of contextualized concepts brought forth by autonmous actors in action and movement. In the first place, we will focus on re-presentational acts, in particualar speech acts, thus taking action in perception for granted. However, due to the context-sensitivty of quantum interaction this does not undermine the rejection of representations.

With respect to the entanglement of concepts and their meaning, the State-Context-Property (SCOP) theory draws from quantum mechanics and provides an ecological approach to modelling [1, 3, 4]. It supports the non-representational contextualization of concepts as well as combination mechanisms and similarity (compatibility and correlation) measurements between concepts. Several empirical tests have been conducted so far. Results are promising as they validate the predictive value of quantum formalisms in the context of human categorisation tasks, e.g. deciding typicality of exemplars and applicability of properties. In merging SOM and SCOP the context-sensitive nature of interaction design will significantly contribute to more accurate conceptual models.

5 Conclusion and Future Work

The increasing importance of designing spaces for human communication and interaction will lead to expansion in those aspects of computing that are focused on people, rather than machinery [53]. In this paper, it was argued against representational modelling and its preconceptions as it is still omnipresent in many disciplines [54]. Information systems are social systems with autonomous actors interacting in a context-sensitive way. Action-oriented modelling looks at information systems from an inside view in a non-representational fashion. It was argued that speech acts despite being actions emerge from a more fundamental mechanism which is sensorimotor activity or motor intentionality [55]. Irrespective of action in perception or action in language, ecological modelling understands concepts not as identifiers rather than bridges between the illusory mind-world duality. Meaning of concepts emerges through interactions with elements generally considered external to them. Eventually, actions, measurements, observations, doings, movements etc. actualize meaning in disclosing the external.

We are about to design a case study with several actors communicating via intentional acts. As negotiations are highly susceptible to change, especially during initiating and contracting phases we want to substantiate the context-sensitive and associative nature of complex interactions. In this process, we will devise guidelines and semi-formalisms supporting interaction modellers in the design of ecosystems.

References

1. Gabora, L., Rosch, E., Aerts, D.: Toward an ecological theory of concepts. Ecological Psychology **20(1)** (2008) 84–116
2. Varela, F., Thompson, E., Rosch, E.: The Embodied Mind - Cognitive Science and Human Experience. MIT Press (1991)
3. Gabora, L., Aerts, D.: Contextualizing concepts using a mathematical generalization of the quantum formalism. Journal of Experimental and Theoretical Artificial Intelligence **14(4)** (2002) 327–358
4. Gabora, L., Aerts, D.: Contextualizing concepts. In: Proceedings of the 15th International FLAIRS Conference, Pensacola Florida, May 14-17, 2002, American Association for Artificial Intelligence. (2002)
5. Komatsu, L.: Recent views of conceptual structure. Psychological Bulletin **112** (1992) 500–526
6. Smith, E., Medin, D.: Categories and concepts. Cambridge, MA: Harvard University Press (1981)
7. Gerrig, R., Murphy, G.: Contextual influences on the comprehension of complex concepts. Language and Cognitive Processes **7** (1992) 205–230
8. Medin, D., Shoben, E.: Context and structure in conceptual combination. Cognitive Psychology **20** (1988) 158–190
9. Murphy, G., Medin, D.: The role of theories in conceptual coherence. Psychological Review **92** (1985) 289–316.
10. Agerfalk, P.J.: Investigating actability dimensions: a language/action perspective on criteria for information systems evaluation. Interacting with Computers **16:5** (2004) 957–988
11. Dietz, J.L.G.: The Deep Structure of Business Processes. Communications of the ACM **49** (2006) 58–64
12. Ferstl, O.K., Sinz, E.J.: Foundations of Information Systems (In German), 5. Edition. Oldenbourg (2006)
13. Johannesson, P.: A Language/Action Based Approach to Information Modeling. In: Information Modeling in the New Millennium. Idea Group Publishing (2001) 94–109
14. Lyytinen, K.J.: Implications of theories of language for information systems. MIS Quarterly **9:1** (1985) 61–74
15. Weigand, H.: The language/action perspective. Data & Knowledge Engineering **47:3** (2003) 299–300
16. Winograd, T., Flores, F.: Understanding computers and cognition. Ablex Publishing Corp. Norwood, NJ, USA (1986)
17. Austin, J.L.: How to do things with words. Oxford University Press, Cambridge (1962)
18. Searle, J.R.: Speech acts. Cambridge Univ. Press Cambridge (1969)
19. O'Regan, J.K., Noë, A.: A sensorimotor approach to vision and visual consciousness. Behavioural and Brain Sciences **24 (5)** (2001) 939–973
20. O'Regan, J.K., Noë, A.: Acting out our sensory experience. Behavioural and Brain Sciences **24 (5)** (2001) 1011–1031
21. Noë, A.: Action in Perception. MIT Press (2004)

22. Bruza, P.D.: Quantum interaction. AI Magazine, AAAI Press **28 (3)** (2007) 99–101
23. Bruza, P.D., Kitto, K., Nelson, D., McEvoy, C.L.: Entangling words and meaning. In: Proceedings of the Second Quantum Interaction Symposium, Univeristy of Oxford. (2008)
24. Bruza, P.D., Lawless, W., van Rijsbergen, C.J., Sofge, D., Coecke, B., Clark, S., eds.: Proceedings of the Second Quantum Interaction Symposium, Univeristy of Oxford, College Publications (2008)
25. Gibson, J.J.: The ecological approach to visual perception. Boston: Houghton-Mifflin. (1979)
26. Winograd, T.: Designing a new foundation for design. Communications of the ACM **49:5** (2006) 71–74
27. Thompson, E.: Mind in Life - Biology, Phenomenology and the Sciences of Mind. Harvard University Press (2007)
28. Sutcliffe, J.: Concepts, Class and Category in the Tradition of Aristotle. In: Categories and Concepts: Theoretical Views and Inductive Data Analysis. London: Academic Press (1993) 36–65
29. Rosch, E.: Prototype Classification and Logical Classification: The two systems. In: New Trends in Conceptual Representation: Challenges to Piagets Theory? Hillsdale NJ: Erlbaum (1983) 73–86
30. Barsalou, L.W.: On the Indistinguishability of Exemplar Memory and Abstraction in Category Representation. In: Advances in Social Cognition, Vol. III, Content and Process Specificity in the Effects of Prior Experiences. Hillsdale, NJ: Erlbaum (1990) 61–88
31. Rosch, E.: Reclaiming concepts. Journal of Consciousness Studies **6(11)** (1999) 61–78
32. Rosch, E.: Principles of Categorization. In: In Cognition and Categorization. Hillsdale, NJ: Erlbaum (1978) 27–48
33. Rosch, E.: Cognitive reference points. Cognitive Psychology **7** (1975) 532–547
34. Nosofsky, R.: Exemplars, prototypes, and similarity rules. In Healy, A., Kosslyn, S., Shiffrin, R., eds.: From Learning Theory to Connectionist Theory: Essays in Honor of William K. Estes. Volume 1., Hillsdale NJ: Lawrence Erlbaum (1992) 149–167
35. Nosofsky, R.: Exemplar-based accounts of relations between classification, recognition, and typicality. Journal of Experimental Psychology: Learning, Memory, and Cognition **14** (1988) 700–708
36. James, W.: The Principles of Psychology. New York: Dover ((1890/1950))
37. Piaget, J.: The Language and Thought of the Child. London: Routledge & Kegan Paul (1926)
38. Storms, G., De Boeck, P., Van Mechelen, I., Ruts, W.: Not guppies, nor goldfish, but tumble dryers, noriega, jesse jackson, panties, car crashes, bird books, and stevie wonder. Memory and Cognition **26** (1998) 143–145
39. Chen, P.: The Entity-Relationship Model-Toward a Unified View of Data. ACM Transactions on Database Systems **1** (1976) 9–36
40. Agerfalk, P.J., Eriksson, O.: Action-oriented conceptual modelling. European Journal of Information Systems **13** (2004) 80–92
41. Poerkson, B., Maturana, H.: From Being to Doing. Carl-Auer (2004)
42. Booch, G.: Object-oriented analysis and design with applications. Benjamin-Cummings Publishing Co., Inc. Redwood City, CA, USA (1993)
43. Maturana, H., Varela, F.: Autopoiesis and Cognition - The Realization of the Living. Dordrecht, Boston, London, D. Publishing Company (1980)

44. Rudrauf, D., Lutz, A., Cosmelli, D., Lachaux, J.P., van Quyen, M.L.: From autopoiesis to neurophenomenology: Francisco varela's exploration of the biophysics of being. Biological Research **36** (2003) 27–65
45. Thompson, E.: Sensorimotor subjectivity and the enactive approach to experience. Phenomenology and the Cognitive Sciences **4** (2005) 407–427
46. Torrance, S.: In search of the enactive: Introduction to special issue on enactive experience. Phenomenology and the Cognitive Sciences **4** (2004) 357–368
47. Bruza, P.D., Cole, R.: Quantum logic of semantic space: An exploratory investigation of context effects in practical reasoning. In Artemov, S., Barringer, H., d'Avila Garcez, A., Woods, J., eds.: We Will Show Them: Essays in Honour of Dov Gabbay, College Publications (2005) 339–361
48. Busemeyer, J.R., Wang, Z., Townsend, J.T.: Quantum dynamics of human decision making. Journal of Mathematical Psychology **50** (2006) 220–242
49. Aerts, D., Gabora, L.: A state-context-property model of concepts and their combinations ii: A hilbert space representation. Kybernetes **34(1&2)** (2005) 192–221
50. Weigand, H.: Two decades of the language-action perspective. Communications of the ACM **49:5** (2006) 44–46
51. Taylor, J.: Rethinking the Theory of Organizational Communication: How to Read an Organization. Ablex, Norwood (1993)
52. Jaegher, H.D., Paolo, E.A.D.: Participatory sense-making: An enactive approach to social cognition. Phenomenology and the Cognitive Sciences **6(4)** (2007) 485 –507
53. Winograd, T.: The design of interaction. In: Beyond Calculation, The Next 50 Years of Computing. Springer-Verlag (1997)
54. Riegler, A., Peschl, M., von Stein, A.: Understanding representation in the cognitive sciences. Dordrecht Holland: Kluwer Academic (1999)
55. Merleau-Ponty, M.: Phenomenology of Perception. Translated by Colin Smith. London: Routledge Press (1962)