Grounding Knowledge of Engineering Applications in Systematic Terms

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Abstract. In the main research of internet-computing enabled knowledge management, we use some of the most advanced research scenarios, arguing that we critically need a system approach to question where knowledge comes from. In particular, within a given engineering domain, we synthesis the problems and reveal, that the knowledge is embraced by interactions among systems, system observers, observables, engineering objects and instruments; that the complex system interactions must be dispatched into infrastructural layers based on physics-ontologies; that the ontologies must be dedicated to human and data communications. Such a synthesis would impact on knowledge technologies for solving engineering problems in scalabilities, as well as in collective vocabularies that must associate with the communication crossing the layers in the problem solving environment.

1 Introduction

A crucial object to study seems to be missing in the mainstream concept of internet computing enabled knowledge management[1] (KM): where is the knowledge? Many conceded that there must be an emphasis on tools and rules for KM that is out of step with human modes of capturing, sharing, processing and determining information in business organisations [17], [7], [27]. Moreover, Wilson concludes that KM is nonsense as a field of management consultancy practice after extensively surveyed journal literatures and reports from Accenture, Cap Gemini Ernst and Young, Deloitte and Touche, Ernst and Young, KPMG Consulting, McKinsey and Company, and PricewaterhouseCoopers [42]. But, what about KM for solving problems in an engineering domain, e.g., [38], [20], [21], [22]?

Engineering is a human effort to change or facilitate a kind of environment in order to make that environment more suitable or responsive to perceived human needs and wants. Such an effort results many kinds of physical outputs; it may define, design, develop or maintain a system. Many actors take part in engineering. One group are engineers; others are managers; still others are ones who create artifacts such as numerical models according to specifications. Much knowledge is derived from human observations, designs and experiments. They all only know what they know when they need to know it. From a computing perspective, the KM must have its meta-systems in whatever forms showing how knowledge is *grounded* from a level of engineering to a level of business organisation that manages the engineering processes. At either level, the KM research must recognise the importance of methodological inter-disciplinarity, so the research can be continued and making sense [6]. There are lengthy discussions on understandings of the notion “engineering”[2], “knowledge”[3] or (symbolic) “grounding”[4]. However, to address the problems more adequately, this paper uses some advanced research scenarios and cases, arguing that we critically need a system approach to open up the “where” question, so as to reconcile some multi-disciplinary differences to enable researchers to cross the invisible boundaries, rather than continue a research in isolation from one another. As Popper noted [23]:

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[1] A report of over 100 pages surveyed and studied systems, products and methods that challenge the knowledge sharing [39], where the author, Dave Snowden, a director of IBM's newly created Cynefin Centre for Organisational Complexity and formerly a director of IBM’s Institute for Knowledge Management, calls for the third generation of knowledge management making sense models with adaptive systems theory [35]; Also, see, the book 'The Knowledge Management Fieldbook' [3].

[2] See, e.g., [30], [9], [24], [40].

[3] See, e.g., [13], [1], [15], [4], [19], [8].

[4] See, e.g., [2], [29], [44], [12], [14].

> "studies or disciplines are distinguishable by the subject matter which they investigate, [this] appears to me to be a residue from the time when one believed that a theory had to proceed from a definition of its own subject matter… But all this classification and distinction is a comparatively unimportant and superficial affair. We are not students of some subject matter but students of problems. And problems may cut right across the borders of any subject matter or discipline".

Indeed, subjects in KM are increasingly diversified; so are the objects to study. Many technologies are under developing on one hand, but on the other are piled up, not added up inter-relatedly, because making the technologies deployable by one another is not that obviouse. Once a new research program is initiated, it becomes very difficult to establish a feasible framework to orientate the research. See, e.g., the lessons [23]. The position of this paper is that, in an engineering domain, knowledge is grounded in a coherent infrastructure interacting with humans, systems, data, experiments, organised communications, objects to achieve or problems to solve, as well as tools that support all this, including computers, the web, and data networks. In the systematic terms (we here use to simplify the following discussions), knowledge is embraced by interactions[5] among systems, system observers, observables, engineering objects, and instruments; knowledge is embodied in observers primarily and embedded in layers and tiers of data and human communication infrastructures; knowledge is usable only if it flows via the infrastructures and outsourced during problem solving processes[6]. The rest of the paper is organised into three parts.

First we illustrate that there are ongoing computing research themes on the KM that are largely diversified, but equally important to engineering applications. Second, in order to identify the critical problems, we review some systematic notions. Third, by using the notions, we intend to describe how the knowledge is derived from the various interactions.

2. Is Knowledge …

2.1... from computing technologies? …

One of the foremost objectives for computing research advancing KM today is to provide means, on account of advantages for developing the web driven technologies, to serve the needs for knowledge pervasively in a problem-solving environment (PSE)[7]. As an investigation of a realisation proceeds to achieve this end, a given computing application often shows many facets in large scales. For example, a UK e-Science program has recently argued the case for creating new types of digital libraries for automating the process from flooded raw data to knowledge. The web services, the semantic web, ontologies, meta-data, data archiving, data mining, Grid computing and middleware, multi-agents, pervasive computing, artificial intelligence, digital libraries, etc. are all deployed [10].

2.2.… from data? …

As a case of engineering knowledge from data, or of data mining so to speak, Rolls-Royce places itself on the knowledge technologies of the future with a multi-million pounds project with AKT (Advanced Knowledge Technologies). Another £3m grid-computing research, namely, Distributed Aircraft Maintenance Environment (Dame) project is initiated for developing technologies in two areas [5, p. 12]:

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[5] The term "system interactions" is studied in [21] for managing software production, and, for developing decision support systems in water resources management [20].

[6] In [16], Hull even views science as a process.

[7] In [46], a PSE is described as a computer system that provides all the computational facilities needed to solve a target class of problems. These features include advanced solution methods, automatic and semiautomatic selection of solution methods, and ways to easily incorporate novel solution methods. Moreover, PSEs use the language of the target class of problems, so users can run them without specialized knowledge of the underlying computer hardware or software. By exploiting modern technologies such as interactive colour graphics, powerful processors, and networks of specialized services, PSEs can track extended problem-solving tasks and allow users to review them easily. Overall, they create a framework that is all things to all people: they solve simple or complex problems, support rapid prototyping or detailed analysis, and can be used in introductory education or at the frontiers of science.

a) collecting real-time engine diagnostics while the plain is in flight and analysing the vast amounts of data gathered from the thousands of Roll-Royce engines used around the world, and
b) finding out the last time an engine went “bump” and “squeak” when a field in the database called “bump” or “squeak” cannot be found. What should also be found is all the conditions before and after what happened on the engine.

2.3.… from human?

Human problem solving is done within a context which constrains the solution space. It is human who needs the knowledge to solve a problem in that context, and knows what is known by means of data analysis, experiences, perceptions, communication, experimentation, reasoning or other kinds of cognitive processes. Considering the Rolls-Royce case mentioned above, we have a relative environment and an absolute environment. If a system to be maintained is as it is from our own knowing perspective, we are in a relative environment. If a system to be maintained is as it is in itself, we are in an absolute environment. Maintenance engineers are constantly involved in both environments. Thus, the two environments are coherent with the engineers.

3 Back to the Basics: Some Concepts, Principles and Notions

But before coming to the position that knowledge is grounded in a coherent infrastructure of all the interactions on the dimensions in section 2, we need to review some systematic concepts, principles and notions[8].

3.1 Some System Concepts and Principles

System methodology has been widely employed in solving many kinds of problems: from the concern for classic engineering analysis, such as flow of matter and/or energy, to the concern for modern-day controlling communications, such as information. Hence, for a research strategy, it forces one to look at a problem in its entirety. To contribute KM research in particular, it interrelates a large range of engineering processes which appear to be derived from different domains on one hand, but on the other, have to be constricted under different disciplines for the same objectives, and to be managed within one frame – a real or abstract simplification of the problems situated in a problem solving environment.

> <u>Def</u> *1: A system is a collection of components, also called parts, either physical or non-physical in nature, that a) exhibit a set of interrelations among themselves and interact together towards on or more goals; b) exhibit properties processed differently from the collection of properties processes by the individual parts.*

Let us now consider a system in terms of engineering. In other words, a system is now considered as an object to engineer. Thus, a consideration of a system is encompassed by the most important objects or classes of objects that an engineering effort targets, including, for example,

a) a product that is to be delivered to users after completion of the necessary engineering processes;
b) the engineering processes that have to shape the product itself, such as establishments or requirements’ elicitation.

> <u>Def</u> *2: A system observer is someone who starts with something for some reason of his own intentions to describe that ?something? holistically, that is to say, in terms of whole elements linked in hierarchies.*

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[8] Cybernetics as a field of system research has thoughly come into studying the nature of knowledge. See a good web site http://www.pangaro.com/published/cyber-macmillan.html. Here we only review the system notions for further practice-aspiration.

But, a system must be observable. For example, if there were no data coming from an engine, there would be nothing to tell about the state of that engine.

Def 3: A system observable is a piece of information that a system observer perceives and believes that it tells something about the system that the observer observes.

Def 4: An observing instrument is anything by which that a system observer is aided to obtain a system's observable.

From Def 1-4, we have the following principles:

Principle 1: A system has no existence independent of its system observer

Principle 2: A system observable must exist between a system and its system observer.

Principle3: In order to "see" a system, a system observer of that system often needs an instrument.

Now let us briefly review a few technological notions.

3.2 The Web Ontology

The notion ontology has a long history in philosophy, where ontology is about a systematic account of beings, or existence of things, or to being in the abstract as a "reality". Science has shown a reality that is structured all the way down. At bottom it consists not of four types of gunk: earth, water, air, and fire, but rather of a finite number of definite particles, lawfully related one to the other [45]. Then, it comes to the hope that we might build up substantial information about our world from the elementary information we find at the bottom of reality. So, the ontology in terms of philosophy is a theory of arguing and explaining. The term 'ontology' has been used in this way for a number of years by the artificial intelligence and knowledge representation community, but is now becoming part of the standard terminology of a much wide community including object modelling and XML [27]. The key ingredients that make up the web ontology are vocabularies of basic terms and a precise specification of what those terms mean. Numerous researchers believe that the web ontology can be the useful tools for the following reasons (revised from [11]):

a) The web ontology is more than an agreed vocabulary. It provides a set of well-founded constructs that can be leveraged to build meaningful higher level knowledge. The terms in ontology are selected with great care, ensuring that the most basic (abstract) foundational concepts and distinctions are defined and specified. The terms chosen form a complete set, whose relationship one to another is defined using formal techniques. It is these formally defined relationships that provide the semantic basis for the terminology chosen.

b) The web ontology is more than a taxonomy or classification of terms. Although taxonomy contributes to the semantics of a term in a vocabulary, the web ontology includes richer relationships between terms. It is these rich relationships that enable the expression of domain-specific knowledge, without the need to include domain-specific terms.

The last notion we need to explain here is "infrastructure".

3.3 The Infrastructure

Infrastructure seems to be singularly boring as an object for scientists to study. It is often referred to as a list of technical specifications, black boxes, places, wires, plugs, roads, bridges, stations, etc. Infrastructuring is usually seen as an engineering work to establish public services and utilities for social communities. Roads, railways, bridges, pipe lines, electricity, etc. are instances of social infrastructures. Because of the world's technical sound, people now use the term infrastructure to refer to any substructure or underlying structure of systems [36] - most notably the information superhighway - the global information and communication infrastructure of networks that include the

Internet, WWW, telephone networks, cable, satellite, wireless, or electronic sensor based data networks. These are the backbone infrastructures of our electronic communications today. The web is a collection of interlinked electronic items including documents, texts, images, music files, video, etc. hosted on servers all over the world, mostly hosted on HTTP (Hyper Transfer Protocol) servers [33]. The web lives on the internet by a set of protocols running over the net. Although the web is part of the net, the net is much larger than the web. The net hosts e-mail, FTP, peer-to-peer, VPNs, telephony, etc. So, there are software coded layers and tiers driven by the web: servers, clients, peers, portals, gateways, or protocols as many as the technical approaches and tools to design them, most notably, XML/RDF, the metadata, the semantic web, the web service, and the web ontology.

4 Knowledge Grounding

In this section, we use the notions defined to describe where the knowledge comes from. Again, we use the Rolls-Royce case in section 3.2. Reportedly, the case is significant [5], because some 44 per cent of Rolls-Royce's revenue comes from the maintenance and servicing of its engines in aircraft, ships and power stations. Instead of selling engines to airlines, the firm charges for use of the trusted they provide, on a "power by the hour" basis. The sooner engineers can be made aware of problems, the quicker they can be resolved and the longer a plane can spend in the air, earning the money for the supplier. Thus, the advent of the web driven KM technologies has presented huge opportunities for the operational improvements. The foremost objective in achieving this is to provide the latest and evidential information indicating the system's conditions, so to improve the efficiency of the operational processes taking place pervasively and, in turn, to have significant cuts in the cost of the maintenance. However, this strategic vision needs to have a more careful justification for research into more dedicated infrastructures.

4.1 In Physics Based Infrastructure

At this layer, the purpose of system diagnostics or monitoring is to reduce actions taken on the basis of judgements made from directly measured or inferentially calculated information with varying degrees of emphasis dictated by the needs and capabilities of their individual organisations. Engineers are interested in both determination of initially installed system's condition and in condition throughout the operation phase.

Intrinsically, the maintenance processes are rarely repetitive in the same manner as normal operational tasks. The processes do not lend themselves to systemisation and computerisation. Specifically, in an absolute environment referred in section 2.3, advances in sensor technologies, instrumentation, microprocessor-based controllers are increasingly used [25], [41]. Networks of sensory or actuator nodes with computational capabilities, connected wirelessly or by wires are getting much cheaper. Components are increasingly complex in structures and functions, but becoming more and more reliable. Only the down-time experienced can be very large. Taking all this into an account, engineers often face unknown or known problems that require various skills, kinds of information and knowledge through the interactions among (see, Def 1 – Def 5):

a) systems to be observed: an engine turbine and its properties as such time, functions, conditions, or states;
b) observers: engineers; engineering objects, acceptable engine conditions;
c) instruments: sensors, test appliances, computers, data process software, engine monitors;
d) observables: data artefacts, time series data patterns.

Let us assume there are web ontologies in this type of physics based infrastructure; we call the ontologies "physics -ontologies". We then have a layer of physics-ontology-infrastructure.

4.2 In Physics-ontology-infrastructure

By the notion "web ontology", the key ingredients that make up ontology are vocabularies of basic terms and a precise specification of what those terms mean. But abstracting the vocabularies and their relationships is only one way to support human communications. To make the ontology operational on persistent tiers and layers of infrastructures is something entirely different. It is on these layers where data are collected, distributed and measured; that reports are circulated; and that groups are participating and communicating with one another. Data in a physics based infrastructure cannot be explained merely as a consequence of a differing coherence of an utterance. They depend on who makes the utterance, where the sensors are situated, where the data are channelled, how the data are stored and filtered, or what methods are used to understand and explain an observed phenomena.

Thus, the web ontology must be systematically constrained by the physics based infrastructure as Kharkov has also studied [18]. The priori knowledge for the ontology design must be closely inherent to understandings of physical systems, as well as practical experience with the systems. A problem solving process for a given application can then be supported by the "content" of the priori system information. The third interactive layer is human oriented. We note this as human-physics-ontology-human communication infrastructure.

4.3 In human-physics-ontology-human communication infrastructure

At a level of management, the system maintenance is extremely critical for industrial companies to sustain their productivity. An engine's maintenance is no longer just a traditional event of a repair – call an engineer in with parts and tools to fix it. It is a matter of how to detect the first sign from the engine, so something is known priorily if there is a need for preventing the "disasters". This is the essential idea behind the method called condition based maintenance [43].

Whether to proceed with the emergency repair may well be informed by the effects on the bottom line in the physics-based infrastructure. Maintenance can be based on equipment run times and starts and stops thus providing the basis for predictable maintenance. Engineers can properly analyze equipment failures and forecast the probability of the same equipment failing in the same plant or other business units, or undertake the processes, such as data collection, data clustering, testing, fault or defect diagnosis, planning spare parts, making recommendations, reporting major factors affecting a system' s life, all in a technical and timely manner.

All the web layers are meaningful and usable only when a system observer participants in a particular communication [34]. Whether a maintenance engineer can exploit in elliptical or anaphoric resolution is depending in part on the role that the engineer has most recently played in the communication in the physics-based infrastructure. As Quine remarkably observed and his points are still significantly relevant for today [32]:

> "the things in sharpest focus are the things that are public enough to be talked of publicly, …., and near enough to sense to be quickly identified and learned by name and labels; Moreover, a common sense talk of physical things often goes forward without benefit of explanations in more intimately experimental terms. …If we improve our understanding of ordinary talk of physical things, it will not be by reducing that talk to a more familiar idiom; There is none. It will be by clarifying the connections, causal or otherwise, between ordinary talk of physical things and various further matters which in turn we grasp with help of ordinary talk of physical things" .

5 Conclusion

To reconcile some multi-disciplinary differences and to cross the invisible research boundaries in KM research, system methodologies enable us to dispatch the complex knowledge grounding contextures into hybrid infrastructural layers. In an engineering domain, knowledge is embraced by interactions among system observers, systems, observables, engineering objects, and instruments. Knowledge is embodied in observers primarily, embedded in layers and tiers of infrastructures, and only usable if it flows via the infrastructures and outsourced during a problem solving process. KM requires such an infrastructure as a higher order system environment to be understood and controlled, so as to dedicate KM methods, solutions and practice to a problem solving process. Such a system synthesis is crucial for KM; it considerably impacts on a) a system scalability for a given application, b) a level and a scope of ontology design, and c) collective vocabularies in ontology design that must associate with meanings to be understood within the infrastructures.

References

1. Benrnecker, S & Dretske, F.: Knowledge – Readings in Contemporary Epistemology. Oxford University Press (2000)
2. Bryant, A.: Grounding Systems Research: Re-establishing Grounded Theory. In: Proceedings of the 35th Hawaii International Conference on System Science, IEEE Computer Society Press (2002)
3. Bukowitz, W. R., Williams, R. L.: The Knowledge Management Fieldbook. Financial Times-Prentice Hall (2001)
4. Compbell, D. T.: From Evolutionary Epistemology via Selection Theory to a Sociology of Scientific Validity. *Evolution and Cognition (1997)* 3, p. 5-38
5. Computing: Rolls-Royce Is Confident Grid Technology Will Earn its Wings. Written by Bryan Glick, *Computing*, 30 April (2003)
6. Dervin, B.: Human Studies and User Studies: a Call for Methodological Inter-disciplinarity. *Information Research*, Vol. 9 No. 1, October (2003)
7. [Does KM=IT? Hompage], http://www.brint.com/advisor/a091599.htm
8. Dretske, F.: Knowledge and the Flow of Information. Basil Blackwell (1981)
9. Dym, C.: Engineering Design: A Synthesis of Views. New York: Cambridge University Press (1998) p. 15
10. eSI-Report: Scientific Data, Mining, Integration, and Visulization. In: Mann, B., Williams, R., Atkinson, M., Brodlie, K, Storkey, A. & Williams, C.: Report of the Workshop Held at the e-Science Institute. Edinburgh, 24-25 October (2002) http://www.cacr.caltech.edu/~roy/papers/sdmiv-ltr.pdf
11. Fensel, D.: Ontologies: Silver Bullet for Knowledge Management and Electronic Commerce. SpringerVerlag (2001)
12. Galison, P.: Contexts and Constraints. In: Buchwald, J. Z. (eds.): Scientific Practice: Theories and Stories of Doing Physics. Chicago, University of Chicago Press (1995)
13. Gennari, J. H., Musen, M. A., Fergerson, R. W., Grosso, W. E., Crubezy, M., Eriksson, H., Noy, N. F., Tu, S., W.: The Evolution of Pretege: an Environment for Knowledge-based Systems Development. *Int. J. Human-Computer Studies*, 58 (2003) 89-123
14. Harnad, S.: The Symbol Grounding Problem. *Physica*, D 42 (1990) 335-346
15. Hooker, C. A., Christensen, W. D.: The Organisation of Knowing: Autonomy, Evolution, and Evolutionary Epistemology. In: Festschrift for Donald T. Campbell, Hays, C. & Hull D (eds.). Chicago: University of Chicago Press (1998)
16. Hull, D.: Science as a Process. Chicago, University of Chicago Press (1988)
17. IBM: Next Generation Knowledge Management: The complexity of Humans. Executive Tek Report, *IBM Global Services*, 13 November (2002) http://www.ibm.com/services/files/etr_cynefin.pdf
18. Kharkov: Ontology Development for Gas Compressing Equipment Diagnostics Realized by Neural Networks. Report on System Development Project, Kharkov's Branch, Artifical Intelligence Department, Industrial Ontologies Group, The Ministry of Education and Science of Ukraine, Kharkov National University of Radioelectronics, Ukraine 2003) http://www.cs.jyu.fi/ai/OntoGroup/NN_Ontologies.pdf
19. Levinson, P.: Mind and Large: Knowledge in the Technological Age. Jai Press INC (1998)
20. Liu, Y., Veer, vd.P.: To Approaching an Intelligent System in Coping with an Aspect of Complexity. In: Proc. of the 1993 ACM Symposium on Applied Computing, Indianapolis (1993)
21. Liu, Y.: Treating the Interactions Systematically. *Software Engineering J.*, IEE/BCS Press, March (1994)
22. Liu, Y.: Decision Support Environment for Engineering Use", In: Blain, W. R., Katsifarakis, K. L. (eds.): Water Resources and Distribution. Computational Mechanics Publications (1994)
23. Liu, Y.: Geo-referenced Digital Libraries: Experienced Problems of Purpose and Infrastructure. *Library Philosophy and Practice*, Vol. 6, No. 1, Fall (2003) http://www.webpages.uidaho.edu/~mbolin/liu.pdf

24. Mitcham, C.: Thinking through Technology: The Path between Engineering and Philosophy", Chicago: University of Chicago Press (1994) p. 19-38
25. Muruganandam, T. M., Kim, B., Olsen, R., Patel, M., Romig, Seitzman, J. M.: Chemiluminescence Based Sensors for Turbine Engines. In: 39th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, AIAA 2003-4490, Huntsville, Alabama, USA, 20-23, July (2003)
26. Nalhotra, Y., Is Knowledge Management Really on Oxymoron? Unravelling the Role of Organizational Controls in Knowledge Management. In: White, D. (ed.): Knowledge Mapping and Management. Hershey, PA: Idea Group Publishing (2002) p. 1-13 http://www.brint.org/KMOxymoron.pdf
27. Nambiar, U., Bressan, S., Lee, M. L., Li, Y-G.: Current Approaches to XML Management. *IEEE Internet Computing*, July-August (2002)
28. Vesilind, P. A., Alastair, S.: Gunn, Engineering, Ethics, and the Environment. New York: Cambridge University Press (1998)
29. Paek, T.: Grounding Criterion: Toward a Formal Theory of Grounding. Technical Report, MSR-TR-2000-40, Microsoft Research, Microsoft Corporation, Redmond, WA 98052, USA (2000)
30. Podgorecki, A., Alexander, J., Shields, R. (eds.): Social engineering. Carleton University Press (1996)
31. Popper, K.: Conjectures and Refutations – The Growth of Scientific Knowledge. London and Henley, Routledge and Kengan Paul (1963)
32. Quine, W.v. O.: Word and Object. MIT Press (1960)
33. Schatz, B. R., Hardin, J. B.: NCSA Mosaic and the World Wide Web: Global Hypermedia Protocols for the Internet", *Science Magazine*, Vol. 265, 12 August (1994) 895-901
34. Siebes, R.: Peer to Peer Solutions in the Semantic Web Context: An Overview", EU-IST Project Report, IST-2001-34103 SWAP, Vrije Universiteit Amsterdam, Holland (2002)
35. Snowden, D.: Complex Acts of Knowledge: Paradox and Descriptive Self-awareness. *J. of Knowledge Management*, Vol 6, No. 2. (2002) http://research.microsoft.com/users/timpaek/Papers/MSR-TR-2000-40.pdf
36. Star, S. L.: Got infrastructure? How Standards, Categories and Other Aspects of Infrastructure Influence Communication: In: *the 2nd Social Study of IT Workshop at the LSE ICT and Globalization*, London, 22-23 April
37. Yu, J., Hunter, J., Reiter, E., Sripada, S.: An Approach to Generating Summaries of Time Series Data in the Gas Turbine Domain", In: Proceeding of ICII2001 (Beijing), IEEE Press, p. 44-51, Received 'Outstanding Paper' award at ICII2001 (2001)
38. Yu, J., Reiter, E., Hunter, J. & Sripada, S., SumTime-turbine: A knowledge-based System to Communicate Time Series Data in the Gas Turbine Domain. In: IEA/AIE-2003 (The 16th International Conference on Industrial & Engineering Applications of Artificial Intelligence and Expert Systems) (2003)
39. White-Paper (2002): The Knowledge Sharing Challenge. The Sensemaking White Paper. http://www2.parc.com/istl/groups/hdi/papers/ sensemaking-whitepaper.pdf
40. Wiener, N. (1989)[1950], The Human Use of Human Beings. London, Free Association Books (1989)[1950]
41. Wild, P.: Industrial Sensors and Applications for Condition Monitoring", London: Mech. Eng. Publishing (1994)
42. Wilson, T. D.: The Nonesense of Knowledge Management. *Information Research*, Vol. 8, No. 1. October (2002)
43. Wireman, T.: Computerized Maintenance Management Systems. Industrial Press, Inc (2003)
44. Ziemke, T.: Re-thinking Grounding. In: Riegler, A.., Peschi, M (eds): Does Representation Need Reality? – Proceedings of the international conference 'New trends in cognitive science (NTCS 97), (1997) p. 87-94
45. Zimmerman, D. W.: Could Extended Objects be Made Out of sSmple Parts? An argument for 'atomless gunk", *Philosophy and Phenomenological Research*, 51 (1996) 1-29
46. Houstis, E., Gallopoulos, E., Bramley, R., & Rice, J. (eds., Problem-solving Environments for Computational Sicence. *IEEE Computational Science & Engineering,* special issue, July/September (1997)