International Journal of Computer Science and Applications,

Vol. 9, No. 2, pp. 42 – 52, 2012

LOGICAL FIBERING AND KNOWLEDGE BASES

JACQUES CALMET

Karlsruhe Institute of Technology, Institute IKS, Am Fasanengarten 5,
Karlsruhe, 76131, Germany
calmet@ira.uka.de
http://sites.google.com/site/jfcalmet/

MARVIN OLIVER SCHNEIDER

University of São Paulo at São Carlos, Institute ICMC, Av. Trabalhador São Carlense 400,
São Carlos,13560-970, Brazil
marvin.schneider@gmail.com
http://www.marvinschneider.com

The present paper introduces a method of grasping knowledge and cooperation over a series of domains in a systematic manner by the application of a multi-agent model. After general considerations about motivation and the possibility of the mechanization of mathematics, related work is discussed. We provide an insight into the abstractions ABIT (Abstraction Based Information Technology) and the more agent-oriented variation AOA (Agent Oriented Abstraction Model). Finally an implementation via Virtual Knowledge Communities is presented, basing data management and interaction on the principles of Logical Fibering. The present work is meant to present a fundamental contribution to a more intelligent management of knowledge and the establishment of trust in virtual communities.

Keywords: Agent Oriented Abstraction Model; Virtual Knowledge Communities; Logical Fibering; Knowledge Base; Cognitive Trust.

1. Introduction

"The world is drowning in data, but lacks knowledge", also called "data paradox" (e.g. as in Messatfa et al., 2011) is a common-sense feeling on what is happening through ever larger distribution of data and noise, which cause more distraction than information or knowledge in itself. To mine data effectively appears to be a greater challenge and a series of straightforward approaches are being developed to try to fix somehow this pressing problem.

It may seem trivial to think of Artificial Intelligence methods to help in this aspect, the only remaining questions is how, for instance, Data Mining or Artificial Neural Networks could possibly be of benefit in situations, which are far more complex than their narrow, technical scope. Especially in the fields of human sciences their scopes do not seem wide enough to catch the necessary characteristics.

The present approach shows a novel way of modeling knowledge through an Agent Oriented Abstraction Model (AOA), implementing it via Virtual Knowledge

Communities and using Logical Fibering as proposed by Pfalzgraf (2000) to provide an intelligent dynamic data structure.

Logical Fibering can be seen as a methodology in symbolic computation. We have thus a direct link between symbolic computation and AI.

There is an extensive literature on trust in virtual communities. However, there is, to the best of our knowledge, no common grounds between these approaches and the one we develop, as illustrated by two references among many possible ones (Burauskas and Aldama, 2008; Hailes and Abdul-Rahman, 2000).

The main result of this paper is to present the theoretical framework of our approach. Parts of this work has been previously published as shown by the citations but, the originality of this contribution lies in its new organization, the definition of the specification of a semantics for knowledge bases and the introduction of Logical Fibering as a key tool to enable communication among knowledge bases.

2. Motivation

The current world is living a moment of extraordinary empowerment and globalization through the force of information technology. The use of information technology and especially the Internet has been subject of many publications, stating the positive social effect and group building (Raine et al., 2011), the potential to raise quality of life through deep and lasting relations (Leung, 2005) or even its early employment for activism (as in O'Brien, 1999). Many users give considerable highlight to their virtual relationships and efficient communication is definitely in focus whereas the positive social results may be felt the same way as with "offline" interaction. The social component of information technology is significant, just as the knowledge produced by communities, forums, Internet databases or pure individual interaction.

Meanwhile a good way of representation has yet to be found to digest all that information successfully. Computability considerations as those of Gödel and Turing (see Russell and Norvig, 2009), may be judged outdated for this type of scenario. Yet studied in computer science courses, they provide only a mere basis of understanding whereas today's world is in need of a powerful way of representation, beyond data warehouses and classic business intelligence systems.

In this paper we show a way for the use of mathematics in knowledge representation. We furthermore discuss a means of defining trust and culture in a more abstract way in order to be able to arrive at an appropriate model, which could be applied to many different contexts. Trust, is in our case a prerequisite to have the possibility to have access to other individual's knowledge bases. Culture, which is created by the interchange in communities, arises naturally.

Culture, in a real life context, is a central momentum of every society. Rules, written and non-written, are built on it (Moran et al., 2007). Individuals' behavior patterns are based on it and the core of society is nourished by its culture. Knowledge implies thus a behavioral pattern, which is cemented by culture, meaning that knowledge, culture and decision making always go hand in hand. As knowledge is produced at a whole series of different places, culture is a cross- and interdisciplinary issue. Modeling via Logical

Fibering where logics are employed at different places and thus offer different views, appears very feasible and straightforward, as discussed in section 5 below.

A recent book (Castelfranchi, 2010) introduces a socio-cognitive and computational model for trust theory. We propose another attempt inspired by several methodologies arising directly from the mechanization of mathematics. This does not imply that trust is not related to some degrees of belief but it does imply that beliefs are seen as conditions validating a theorem.

3. Mechanization of Mathematics

In the same way as today's computer users are unaware of the greater spectrum of available computational functions (and it is actually wanted by modern software engineering to keep the interface simple and hide details from them, as for instance discussed in the classical book of Pressman, 2001) common people are generally not involved in higher mathematics. To somebody not familiar with the topic, it may even seem that the world may survive without any mathematics at all. This, however, does not at all consider the high influence mathematical knowledge, since the times of Aristotle and before, had on human development. Or, as put by Kline (1964), mathematics has been a major cultural force in western civilizations. The invited talk of Pierre Cartier at CICM 2010 "Can we make Mathematics universal as well as fully reliable?" (CICM, 2010) extends this picture to other cultures. With relation to computing facilities he states that now a "globalization in mathematics" should be reached and that it should become truly universal. Whereas mathematics drives globalization, globalization poses new demands of scalability on mathematics as domains are becoming larger and much fuzzier.

Within this wider and more challenging context we understand that decision making can be interpreted as a theorem proving process. Mathematically speaking, we may see trust as proving a theorem in a cognitive world. As long as we are able to express knowledge formally, trust may be established in an objective, and thus more solid, manner. This approach is inspired by mechanized mathematics. Throughout the further development of this approach, we might furthermore also provide topological paths to interdisciplinarity. For now, this, however, remains beyond the scope of this paper.

4. Abstraction

As the first step in the process we should set up means of abstraction. Abstraction, in our scenario, means to grasp reality through classification of characteristics and thus prepare it to be aptly modeled throughout the subsequent steps of the process. First approaches were the Open Mechanized Reasoning Systems (OMRS) (Giunchiglia et al., 1994), Open Mechanized Computational System (OMCS) (Calmet and Homann, 1996) and Open Mechanized Symbolic Computation System (OMSCS) (Bertoli, Calmet, Giunchiglia, and Homann, 1999). Because of this paper's focus, we will not go into details of each and indicate the references given above for further details. In the following part we provide further information on Abstraction Based Information Technology (ABIT) (Calmet, 2009) and the Agent Oriented Abstraction Model (AOA) (Calmet et al., 2004), which support the further steps of our implementation.

4.1. *Abstraction Based Information Technology*

Abstraction Based Information Technology is a way of understanding knowledge, interaction and control in many different domains. It explicitly covers humanities in this sense whereas the approaches mentioned above remained much more on a purely mathematical and/or computational side for better control and easier modeling.

The concept "ABIT" (Abstraction Based Information Technology) proposed in (Calmet, 2009) consists of:

- A theory, which represents a set of rules and findings over the domain;
- Control mechanisms on the theory, which result in its application in real life and successful interaction. These mechanisms refer to the decision making process.
- The environment, which is the main setting around the domain, defining external influences.

As said, ABIT is valid for any field in science or humanities. In table 1 below we give some examples of classification from the fields of law, philosophy, sociology, business and culture:

Table 1. Abstract definition in different domains.

	Law	Philosophy	Sociology	Business	Culture
Theory	Set of laws	Set of basic laws describing the world	Set of agents with well-defined actions	Corporate knowledge	A theory is an ontology
Control	Application decrees	Interpretation of laws (chapels)	The concept of society arising from this theory	Management of this corporate knowledge	Infer facts on ontology/ decision making process
Environment	Jurisprudence and litigation procedures	Behaviors resulting from the controlled theory	The way society is governed	Virtual networking of enterprises	Setting these facts to specific cultural group

The example of "business" is presented in a quite generic way. It is the one frequently used to solve intercultural differences among Virtual Enterprises, modeling the circumstances respectively.

4.2. *Agent Oriented Abstraction Model*

Knowledge put into a social context is implemented via the successful interaction of natural agents. In analogy, using the Agent Oriented Abstraction Model (AOA), for the representation of knowledge and its implementations we assume a world of agents. AOA is a form of implementation of the wider findings of ABIT. Using AOA, we should firstly define the concept of society which leads to the following definitions, previously proposed by Calmet et al. (2004) and based on Weber's (Mommsen, 2004) approach to sociology as well as game theory by Von Neumann and Morgenstern (1980).

AOA provides six main definitions:

- Definition 1: An agent is an entity made of annotated knowledge coupled to a decision mechanism.
- Definition 2: The decision mechanism of an agent is the process by which an agent can reach its assigned goals. It is based upon the contents of the knowledge component. A decision mechanism is characterized by its utility.
- Definition 3: Knowledge annotations are classes or types structuring the knowledge possessed by or associated to agents.
- Definition 4: The utility of a decision mechanism is a measure of the efficiency of this mechanism. It is structured into utility classes
- Definition 5: A society of agents is the societal organization arising from the actions performed by individual agents in the agent world assigned to a problem.
- Definition 6: A specialization is an implementation of the abstract classes for knowledge or utility.

It is important to stress that definitions 1 to 4 define a theory, definition 5 defines the control on the theory and definition 6 deals with the environment (very different from usual concepts in Multiagent Systems). This demonstrates the link between the technical implementation (AOA) and the overall theoretical level (ABIT).

The next step implies to abstract cognitive bases, where cognitive does not imply solely ontologies. We propose a new abstraction which is based upon types and specifications in analogy with their use in mathematics and computer science.

As in Mathematics, we define a semantic upon 3 concepts:

- Types: the domain of validity of the knowledge. It is possible to have subtypes and an inheritance mechanism.
- Operators on a given domain. They can be of very different nature: classification, simulation, comparison …
- Properties of these operators: such properties can be facts or beliefs.

To illustrate, we should give an example in the field of business:

- Type: virtual enterprise. A possible subtype is: consulting.
- Operators: search for partners or contract writing for instance.
- Properties: what kind of partners, not transitive operation, security constraints and many more.

Several other examples from the domains above could be given, but it should be stressed that their implementation always highly depends on the domain itself and its inherent characteristics, which have to be treated in an individualized manner and not all the same way.

4.3. *Knowledge and Virtual Knowledge Communities*

A technical realization of the above abstraction may be done via Virtual Knowledge Communities (VKC), which aptly model knowledge, interaction (Earl, 2001) and trust as we define it.

VKC's, being similar to online forums as we know them from the Internet, are places where agents (humans or software) meet in order to interchange information, collaborate for their own purposes as well as any predefined collective goal (Maret and Calmet, 2009). Communities typically include individuals interested in a specific topic or with knowledge in a defined field, which gives each community a specific focus and purpose.

This distributed environment suggests a bottom-up approach, where the description is reached by the connection of new elements, which also aptly treats the characteristic that knowledge does not have boundaries or limits and that every approach simply means a new view on the same domain or even modifying the domain itself.

Main elements of VKC's are:

- A leader, who is any agent initiating the topic;
- A topic which must be part of the leader's knowledge;
- Members, who are any other agents;
- Ways of communication - the leader controls the message buffer used for communication.

Software Agents can be used in every stage of the life of a Virtual Enterprise (search for partners and information, negotiations, contract making, etc.). A society of Software Agents itself could be understood as a Virtual Enterprise. The use of Software Agents in Virtual Enterprises should be regulated with special contract clauses:

- No limit for the number of VKCs;
- An agent may create or join several VKCs;
- Lifetime of a VKC is defined by the leader.

The basic process for the treatment of topics may be modeled by the following steps:

- Initiate: an agent proposes a topic;
- Join: agents interested in the topic a community join it;
- Inform: the leader informs of the existence of a VKC;
- Request: an agent asks for the existence of a VKC;
- Leave, delete, terminate.

There is already a range of VKC implementations, which have been developed or are under development. One of these is the approach mentioned in Calmet et al. (2006), which presented a simulation in virtual knowledge communities. Another implementation, more focused on the implementation of uncertain knowledge, but yet using VKCs, may be found in Yang and Calmet (2006). Finally, another practical application, more related to the field of security applications, is shown in Huang (2007).

There are many more possible practical applications as a distributed way of modeling knowledge and interaction presents a very natural approach to problem solving in many domains. A new trend is to implement VKC's via mobile agents.

VKCs may be very aptly used for the following ways of implementation/description:

- Building of ABIT theories
  - Shared knowledge in-between agents
  - Limited to a given topic (no huge data base)
  - Worldwide lexicon/ontologies can be used
- Description of ABIT controls
  - Functions, processes (available or to be described – good practices)
  - Links to the concepts from the theory(ies) can be done
- Descriptions of specializations
  - Cooperative description of the specialization in a cultural context
  - Specialization links and additional low-level items

4.4. *Implementation via Logical Fibering*

In this part we discuss a possible implementation via the application of Logical Fiberings. For the correct implementation of VKCs we need an environment with a universe of agents, each of which is looking on its own state space. A main feature of the implementation is to share and exchange relevant VKCs. Let us assume that a "truth" is valid within a given neighborhood (VKC). Trust implies to move from one Knowledge Base to the second one in a continuous way or to identify the "border" of validity of a piece of trust. The task is to solve this problem by investigating the constraints set by the semantical meaning of this piece of trust.

A first thinkable solution to this problem would be a "pure" topology (from algebraic topology and differential topology, Galois cohomology etc.).

A second suggestion to model such semantics are Logical Fiberings as developed by J. Pfalzgraf on the ground of Polycontextural Logic (PCL) by G. Guenter and shown in Pfalzgraf (2000) and Pfalzgraf and Edtmayr (2004). Before we get into possible implementations details, first, we should introduce the concept of Logical Fiberings for better understanding.

By definition, a Logical Fibering is a quadruple, consisting of the basic elements (E, π, B, F):

- Total space E with logics;
- Projection map $\pi : E \rightarrow B$;
- Base space B;
- Typical fiber F is the logical structure over each point b in the base space.

F may define classic two-valued logics or more complex logical structures, which may even be a fibering itself, thus rendering a "fibered Fibering". The simplest example of a Logical Fibering is a so-called free parallel system, also called "trivial fibering". In a trivial fibering we have $\xi = (E, \pi, I, L)$, i.e., the base space is a set of indices I and the typical fiber is a two valued logic L.

In a more complex scenario we might deal with a Derived Logical Fibering (Pfalzgraf and Edtmayr, 2004) with a nontrivial equivalence relation on the set of truth values $\Omega_I=\{T_i,F_i\}$ also denoted $L^{(I)}$. In this case the set of global truth values is the quotient space following $\Omega^{(I)}:=\Omega^I/\equiv$.

The practical use of the mathematical concept of Logical Fiberings has already been explained by Jochen Pfalzgraf himself in (Pfalzgraf and Edtmayr, 2004), where an implementation of a welding task using three robots R_0, R_1 and R_2 is discussed. Each robot has a task assigned: R_1 shall put a steel plate A into the correct position, R_2 shall place a bolt B on it and R_0 finally is to perform the welding task, fixing B on A. Pfalzgraf models this scenario via a fibering in a free parallel system L^3, with the local sets of truth values $\Omega_I = \{T_i,F_i\},\ i \in I = \{0,1,2\}$ and consequently the global set of truth values $\Omega_3 = \{T_0,F_0,T_1,F_1,T_2,F_2\}$. Truth values are set according to the accomplishment of tasks, whereas the two truth values given by R_1 and R_2 trigger the truth value for R_0 and thus the welding. This is a simple case of application in a very limited scenario and with merely a free parallel system. The fact that much more complex situations may be modeled is shown by the airport controller in Pfalzgraf et al. (2000). Furthermore, the intelligent representation characteristics of a Logical Fibering make it a good candidate for data storage and administration in modern systems (see, e.g., Schneider and Calmet, 2005 or Schneider, 2007 where Logical Fibering was used as a powerful data structure in a system for defense against Denial of Service attacks and Distributed Denial of Service attacks).

The fact that a Logical Fibering may be seen as an abstract data structure has lately been discussed in Calmet and Schneider (2011). Defining data interaction by standard operations of “store”, “fetch” and “free”, a data layout for the security system given in Schneider (2007) is discussed, namely its application to a fibered Fibering situation. Not only has this formal definition shown the conceptual feasibility of Logical Fiberings as Abstract Data Type, but also a pattern for its implementation has already been defined. This extends the robotic examples of Pfalzgraf to a large class of practical problems.

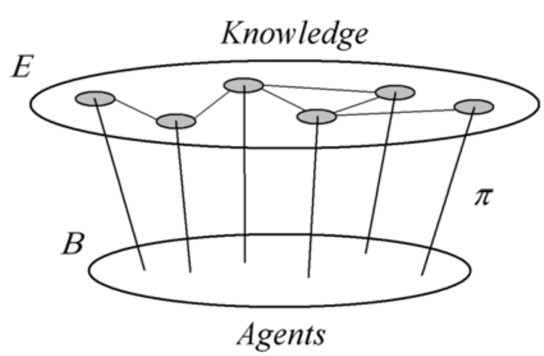

Fig. 1. Proposed Logical Fibering Representation of VKC

Applied to knowledge representation by a VKC, we may see the base space B as the index of agents. The map π is the link to each agent's knowledge, which is represented through local logics L^i (see Fig. 1). Local logics contained in E may be from simple two valued logics to more complex logics or even fiberings themselves, de-pending on the situation of cooperation. Certainly, in real-life situations more complex structures are indicated.

A mediation scheme models communications of the agents and leads to a non-trivial global set of logics based on the local logics of each agent. Computationally speaking, as seen by the robot example above, truth values in one sub-system trigger truth values in another, which provides a means of action and reaction of the agent. This establishes a formalized, standardized and much more tangible way of representation.

5. Expected Results

We expect the following benefits through the modeling of knowledge in VKCs, using Logical Fibers for formalization:

- Dynamic extensibility through the inclusion and exclusion of agents, creation of new interests and topic, update of outdated knowledge and deletion of erroneous information;
- Comparability by the formalization of each agent's knowledge and a similar root implementation in different domains;
- Computability through a logical representation, which has the power to speed up any analytical engine applied to it;
- Trivial implementation through the use of formalisms, similar to those used in nowadays' information systems;
- Bottom-up approach suitable for small size problems;
- Possibility to mix several logical systems and thus to model and assess trust for a given knowledge base.
- To consider different knowledge bases with different Logical Fiberings and thus to investigate transdisciplinarity through communication between knowledge bases by means of topological tools.

The main objective of this work is to guide the way through a theoretical framework up to practical implementation, which may later be realized by computational means. In the fields of human sciences this remains a challenge. We trust that our approach offers a path to continued research, which may even handle this final hurdle.

6. Conclusion

The purpose of this paper was to provide an outlook on a means of intelligent formalization of knowledge in several different domains. Specifically the use of Virtual Knowledge Communities, establishment of trust and cooperation as well as the benefits of Logical Fibering as a data structure were elaborated and their expected benefits were discussed.

This paper put together several abstractions for Multiagent Systems that were already proposed. A first one, AOA implies a specific definition of a society of agents. We build then upon the ABIT concept to enable a consistent handling of any field of science or humanity. The glues for such an approach are methodologies arising from the mechanization of mathematics. We subsequently propose a new abstraction to define the semantics of cognitive knowledge along similar mathematical sources. Finally, assuming that trust is arising from the exchange of pieces of knowledge, we introduce the topological concept of Logical Fibering to enable to assess the trust of knowledge exchanges. The implementation is made possible by the concept of Virtual Knowledge Communities. VKCs have already proven themselves to be efficient. VKCs are a consequence of the AOA abstraction.

Among the forthcoming works are applications in intercultural communication on one side and the mixing of human and artificial artifacts in control systems on the other side. The latter problem is both of practical interest since such a mixed control is present in several factories, and theoretical interest since it provides a meaningful test of the topological binding of knowledge bases.

References

Bertoli, P. G.; Calmet, J.; Giunchiglia, F.; Homann, K. (1999): Specification and integration of theorem provers and computer álgebra systems. Fundamenta Informaticae, Vol. 39, No. 1-2, 39-57.

Burauskas, G.; Aldama, J. I. (2008): Trust in Virtual Communities, Master Thesis, University of Lund.

Calmet, J. (2009): Abstraction Based Information Technology: A Framework for Open Mechanized Reasoning, Invited talk at Calculemus 2009. In Conference on Intelligent Computer Mathematics . Eds. J. Carette et al., Springer LNCS 5625, pp. 14-26.

Calmet, J.; Homann, K., (1996): Structures for symbolic mathematical reasoning and computation. In: Proceedings of DISCO ’96 – Design and Implementation of Symbolic Computation Systems, Calmet J., and Limongelli, Eds., 216-227, LNCS 1128, Springer.

Calmet, J.; Maret, P.; Endsuleit, R. (2004): Agent Oriented Abstraction, In: Revista Real Academia de Ciencias (Madrid), Special Volume on Symbolic Computing and Artificial Intelligence, Vol. 98, No. 1, pp. 77-83.

Calmet, J.; Schneider, M. O. (2011): Logical Fibering as Abstract Data Structure, In: Lasker, G. E., Pfalzgraf, J. (Eds.): Advances in Multiagent Systems, Robotics and Cybernetics: Theory and Practice (Volume IV), (Proceedings of the Intersymp’2010), The International Institute for Advanced Studies in System Research and Cybernetics, Tecumseh, Canada.

Calmet, J.; Subercaze, J.; and Maret, P. (2006): Simulation in Virtual Knowledge Communities, In A. Oropeza, F. Mapica, eds., Social and Organizational Informatics and Cybernetics, pp. 238–242.

Castelfranchi, C.; Falcone, R. (2010): Trust theory – A socio-cognitive and computational model, New Jersey: Wiley.

CICM (2010): Proc. Conference on Intelligent Computer Mathematics, S. Autexier et al. (Eds.), AISC/Calculemus/MKM 2010, LNAI 6167, Springer.

Earl, M. (2001): Knowledge management strategies: Toward a taxonomy. Journal of Management Information Systems, 18(1), 215–233.

Giunchilia, F.; Pecchiari, P; Talcott, C. (1994): Reasoning Theories: Towards an Architecture for Open Mechanized Reasoning Systems. Tech. Rep. 9409-15, IRST, Trento, Italy.

Hailes, S.; Abdul-Rahman, A. (2000): Supporting Trust in Virtual Communities, Proceedings of the 33rd Hawaii International Conference on System Sciences, IEEE.

Huang, D. (2007): A Security Gateway for Web Service Protocols, Doctoral Thesis, University of Karlsruhe, Germany.

Kline, M. (1964): Mathematics in Western Culture, New York, NY: Oxford University Press.

Leung, L.; Lee, P. S. N. (2005). Multiple determinants of life quality: the roles of Internet activities, use of new media, social support, and leisure activities. In: Telematics and Informatics, Elsevier, Vol. 22, Issue 3, pp. 161-180.

Maret, P.; Calmet, J. (2009): Agent-Based Knowledge Communities. In: International Journal of Computer Science and Applications, Technomathematics Research Foundation, Vol. 6., No. 2., pp. 1-18.

Messatfa, H.; Reyes, L.; Schroeck, M. (2011): The power of analytics for the public sector – Building analytics competency to accelerate outcomes. IBM® Global Business Services, Executive Report.

Mommsen, W. J. (2004): Max Weber und die Deutsche Politik, Tübingen, Germany: Mohr-Siebeck.

Moran, R. T.; Harris, P. R.; Moran, S. V. (2007): Managing Cultural Differences – Global Leadership Strategies for the 21st Century, New York, NY: Elsevier.

O'Brien, R. (1999): Social Change Activism and the Internet: Strategic Online Activties, http://www.web.net/robrien/papers/netaction.html.

Pfalzgraf, J.; Edtmayr, J. (2004): The Concept of Logical Fiberings: Distributed Logics for Multiagent Systems. In: Proceedings 17th European Meeting on Cybernetics and Systems Research (EMCSR'2004), Vienna, April 13-16, 2004, R.Trappl (Ed.). Cybernetics and Systems. Austrian Society for Cybernetic Studies.

Pfalzgraf, J.; Frank, K.; Weichenberger, J.; Stolzenberg, S. (2000): Design, Implementation, and Application of a Tool for Optimal Aircraft Positioning, In: Proceedings of EvoFlight2000, April 2000, Edinburgh. Springer Lecture Notes in Computer Science, Vol. 1803, Real-World Applications of Evolutionary Computing, Cagnoni S., et al. (Eds.).

Pfalzgraf J. (2001): The concept of logical fiberings and fibered logical controllers. In: Proceedings CASYS'2000, August 7-12, 2000, Liege, Belgium. American Institute of Physics, AIP Conference Proceedings, Vol.573 (2001), pp.683-693. D.M.Dubois (Ed.). (2001)

Power, D. J. (2002): Decision support systems: concepts and resources for managers. Westport, Connecticut: Quorum Books.

Pressman, R. S. (2001): Software Engineering: A Practioner's Approach. 5th Ed., London, UK: McGraw-Hill.

Raine, L.; Smith, A.; Purcell, K. (2011): Social Side of the Internet. http://pewresearch.org/pubs/1861/impact-internet-social-media-facebook-twitter-group-activities-participation.

Russell, S.; Norvig, P. (2009): Artificial Intelligence: A Modern Approach. 3rd. Ed. Upper Saddle River, New Jersey: Prentice Hall.