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Some Aspects of Distributed Machine Intelligence Algorithms

PhD Thesis Summary

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Introduction

The general goal of this dissertation was to discuss how novel, distributed, autonomic, collective machine intelligence mechanisms such as knowledge sharing, emergent self-organization and knowledge self-revision can be utilized in particular fields, and bring impressive results in means of adaptivity and performance. I extended existing algorithms, applied them to new fields, and also often utilized emergent effects.

The dissertation summarizes my research conducted in three particular fields. The connection point between the fields is the utilization of some kind of novel, distributed and autonomic machine intelligence based approach.

In the ***first thesis group*** I discuss the results achieved in the fields of open collective-adaptive multi-agent systems. I synthesized a novel approach (OLAKO) for highly dynamic environmental requirements by combining online learning autonomous agents, society-wide emergent pair-wise knowledge sharing between the agents and a knowledge self-optimization mechanism to optimize and clean the knowledge. I showed that the system enables high adaptivity, knowledge sharing spares time for the individuals, and the knowledge self-optimization speeds up the learning curve for the agents.

In the ***second thesis group*** I discuss the results achieved in the field of on-demand clustering in self-organizing mobile networks. I created a new on-demand clustering algorithm (Shuffling ODC) by extending a baseline On-Demand Clustering (ODC) algorithm. I showed that Shuffling ODC overcomes ODC's topological starvation problem, results in higher clusters and more clustered nodes and better load balancing performance without breaking the principle of locality, and without significant communicational overhead, compared to the baseline algorithm.

In the ***third thesis group*** I discuss my results in the field of sentiment mining from natural language texts. I defined the problem of named entity centric opinion mining, I proposed a general, language independent, adaptive algorithm for the task. I showed with experiments that the model produces high precision and recall. Above that, I created an unsupervised self-analysis methodology, including a self-revision algorithm for the term dictionary, a completeness checker for the (non-annotated) test corpus and the term database, and an approximation for precision and recall of an evidence based dictionary extension.

Attribution

The work that also resulted in this thesis, at some points, was conducted in cooperation with students and colleagues. The attribution is discussed in its details in the preface of the dissertation. All theses worded in this summary refer to my own particular results.

I. OLAKO: An Approach for an Open Collective-Adaptive System

I.1. Background and Motivation

The concept of *autonomic ICT* and *adaptive systems* has gained significant interest in the last decade. By definition, these systems are able to adapt their behaviour to a certain level of changes in the environment without human help. A basic approach to achieve adaptivity is to use a feedback loop: monitor the environment, select the best action to do, carry out the action and start over with monitoring the effects. Compared to traditional control systems, an important difference in the adaptive case is, that there is no static optimum to find, instead, the world, so the adaptation target changes from time to time and the system must follow it accordingly.

Adaptive systems today typically use explicit, pre-injected models (world model, self-model) describing how the world and the system itself work. These models help in selecting the next action during normal operation, and determine the incident handling or adjustment mechanism when abnormal conditions occur. Powerful tools such as reasoning, ontology or semantics may be utilized in order to guarantee that the operation is effective and convergent. However, the success of this model based approach heavily relies on the accuracy of the system's explicit knowledge: on the completeness of the models and on the efficiency of the resulting adjustment mechanisms. As long as the environment is in line with the model, the system is guaranteed to operate and adapt efficiently; however, it is theoretically impossible for the system to react to un-modelled changes or to perform out-of-model adjustment strategies. In other words, preconceptions that make the adaptation fast and effective in some cases form an obstacle in others; hence, the adaptation potential of the system gets restricted by such hard preconceptions.

One goal of this research was to investigate whether the level of explicit knowledge or preconceptions for a system could be replaced, or at least relaxed, through the excessive use of online learning. In other words, is it possible to unbind the adaptation process, and let the system openly find its way for adaptation, instead of blindly following the knowledge that was once injected and may not even fit well for the current problem instance? Openness may be desired on several layers: an open world model continuously refined with the actual experience observed by the system; open adaptation strategies where the system builds its strategy from simple blocks instead of picking one of the pre-coded strategies; social openness to share the knowledge with others and make use of the presence of multitudes of learners even if we are not sure that everyone faces the same problem; and, finally openness for self-revision such as knowledge cleaning, deprecation, and some form of knowledge optimization.

Collective behaviour, swarm intelligence and emergence have often been coupled with autonomous or adaptive systems not just due to their proven efficiency in nature, but also because the use of simple but connected entities or a society of entities fits well with many real world problems. Often, simple actions of a multitude of entities result in an *emergent* behaviour, i.e. the global result of a different, higher quality or level. Considerable work has been done in certain particular fields, such as emergent self-organization.

The goal in this area was to better understand the advantages and bottlenecks of collective learning in an open adaptive system: what gains may knowledge sharing bring, and what kind of bottlenecks should be anticipated when knowledge sharing is used excessively in an environment of limited observability and changing requirements. According to my knowledge, this field, i.e. open learning plus collective-adaptive system, has not been extensively analysed before.

I describe an approach for highly adaptive online learning, self-optimization and collective knowledge sharing between learners in a complex, possibly changing and not fully observable environment. My approach, OLAKO, differs from the existing state of the art at two major points: (i) I excessively use online learning combined with self-* properties in order to create an autonomous adaptive system, and (ii) the model allows for an intensive, even society-wide, sharing of the individuals' independently developed knowledge, leading to a better learning curve.

I.2. Objectives

The goal of the research was to answer the problem of collectively adapting to dynamically changing environmental requirements with a novel approach where the level of explicit, pre-injected knowledge of the system is low. The most important questions were the following.

- Is online learning applicable within a collective-adaptive system? Can the level of explicit knowledge or preconceptions for the system be replaced, or at least relaxed, through the excessive use of online learning?
- How to bring together the idea of knowledge sharing and the independent, self-optimized knowledge creation at the agents.
- What are the effects of knowledge sharing on the individual level and on the level of the society?
- Can a dynamically created or partially imported knowledge base be self-optimized at runtime (on-the-fly)? Is it possible for an agent to review the way it observes the world, i.e. the features, and dynamically reorganize and clean this abstraction?
- Can online learning enable the system to adapt to seamlessly occurring but drastic changes in the requirements?

I.3. New Scientific Results

Thesis I-1. *(OLAKO model) I proposed a complex model, an online learning based collective-adaptive multi-agent society, for the problem of adapting to dynamic environmental requirements. OLAKO synthesizes online learning, an emergent knowledge sharing mechanism between agents, and an autonomous knowledge self-optimization mechanism. I proposed a formal framework to analyse the model, along with a set of statements that the formal description implies.*

Related publications: J3, J8u, C9

Thesis I-2. *(OLAKO Knowledge Self-Optimization) I extended Least-Squares Temporal Difference learning with the concept of using online, dynamically created features. I proposed the model of hierarchical feature unification by grouping. I proposed a knowledge self-optimization algorithm to dynamically create and remove features at runtime. I proposed a knowledge de-optimization algorithm to transform the knowledge back to the original, non-optimal form, containing the initial features. I showed with simulations that the knowledge self-optimization results in 11-18% faster learning on a showcase problem.*

Related publications: J3, J8u, C9

Thesis I-3. *(OLAKO Knowledge Sharing) I proposed a model and an algorithm for importing an externally, independently developed Least-Squares Temporal Difference learning based knowledge block to an agent. I proposed knowledge import strategies, consisting of an agent coupling mechanism, an import decision making mechanism and a knowledge integration mechanism. I showed with simulations on a showcase problem that knowledge import is able to improve the performance of agents (+46-84% non-failure rate, +2% success rate). I described the emergent effect of society-wide knowledge import. I showed with simulations that society-wide random knowledge import has an emergent negative effect, in a showcase problem it impairs the learning ability of agents, their performance does not improve with time. I showed with simulations that society-wide smart knowledge import, where the acceptance criterion depends on an estimated utility, has a positive emergent effect: it results in 21% higher success rates and 30% higher non-failure rates on a showcase problem, compared to the case without knowledge import.*

Related publications: J3, J8u, C9

I.4. Application of the Results

The OLAKO model is a fairly general approach. The model is applicable for any field where the problem can be modelled as a time series of world states, a finite number of actions, occasional feedback; and in order to use knowledge sharing, it is good if multitudes of learners face the problem at the same time.

One concrete area of application is the field of intelligent gadgets or services for humans, such as an adaptive graphical interface, a proactive cache, or a proactive intelligent building system that makes the user's everyday life easier by learning the general habits of humans as well as the personal specialties of each user. Another application area is adaptive networking, for example, a quality of experience (QoE) based media stream controller that uses the human's feedback to change the underlying settings of the stream. A third specific application area is in online gaming and augmented reality, where machine agents need to interact with humans in a virtualized environment, similarly to the showcase world where the experimental evaluation of OLAKO took place.

II. Improved Self-organization with Shuffling ODC

II.1. Background and Motivation

Self-organization in networks is gaining significant interest today in various application fields from 3GPP Long Term Evolution (LTE) to pervasive computing and other mobile ad-hoc network scenarios. Elements in these networks need to share resources, communicate with each other, perform load balancing, or provide services to each other without the help of a central management entity.

While human network managers possess information about the state of the whole network, in case of self-organization, nodes need to rely on *locally available information,* even if it is incomplete and non-objective, when making their autonomous decisions. This is referred to as the locality principle, or the principle of locality. Self-organization often uses simple algorithms with *emergent* properties, i.e. the multitude of executions result in a complex, "intelligent" high-level behaviour which is of a different quality than the simple building blocks themselves. Emergent algorithms are often inspired by biological, chemical or physical phenomena like the behaviour of swarms, insect colonies, the human brain, or the immune system.

Clustering in a self-organizing network means that entities of the network search for other entities that meet a certain criterion (similarity in case of normal clustering and complementariness in inverse clustering) and establish connections with them in form of overlay network links. The resulting overlay network can be used for various purposes. *Load balancing* is one of these use cases: entities share their local workload with members of the cluster. While the efficient creation of clusters is a prerequisite for efficient load balancing, it is not a sufficient condition: the load balancing algorithm must also answer the questions of when and with which cluster member to share the load, and what information to use (collect, store and update) when making these decisions.

My work focuses on biologically inspired, fully distributed self-organization algorithms for large overlay networks, with an emphasis on clustering and load balancing. I considered the problem of on-demand clustering, where the goal is to expand the cluster when demand for that occurs, for example the cluster has more workload than it can process. The demand-driven problem statement has two main differences from the general case: (i) the amount of clustering is proportional to the demand, hence there's no driving force to expand clusters to their theoretical maximum size or to assign each and every node to a cluster, and (ii) the speed of cluster formation is more crucial, because the demand depicts an immediate request, one, that cannot wait.

The novelty in my work is the improved clustering ability, achieved with the modification of a well-known baseline clustering algorithm, and demonstrated through a load balancing scenario.

II.2. Objectives

The goal of the research was to improve the performance of British Telecom's original on-demand clustering (ODC) algorithm without breaking the locality principle, and without increasing the resulted communication overhead significantly. The research focus was organized around the following questions.

- What are the bottlenecks of the original ODC?
- How can the performance be improved?
- What are the effects of the modifications in the algorithm? Are there emergent or unexpected side effects?
- How do the modifications influence the principle of locality and the communication overhead of the algorithm?

II.3. New Scientific Results

Thesis II-1. *(Topologic Starvation) I described the phenomenon of topologic starvation, an emergent negative effect of using only direct-gain link reconfigurations in the self-organization mechanism. I described how the baseline ODC algorithm facilitates the topologic starvation with time.*

Related publications: J4, J5, C8

Thesis II-2. *(Shuffling ODC) I extended the baseline ODC algorithm with the concept of link reconfiguration without direct gain. The resulting algorithm, Shuffling ODC, injects minor modifications into the adjacent topology when an attempt for cluster expansion is unsuccessful. I showed with simulations that Shuffling ODC, by avoiding the topologic starvation, results in 25-30% more clustered nodes, 17-23% more processed jobs per round, 20-30% improvement in job sharing, and 30-50% less job processing time, compared to ODC.*

Related publications: J4, J5, C8

Thesis II-3. *(Communication Overhead of Shuffling ODC) I showed that the messaging overhead of Shuffling ODC is linear with the messaging overhead of ODC. I showed that the messaging overhead of Shuffling ODC and ODC are equal when the lookup is always successful.*

Related publications: J4, J5, C8

Thesis II-4. *(Locality Preservation in Shuffling ODC based Load Balancing) I showed with simulations that Shuffling ODC, when used for load balancing, does not break the rule of locality. The resulting workload sharing distance remains 56-63% smaller than the increment in the cluster size.*

Related publications: J4, J5, C8

II.4. Application of the Results

Shuffling ODC can be applied in areas, without specific restriction, where on-demand clustering is required.

The first significant application area of on-demand clustering is peer-to-peer networks and data grids. Here, nodes need to find cluster members for load sharing, or for data duplication.

Another significant application area is the field of overlay networks, for example a service overlay, where the entity in need for a service can locally look up service providers (inverse clustering), or a service with excess workload is able to locate partners for workload sharing and load balancing.

III. Vox Populi: Named Entity based Sentiment Mining from Texts

III.1. Background and Motivation

With the expansion of social media, what people think or read is not just an interesting supplement, but an important input for business decisions, both at personal level and for companies. Sentiment analysis or opinion mining of various texts such as news articles, product reviews, blogs or the social media has become of considerable interest in the last years.

Sentiment analysis tackles with the semantic orientation expressed in the texts. This can also be considered as a special case of document categorization, where the category of the document is based on its sentiment rather than the topic. Subtasks include: polarity analysis to determine the direction of the opinion (e.g. positive, negative, or neutral attitude), strength analysis to identify the intensity of the opinion, and subjectivity analysis to differentiate between objective and personal expressions. I tackle with the first two tasks.

In means of tools, a large range is known from simple term matching to complex grammatical analysis and machine learning based approaches. Term matching, often also mentioned as bag-of-words model, uses a list (dictionary) of terms along with their calculated or estimated sentiment; and the words in the text are compared with this dictionary. The dictionary may be created manually or automatically. An example for the automatic direction is SentiWordNet, where a semantic word network (WordNet) was used for propagating the polarity of a handful of manually selected basic seed words. Often, grammatical analysis of the text, or machine learning based topic structure identification is used in combination with the bag-of-words model.

Opinion mining may happen at different levels, for example on the complete document, per blog comment, or per paragraph or sentence.

The research goal slightly differs from the common task of identifying the overall sentiment of a document or fragment. I focused on the named entities, such as persons, brand names, places, occurring in the texts, and the opinions expressed towards them. I extract information per named entity occurrence, and collect this information over time and from various sources.

Most of the literature in the field assumes that the language is used by humans in a fixed, static way, i.e. changes in the sentiment attached to the word, with time, are not considered.

Adaptivity is a basic concept in my model. I created an automatic self-analysis mechanism to detect potential static or dynamic flaws in the term database. The self-revision algorithm is unsupervised in terms of not requiring an annotated reference corpus in order to work. This mechanism first of all, enables the adaptive fine-tuning of the term dictionary according to people's ever-changing word usage. Besides that, this algorithm also enables us to turn a rough initial term database, via self-revision rounds, into a clean dictionary. An initial, rough term database may, for example, even be a machine translated SentiWordNet, if we want to execute sentiment mining for a language other than English.

The novelty of the work is the approach to sentiment mining, i.e. named entity centric analysis, and the adaptivity which is achieved with help of a set of self-analysis mechanisms.

III.2. Objectives

The focus of the research was to investigate how automatic opinion mining can be achieved for named entities occurring in various natural language texts. The most important questions the research tackled with were the following.

- What kind of data architecture is required for named entity based opinion mining?
- How to extend or modify existing algorithms to identify the opinion expressed towards a named entity, instead of identifying the totality of opinions in the text segment?
- Is it possible to make the system self-aware or adaptive, i.e. to equip it with some sort of unsupervised self-analysis ability?
- Is it possible to analyze the term dictionary without the need for an annotated reference corpus to run measurements on? Is it possible to execute similar unsupervised algorithms for other components of the system?

III.3. New Scientific Results

Thesis III-1. *(Vox Populi) I proposed a model for adaptive, named entity centric opinion mining. I proposed building blocks and the data flow paths for the system. I showed with experiments that the model is applicable for the Hungarian language.*

Related publication: J10u

Thesis III-2. *(Named Entity based Sentiment Mining Algorithm) I proposed an algorithm to identify the sentiment expressed towards a named entity that occurs in a text, with a bag-of-words model extended with basic linguistic analysis (negation handling and word stemming) and with the use of weighted contextual frames around the named entity. I proposed an algorithm to dynamically adjust the runtime parameters, such as the frame lengths, of the algorithm. I showed with measurements on a manually tagged reference corpus that the algorithm produces 68-89% precision and 67-87% recall.*

Related publication: J10u

Thesis III-3. *(Term Self-Revision Mechanism) I proposed an unsupervised self-revision algorithm for the term dictionary, to identify potential flaws in it, without the need for an annotated reference corpus. I gave a formal definition of the algorithm and the related assumptions. I proved that if the assumptions are true, the algorithm locates the flaws in the dictionary. I proposed a data structure, called Expectations-Encounters (EE) matrix to handle the totality of the results.*

Related publication: J10u

Thesis III-4. *(Precision-Recall Estimation for an Evidence based Dictionary Expansion) I proposed an algorithm to estimate the precision and the recall of the evidence based extension of the term dictionary. I showed with measurements that the evidence based dictionary expansion with the Vox Populi opinion mining model for Hungarian texts would bring weak results (43-44% both in precision and recall), therefore it is not advised.*

Related publication: J10u

III.4. Application of the Results

Opinions, with the expansion of social media and the world-wide web, are becoming more important than ever before. The reception of products by the public, expressed in news, blogs and other forms, are significant influencers; and as so, are important inputs for decision makers.

The Vox Populi model of named entity centric opinion mining produces results that are ready to utilize for business decisions, both as an individual and on corporate level. Vox Populi collects named entity related opinions from various web data sources over time. The opinion information can be flexibly utilized in various ways. A few examples are: (i) Querying the current standings. What is the opinion about this product now? (ii) Analysis over the time axis. How did the opinion of people change in the last year regarding the product? (iii) Analysis by sources or source types. How is the product rated in the mainstream media in contrast to private blogs? (iv) Pair-wise comparison. Which of the two brands is thought to be more positive? About which of them did people's opinion change more?

A pilot version of Vox Populi is in experimental use at Magyar Telecom Nyrt. since September 2010.

List of Publications

Book chapters

B1 Borbála Katalin Benkő
Increasing the syntactical parse efficiency using "strong rules".
In: Eloína Miyares Bermúdez, Leonel Ruiz Miyares (eds)
Linguistics in the Twenty First Century.
Cambridge: Cambridge Scholars Publishing, 2006. pp. 289-298.
(ISBN: 1904303862)

B2 Tamás Katona, Borbála Katalin Benkő
Information retrieval in homogeneous document sets using syntactical parse information.
In: Eloína Miyares Bermúdez, Leonel Ruiz Miyares (eds)
Linguistics in the Twenty First Century.
Cambridge: Cambridge Scholars Publishing, 2006. pp. 307-316.
(ISBN: 1904303862)

B3 Endre Sándor Varga, Bernát Wiandt, Borbála Katalin Benkő, Vilmos Simon
Autonomously Evolving Communication Protocols: The Case of Multi-Hop Broadcast.
In: Dinesh Verma, Pietro Lio' (eds)
Biologically Inspired Networking and Sensing: Algorithms and Architectures.
New York: IGI Global, Information Science Reference, 2011.
(In Press)

Journal papers

J1 Borbála Katalin Benkő, Tamás Katona, Róbert Schulcz
CASCADAS – Autonomic communication and pervasive situated services.
HÍRADÁSTECHNIKA LXII:(1) pp. 41-46. (2007)

J2 Borbala Katalin Benkő, Vilmos Simon
Nature-Inspired Adaptivity in Communication and Learning.
LECTURE NOTES IN COMPUTER SCIENCE 6209: pp. 323-325. Paper 10.1007/978-3-642-14547-6_31. (2010)

J3 Borbála Katalin Benkő, Lányi Dávid
An Open Learning System.
PERIODICA POLYTECHNICA-ELECTRICAL ENGINEERING. (2011)
(In Press)

J4 Márton Legény, Borbála Katalin Benkő
Topology Cache Aided Self-organization Directions for Ad-hoc Mobile Networks.
CYBER JOURNALS-JOURNAL OF SELECTED AREAS IN TELECOMMUNICATIONS 2011:(3) pp. 56-63. Paper 08. (2011)

J5 Borbala Katalin Benkő, Marton Legény
Improved On Demand Clustering on Scale-Free Topologies
Infocommunications Journal (2011)
(In Press)

J6 Laszlo Muka, Borbala Katalin Benkő

Meta-level performance management of simulation: The problem context retrieval approach
PERIODICA POLYTECHNICA-ELECTRICAL ENGINEERING. (2011)
(In Press)

J7u Borbala Katalin Benkő, Nermin Brgulja, Antonio DiFerdinando, Edzard Höfig, Rico Kusber, Marco Mamei
Autonomic Communication Elements: Design,Evaluation and Application
Under review for ACM Transactions on Autonomous and Adaptive Systems
Submitted: December 2008
Revision submitted: January 2011

J8u Borbala Katalin Benkő, David Lányi, Karoly Farkas
OLAKO: An Approach for an Open Collective-Adaptive System
Under review for ACM Transactions on Autonomous and Adaptive Systems
Submitted: Marc 04 2011

J9u Endre Sándor Varga, Bernát Wiandt, Borbála Katalin Benkő, Vilmos Simon
Autonomous Online Evolution of Communication Protocols
Under review for: Elsevier Journals, Journal of Systems and Software, Special Issue on State-of-the-Art in Self-Adaptive Systems
Submitted: April 2011

J10u Borbala Katalin Benkő, Zsolt Kardkovacs
Sentiment Mining for Named Entities from Dynamic Web Contents with Self-Supervision
Under review for IEEE Transactions on Knowledge and Data Engineering
Submitted: May 2011

Conference papers

C1 Borbála Katalin Benkő
On increasing the syntactical parse efficiency.
In: Proceedings of UkrObraz2004. Kyiv, Ukrajna, 2004-2004. Kyiv:

C2 Borbála Katalin Benkő
Increasing the syntactical parse efficiency using "strong rules".
In: Proceedings of the 9th International Symposium for Social Communication. Cuba, 2005.01-2005.01. Santiago de Cuba: pp. 562-566.(ISBN: 959-7174-04-9)

C3 Borbála Katalin Benkő, Tamás Katona
On the Efficient Indexing of Grammatical Parse Trees for Information Retrieval.
In: Proceedings of INISTA2005. Istanbul, Turkey, 2005-2005. Istanbul: pp. 366-369.

C4 Tamás Katona, Borbála Katalin Benkő
Information retrieval in homogeneous document sets using syntactical parse information.
In: Proceedings of the 9th International Symposium for Social Communication. Cuba, 2005.01-2005.01. Santiago de Cuba (ISBN: 959-7174-04-9)

C5 Edzard Höfig, Björn Wüst, Borbála Katalin Benkő, Antonietta Mannella, Marco Mamei, Elizabetta Di Nitto
On Concepts for Autonomic Communication Elements.
In: Proceedings of IEEE International Workshop on Modelling Autonomic Communications Environments. Dublin, Ireland, 2006 Dublin: pp. 1-5.

C6 Borbala Katalin Benkő, Robert Schulcz
Mapping external functionalities into autonomic services.
In: Bio-Inspired Models of Network, Information and Computing Systems, 2007. Bionetics 2007. 2nd. Budapest, Hungary, 2007.12.10-2007.12.12. Budapest: pp. 270-276. (ISBN: 978-963-9799-05-9)
DOI: 10.1109/BIMNICS.2007.4610125

C7 Borbála Katalin Benkő, Nermin Brgulja, Edzard Höfig, Rico Kusber
Adaptive Services in a Distributed Environment.
In: Proceedings of the Eighth International Workshop on Applications and Services in Wireless Networks. Kassel, Germany, 2008-2008. Washington: IEEE Computer Society Press, pp. 66-75. (ISBN: 978-0-7695-3389-6)

C8 Márton Legény, Borbála Katalin Benkő
Design of Novel Self-Organization Mechanisms Through Simulation.
In: ISC'2010. Budapest, Magyarország, 2010.06.07-2010.06.09. pp. 10-14. (ISBN: 978-90-77381-5-57)

C9 Dávid Lányi, Borbála Katalin Benkő
A Nontraditional Approach for a Highly Interactive Collective-Adaptive System.
In: NexTech 2010. Firenze, Italy, 2010.10.25-2010.10.30. Firenze: pp. 1-6. Paper 19. (ISBN: 978-1-61208-000-0)

C10 Peter H. Deussen, Edzard Höfig, Borbála Katalin Benkő
Body Aura - A New Approach Towards Ambient Intelligence: Vision Paper.
In: NexTech 2010. Firenze, Italy, 2010.10.25-2010.10.25. Firenze: pp. 1-6. Paper 23. (ISBN: 978-1-61208-000-0)

Book chapters in Hungarian

B4 Benkő Borbála Katalin
Futballnyelv az interneten.
In: Balázs Géza, Grétsy László (ed)
Sportnyelvünk a 21. század elején.
Nemzeti Kulturális Örökség Minisztériuma Budapest:2003. pp. 55-66.
(ISBN: 963-210-122-7)

Journal papers in Hungarian

J11 Borbála Katalin Benkő, Zsolt Pándi
Dokumentumkategorizálás távközlési alkalmazásban.
HÍRADÁSTECHNIKA LX:(11) pp. 45-49. (2005)

J12 Borbála Katalin Benkő, Tamás Katona, Róbert Schulcz
CASCADAS – Autonóm kommunikáció és pervazív, helyzetfüggô szolgáltatások.
HÍRADÁSTECHNIKA LXI:(12) pp. 23-28. (2006)