Current topics in IKS-research; a quantitative approach

By Richard Starmans (UU)

Introduction

The area of information and computing sciences is a relatively new, but by now well-established academic discipline. At the same time, it is a heterogeneous, dynamic and therefore complex research area as well. It is heterogeneous, in the sense that it comprises many different disciplines and sub disciplines, emerging from different scientific traditions; each with its own topics, methodologies, research approaches, research strategies, reference disciplines, vision on validation / evaluation and application areas. It is dynamic in the sense that the field is in a constant state of transition: existing disciplines and paradigms may be redefined or adjusted, new themes and topics emerge rapidly and research agenda's are amended repeatedly. Nature and structure of the field are not predetermined or fixed for eternity; at the most an equilibrium for some time can be expected.

Purely from a scientific point of view it might be important to get insight in the nature and structure of the information and computing sciences: to identify its disciplines and sub disciplines, their relative "importance" and "relevance" and their interrelations; similarities and dissimilarities regarding research approaches, research methods and methodology, reference disciplines, scientific output, etc. These issues might be of some concern for those researchers interested in the foundations or philosophy of computer science, studying its epistemological claims and methodological status. Also, if one acknowledges that scientific research in information and computing disciplines, is an important mechanism through which progress in the field of ICT gets initiated, then insight in the nature and structure of scientific research as it is currently being conducted, certainly is worthwhile.

Obviously, many studies examine the nature of research in computer science, but typically they tend to focus on specific areas and sub areas, rather then scrutinizing the field as a whole. (See for example Ramesh, 2004 and Glas, 2004) More specifically, large-scale empirical studies to identify nature and structure or to monitor developments in the field are rather rare.

"Key-words and index terms"

Be that as it may, it is far from trivial to obtain this insight without doing research.
For example, one can hardly rely on generally acknowledged classification schemes or taxonomies. In fact, most attempts to break down the field and come up with classification systems have not been very successful. For instance, the ACM-classification and sub-classification of computer science (CS), information systems (IS) and software engineering (SE) is well known, but much criticized at the same time. And more importantly, scientific conferences and journals are very reluctant to use rigid classification systems or even delineate the research area at stake. Although there are considerable differences between the journals, typically, most of their editorial boards only publish a very small "scope and aims" section, followed by a list with key-words or index terms, usually with no specific order, structure or further explanation. By and large, these terms are rather heterogeneous. Some are very narrowly focused, others cover a broad field. Sometimes two terms do look almost synonymous, another time one term

seems to be subsumed by the other. Also, they are frequently taken from different reference disciplines and taxonomies / classifications.

Now, considering the goals of any editorial board or conference board, this policy is certainly understandable and defendable. But for those interested in the nature and structure of computer science, such an unordered list is not of much use. However, we believe it can be the starting point to gain this insight and understanding. This article is based on the assumption that a detailed analysis of the use of the aforementioned keywords can contribute to our understanding of the field of information and computing sciences, its underlying structure and the relative importance of its topics.

Aim

In this paper, we obviously cannot cover the entire research in information and computing sciences, but we confine ourselves to the research on information and knowledge systems (IKS), which still is a broad field. The aim of this study is to contribute to the insight in the current state and structure of scientific research in the IKS-field in the Netherlands by analyzing the use of a large number of keywords or index terms, mainly taken from conferences and journals in the IKS-field. Following the "meaning is use" adage of the ordinary language philosophy, we believe that meaning, significance and scope of the terms can actually be established "bottom-up" by analyzing how a relevant and sufficiently large group of language-users applies them. By studying the occurrence, interrelations of the index terms, their relative importance, scope and in fact their meaning can be established and (underlying) structures or patterns in the IKS-field can be recognized.

Population

We therefore conducted a large scale empirical research and asked over 200 researchers working in the IKS-field if and to what extent their research can be related to/associated with these keywords. These researchers had two things in common; they were all involved in phd-research in the Netherlands in the period October 2003-October 2005 and in the same period they were all registered in the National Dutch Research School for Information and Knowledge Systems (SIKS). Founded in the mid-nineties by researchers in the field of Artificial Intelligence (AI), Databases / Information Systems (DB/IS) and Software Engineering (SE), SIKS currently identifies eight research themes:

- Agent technology (AGENT)
- Computational Intelligence (CI)
- Knowledge Representation and Reasoning (KR_R)
- Web-based information systems (WEB)
- E-business systems (E_bus)
- Human computer interaction (HCI)
- Data management, storage and retrieval (D_S_R)
- Architecture-driven system development. (Archi)

The over 200 researchers were employed at ten universities and the CWI and although our research population is not a full representation of all research conducted in IKS in the Netherlands, it is sufficiently representative for our explorative purposes in this paper.

Research questions
Since these “founding disciplines” AI, DB/IS and SE are all internationally identifiable fields of research with their own conferences and journals, it is worthwhile to (re)assess their relevance for current research in IKS in our study. For the eight research themes the same argument applies. Confronting the researchers with these topics does not violate our bottom-up approach; rather it is to be considered as a first, preparatory step towards describing and understanding the field and it can be instrumental to better understand or validate the results of an analysis of the other keywords and vice versa. Given the chosen objective and the population, we try to answer the following five questions:

- To what extent are AI, DB/IS and SE still recognizable and relevant in the IKS-field?
- What is the “joint” profile of the IKS-community, based on the eight research themes?
- What are the “separate” profiles of the AI-researchers, DB/IS-researchers and SE-researchers, based on the eight research themes?
- How can the eight research themes be further characterized and interpreted with the help of a list of selected keywords?
- What underlying structure of the IKS fields can be established, based on an analysis of the list of keywords and taking into account the answers to the previous four questions?

Clearly, the first three questions are preparatory and “top-down” in the sense that they are based on an existing classification of rather framework. Question 5 is the key-question we address; it is “bottom-up” oriented, reflecting the original explorative purpose of the paper. Question 4 is intermediary in the sense that it relates the research themes to the keywords and index terms.

Materials
To answer the aforementioned research questions we developed an electronic questionnaire with over 80 questions, all keywords followed by a 5-point scale ranging from “not at all” to “very much”. The general idea is that by indicating if and to what extent these terms are relevant / characteristic for a specific research project, these notions will get shape and their relative importance for IKS can be established. The questionnaire comprised three clusters of questions.
First, in Cluster 1 we asked the respondent if and to what extent his research fits into / can be related to the fields of AI, DB/IS and SE. Put differently, to what extent does the researcher consider himself to be a AI-researcher, or a BD/IS- researcher or a SE-researcher? Obviously, since these three fields are not mutual exclusive categories of one variable, we should not force the respondent to choose for one of them. Therefore, we needed three questions, the answers of which give us some information on the dependencies between the three fields as well.
Secondly, in Cluster 2, we asked if and to what extent the research fits into / can be related to one or more of the aforementioned eight research themes. Put differently, to what extent does the researcher consider himself to be an Agent-researcher, involved in “E-business Systems” or associated with “Human Computer Interaction”, etcetera? Analogously to Cluster 1 we are not dealing with mutual exclusive categories, so eight variables/items in the questionnaire were considered necessary.
Finally, and most importantly, in the third cluster of questions, we confronted the

researchers with a set of 70 heterogeneous "keywords". Not only can we use them to find patterns and structure in the field, but we can utilize them to better understand and validate answers on the questions formulated in Cluster 1 and 2. and vice versa.

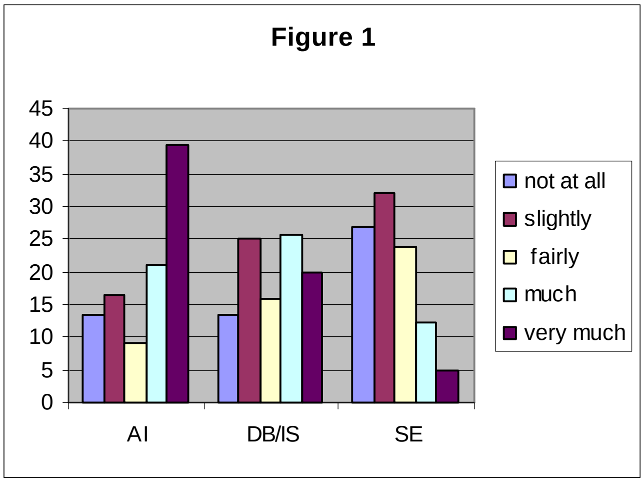
Data manipulation:
For some analyses we use the ordinal ranking provided by the respondents; for example in calculating ordinal correlation coefficients and performing principal components analysis, although formally, the latter technique demands interval level information. For other analyses, we dichotomized the data. We did that in two different ways, using two cut-off points. In the “strong” sense someone is considered to be an DB/IS-researcher/involved in DB/IS-field if he scores “much” or “very much” on that particular item, and is considered not involved else. In the “weak” sense someone is an DB/IS researcher if he scores “fairly”, “much”, or “very much”, and is considered not involved else. So, to make the analysis more robust, we performed analyses twice, using both the strong and weak version. Generally speaking, the differences appeared to be rather small. We only report the results of the “strong”-sense approach. In this short paper neither these differences are taken into account, nor the statistical details concerning the analyses.

Results

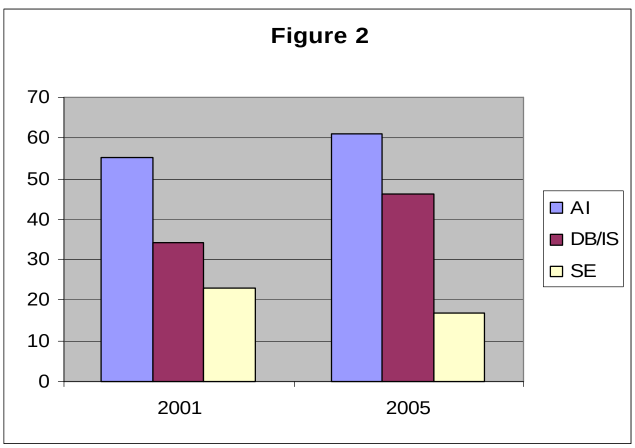
The response percentage was over 90% which is very encouraging. In presenting the main results we follow the order of the five research questions.

Question 1:To what extent are AI, DB/IS and SE still recognizable and relevant in the IKS-field?

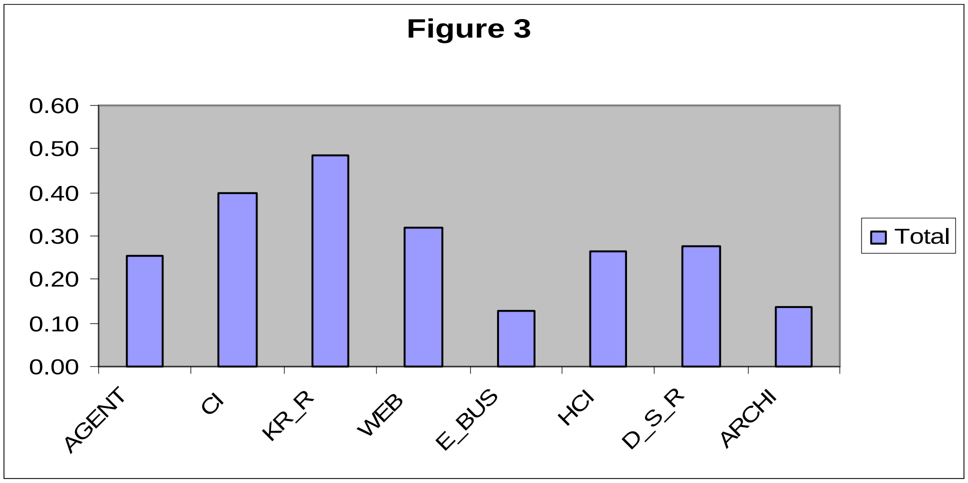
Figure 1 gives a first impression of the relevance of AI, DB/IS and SE for the IKS-field today. It shows the percentages of all five categories of the items. Clearly, AI has a very dominant position. Over 60% scores “much” or “very much” and no less than 40% of the researchers indicates to be “very much” involved. Also noticeable is the fact that very few respondents score “fairly”. Put roughly; researchers do seem to easily make up their mind whether they are involved in AI-research or not.
Regarding the research in DB/IS the distribution is more balanced. Still, 46% scores “much” or “very much”, which suggests a highly relevant research area. Finally, SE plays a rather modest role in the research projects of our population today. Remarkable is that the category “fairly” is stronger represented than in the AI-field or DB/IS-field. Put roughly; relatively many researchers do feel being involved in SE, but not too strongly.



In Figure 2 we compare the results with the situation in 2001, but here the variables are dichotomized in the “strong sense””: only if one scores “much” or “very much” one is considered to be an AI-researcher. Figure 2 suggests that in 2005 AI became even more important. Its relative frequency increased from 54% to 61 %. However, the increase of relevance is even stronger in DB/IS-research. We observe a rise from 34% to 49%. Figure 2 also suggest that the role of SE in our population loses some influence.



The variables are not independent; there still is a distinctive negative correlation between AI and DB/IS (r = -0,39) and a very weak negative correlation between AI and SE (r = -0,12) Unsurprisingly, the correlation between DB/IS and SE is positive, though not strong (r = 0.22) After dichotomizing the data, only 18% of the researchers associates its research with both AI and DB/IS. At this level of analysis the data still suggest two separate worlds.



Question 2: What is the "joint" profile of the IKS-community, based on the eight research themes?

Figure 3 gives a first impression of the relevance of the eight research themes by showing the distribution of their relative frequencies. It suggests that KR_R (49%) and CI (40%) are by far the most dominant themes in IKS-research as represented in our population. KR_R typically is referred to as the foundational area of classical, symbolic AI, whereas CI usually is rather associated with sub-symbolic, numerical techniques. Whether these characterizations are adequate will be made clear in answering the third and fourth research question. Secondly, we observe that WEB, AGENT, HCI and D_S_R are all considered important research areas with scores in the range of 25% to 35%. Finally, our data suggest that ARCHI and E_BUS are numerically relatively small research areas in the IKS-field as represented in our population. Only 17% and 13% respectively indicates to be involved in this research.
This distribution is a first indicator of the relative importance of these themes, but as such does not give much insight in the structure of the field. However, the eight research themes do already shed some light on (the differences in) the profiles of the AI-researchers, the DB/IS-researchers and the SE-researchers, as Table 1 points out.

Question 3: What are the "separate" profiles of the AI-researchers, DB/IS-researchers and SE-researchers, based on the eight research themes?

TABLE 1	Total	AI	DB/IS	SE
AGENT	0.25	0.39	0.13	0.25
CI	0.40	0.52	0.28	0.11
KR_R	0.49	0.63	0.5	0.5
WEB	0.32	0.24	0.58	0.67
E_BUS	0.13	0.12	0.24	0.48
HCI	0.27	0.20	0.36	0.37
D_S_R	0.28	0.17	0.55	0.36
ARCHI	0.14	0.10	0.2	0.44

Table 1 should be read as follows. From the AI-researchers only 12% considers himself involved in E-BUS, from the DB/IS-community more than half associates its research with D_S_R and from the SE-researchers nearly 70 % is involved in WEB. This rather condensed table shows some interesting observations that ask for further analysis and explanation. In this short paper, we confine ourselves to the most relevant ones.

First, it is noteworthy that KR_R is the most dominant among AI-researchers (63%), but also very important for DB/IS and SE-researchers. (Both 50%) So in this respect, it is not a very distinctive characteristic or subgroup for this population and the use of the term is not restricted exclusively to the foundational area of classical, symbolic AI. The at first sight paradoxical fact that the overall score (49%) is lower than the scores of the three founding disciplines, can easily be explained by the fact that AI, DB/IS and SE are three distinct variables, not three mutually exclusive and totally exhaustive categories of one variable.
Next, CI appears to be a leading research theme in the IKS-field: among AI- researchers it scores 52% and in DB/IS and SE considerably lower, the data suggest it is a rather distinctive characteristic of the population.
Thirdly, the data indicate that WEB plays a rather important role in DB/IS (58%) but is considerably less dominant in AI. (24%) This is noteworthy given the fact that many AI-researchers are involved in Semantic Web, Ontologies and metadata and Web intelligence. Also the high score of WEB in the SE-community (67%) is notable.
Fourthly, we observe that E_BUS and ARCHI are relatively small, not only in the entire population, but even among DB/IS-researchers. On the other hand WEB (58%) and D_S_R (55%) are very important in DB/IS-research. This suggests that the remarkable rise in DB/IS-research in the Netherlands that Figure 2 suggests is due to a rise in research in database technology (DB) rather than in information systems (IS).
Finally, we can summarize some relations. Roughly put, KR_R, CI and Agent are associated with AI. KR_R, WEB, HCI and D_S_R are dominant in DB/IS and SE is best associated with the research themes WEB, E_BUS, KR_R and ARCHI. So with the exception of KR_R the eight research themes do seem to be pretty distinctive in characterizing the AI-, DB/IS- and SE-community.

Question 4: How can the eight research themes be further characterized and interpreted with the help of the selected keywords?

We will sketch a very short profile of each research theme by indicating to what extent its researchers are involved in the three founding disciplines, how it is correlated with the other research themes, what are the most relevant keywords and what role qualitative empirical research (QUAL) and quantitative empirical research (QUAN) play in it.

Agent technology
Agent researchers consider themselves heavily involved in AI-research (93%) and only slightly in DB/IS (22%) and SE (20%). The NOAG-ICT theme Intelligent systems scores highly as well (85%) Considering the other research themes: KR_R unsurprisingly scores high (59%), and less unsurprisingly CI scores 32%. Regarding the correlations with the other research themes only a few weak associations can be found. Remarkably the correlation with WEB is weakly negative (r= -0.17) and with ARCHI it is weakly positive (r=0.27).
Furthermore, the field is best characterized with the keywords Agent Architectures (73%), Agent Languages (60%), KR_R (59%), Cooperative systems (57%), Interactive

systems (57%), Distributed systems (50%), and Adaptive systems (50%). In addition, the other key words suggest that AGENT is rooted for the main part in the classical, logical or symbolic tradition. Remarkable is that Semantic web only scores (15%) among AGENT-researchers. Amongst AGENT researchers QUAL scores 75% and QUAN scores only 15%.

Computational Intelligence

CI-researchers consider themselves heavily involved in AI-research (88%), noticeably in DB/IS (36%) and only slightly in SE (7%). The NOAG-ICT theme Intelligent systems scores highly as well (70%). Considering the other research themes: only KR_R scores high (59%) and D_S_R still notably (28%) There are no relevant correlations with the other research themes. Furthermore, the field is best characterized with the keywords Machine Learning (72%), Intelligent Data-analysis (48%), Bayesian Networks (42%), Data-mining (40%), Statistical simulation (39%), Reasoning under Uncertainty (39%). In addition the other keywords indicate that CI has few concern with classical AI-issues like Model based reasoning, commonsense reasoning, (modal) logic, planning, etc. QUAN scores 33%, QUAL scores 66% amongst CI-researchers.

Knowledge Representation and Reasoning

KR_R-researchers find themselves heavily involved in AI-research (78%) and DB/IS (46%) and slightly in SE (19%). The NOAG-ICT theme Intelligent systems scores highly as well (68%). Considering the other research themes: CI, AGENT WEB and even D_S_R all have rather high scores. There are no relevant correlations with the other research themes. Furthermore, the field is best characterized with quite diverging keywords: Metadata and ontologies (48%), Reuse of information (44%), Knowledge acquisition and elicitation (44%), Semantic web (43%), Reasoning under uncertainty (40%), Intelligent data-analysis (37%), Digital library(33%), Machine learning (32%) and XML-technology (31%) Agent-architectures (30%). We already observed in Table 1 that the data suggest that KR_R is not only the foundational area of classical AI. The other keywords from the list confirm this view. Finally, among KR_R-researchers QUAL scores 58% and QUAN only 23 %.

Web based systems

WEB-researchers find themselves heavily involved in DB/IS (81%), strongly in AI-research (45%) and considerably in SE (33%). The NOAG-ICT theme Intelligent systems scores highly as well (44%). Considering the other research themes: KR_R scores 52%, D_S_R 48% and HCI 40%. Regarding the correlations with the other research themes there are strong associations with E-BUS (r=0.43) and D_S_R (r=0.42) and a weak negative relation with Agent (-0.17).
Furthermore, the field is best characterized with quite diverging keywords: XML/semi-structured data (0.81), Digital library (62%) Metadata and ontologies (60%) Semantic Web (52%) Reuse of information (48%), Knowledge acquisition and elicitation (44%), Semantic web (43%), Reasoning under uncertainty (40%), Intelligent data-analysis (37%). The analysis of these and other keywords suggest that the research theme WEB essentially has two separated subgroups: one emerging from the DB/IS-community dealing with XML, database technology, D_S_R; the other emerging form the AI-community focusing on semantic web, KR_R, intelligent systems, metadata and ontologies. Under WEB-researchers QUAL scores 67% and QUAN 27 %.

E-business systems

E_BUS researchers consider themselves heavily involved in DB/IS (67%) and considerably in SE (40%) and AI (40%). The NOAG-ICT theme Intelligent systems scores 40%. Considering the other research themes, WEB scores 80%, KR_R 40% and ARCHI 27%. Regarding the correlations with the other research themes there are strong associations with WEB (r=0.43), D_S_R (r=0.42) HCI (r=0.28) and ARCHI (r=0.31). Furthermore, the field is best characterized with the keywords: Business process Modeling (80%) E-services (80%) Distributed systems (60%) Enterprise modeling (52%) Business Process Alignment (47%). Remarkably under E-BUS-researchers QUAL (13%) and QUAN (20 %) obtain low scores.

Human Computer Interaction

HCI-researchers consider themselves strongly involved in DB/IS (60%), AI (44%) and weakly in SE (22%). The NOAG-ICT theme Intelligent systems scores highly as well (45%). Considering the other 7 research themes: Again KR_R scores high (55%), just like WEB (48%) and D_S_R (36%). There are no relevant correlations with the other research themes. Furthermore, HCI is most associated with Interactive systems (66%), Interface design (44%), Multimedia (43%), Hypertext and Hypermedia (43%) XML-technology (36%) and Usability engineering (36%). More than the other research themes HCI-researchers are involved in quantitative empirical research: QUAN scores 40%. QUAL scores 41%.

Data-management, Storage and Retrieval

D_S_R-researchers consider themselves strongly involved in DB_IS research (87%). AI scores 38% and SE scores 22%. The NOAG-ICT theme Intelligent systems scores (36%). Considering the other 7 research themes: WEB scores 57%, KR_R 53% . Furthermore, D_S_R is most associated with quite divergent keywords: Digital library/document retrieval (75%), XML-technology (68%), DB/technology (67%), Metadata and Ontologies (66%), Information Retrieval (66%), Semantic web (50%), Intelligent data analysis (48%), Reuse of information (45%) Information enrichment (41%), datamining (40%). Remarkably under D_S_R-researchers QUAL scores 75% and QUAN 27 %.

Architectures

Archi-researchers consider themselves strongly involved with DB/IS (64%) and SE (55%). AI scores 45%. The NOAG-ICT theme Intelligent systems scores 57 %. Considering the other 7 research themes: WEB scores 50%, E_BUS 45% and AGENT 45% and KR_R 41%. Regarding the correlations with the other research themes there are some associations with E-BUS (r=0.31) Agent (r=0.27) and WEB (r=0.25). Furthermore, the field is best characterized with quite diverging keywords: Distributed systems (68%) software architectures (62%) XML (52%), Database technology (48%). Metadata and Ontologies (48%), Component based development (48%), Adaptive systems (42%), and Information management 43%. Remarkably, under Archi-researchers QUAL scores 75% and QUAN only 5 %.

These eight profiles do give a more detailed view on what the eight research themes are all about. Some of them can be described in a straightforward way, others do not seem to be easily and consistently depicted with the keywords and suggest that a different, more simple structure in the field could be identifiable. This issue will be addressed in the last question of this paper.

Question 5: What underlying structure in the IKS field can be established, based on an analysis of the list of keywords and taking into account the answers to the previous four questions?

To answer this question we first conducted a few principal component analyses on subsets of the entire list of items. In some analyses we restricted ourselves to subsets of the items of cluster 3, in other analysis we also entered the items from clusters 1 and/or cluster 2 to validate the findings from questions 3 and 4, to see how they affect the solutions and to what extent consistency is possible. It is well known that analyses like these are sensitive to the applied algorithms for factor extraction, rotation procedures, the (number of) variables that entered the analysis, etc. However, for our explorative purposes consistency in solutions and interpretability of a solution (also taking into account the answers to the previous questions) is sufficient to meaningfully identify or suggest an underlying structure.
Rather easily in many analyses five factors/components, were consistently found, representing five separate sub areas in the IKS field, only based on our empirical data and for the main part in line with the previous results. It appeared rather straightforward to find a simple structure (where all relevant keywords have high loadings on one particular factor and distinctively lower loadings on the others).

Computational intelligence
In all analyses that we performed, very consistently a component was recognizable / extracted with high loadings for the research theme CI, as well as for the keywords machine learning, intelligent data-analysis, datamining, Bayesian networks, probabilistic reasoning, neural networks, evolutionary computing, statistical modeling and simulation, reasoning under uncertainty and pattern recognition. There is no reason why we shouldn’t keep hold of the old label “Computational Intelligence” to depict this component.

Agent systems
Analogously, we found in all analyses a component with high loadings for the SIKS-research theme AGENT as well as for the keywords agent languages, agent architectures, cooperative systems, distributed systems, cooperative planning and problem solving, compositional design of IKS. There is no reason why we shouldn’t retain the old label “Agent systems” to describe this component

Human computer interaction
In the different analyses quite easily and consistently a factor could be extracted with high loadings for the research theme HCI, as well as for the keywords Interactive systems, Interface design, groupware/ CSCW, virtual reality, usability engineering and quantitative empirical research. There is no reason why we shouldn’t retain the old label “Human computer interaction” to depict this component.

Web and database technology;
We also found in different analyses quite easily and consistently a factor with high loadings for the research themes WEB and D_S_R, for the founding discipline DB/IS, as well as for the keywords information retrieval, multimedia retrieval, semantic web, metadata and ontologies, reuse of information , XML and semi-structured data, databases technology, information enrichment, as well as digital library, content management. Put roughly, it covers the wide-ranging field of retrieval and presentation

of semi-structured document-centric information, but also the supporting technology (storage, novel architectures, algorithms) that scale towards the data volumes that are required in real-life applications. We therefore label this research area here “Web and database technology”.

Enterprise information systems

Analogously, we consistently found in several analyses a factor with high loadings for the SIKS-research theme E-bus and Archi, the founding discipline SE, as well as the keywords Enterprise modeling, requirements engineering, business process modeling, workflow management social and organizational implications of ICT, alignment, component based development and software architectures.

Because all these items are related to / are situated at the “organizational level” (processes, infrastructure, information), we label this factor here “Enterprise information systems”.

Conclusion

To obtain real insight into the nature and structure of a scientific discipline one should address many things, including the research topics that researchers deal with, their research approaches, research methods, reference disciplines and the “level of analysis” (Ramesh, 2004). However, in a complex area like IKS, it seems more recommendable to first identify some structure of disciplines or sub disciplines, before addressing the aforementioned issues. Such a structure can best be identified bottom-up, especially in the absence of a universally acknowledged classification or partition. In this explorative study we essentially tried to identify the most important topics and find some structure in the IKS-field, as it is currently represented in the projects of 200 PhD-students in the Netherlands. The five components that we identified are sufficiently large, internally homogeneous and externally heterogeneous and denote communities as they exist in the field, which makes them a good starting point for further pursuing the aforementioned goal.

Our approach is not without limitations: not all IKS-research is represented, we confined ourselves to PhD-projects and PhD-researchers in our population, our approach was entirely quantitative. Many relations have not been further investigated; not the least the observed differences in QUAL and QUAN between the research areas.

In a next contribution, that will be more qualitatively rather than quantitatively in nature,, we will try to overcome some of these limitations, endeavor for (further) validation and interpretation of the results thus far, and -most importantly- try to describe and compare in more detail the five established subareas of the IKS-field along the dimensions we indicated above.

References

R.L.Glass, V.Ramesh and I. Vessey (2004) *An analysis of Research in Computing Disciplines*. In: Communications of the ACM, June 2004. Volume 47 no.6, 89-94.

V. Ramesh a, Robert L. Glass, Iris Vessey (2004) *Research in computer science: an empirical study.* In: The Journal of Systems and Software 70, pp. 165–176.