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Computer science in Eastern Europe 1989-2014: A bibliometric study

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Computer science in Eastern Europe 1989-2014: A bibliometric study

Structured Abstract:

Purpose: This paper studies the development of research in computer science in 15 Eastern European countries following the breaching of the Berlin Wall in 1989.

Design/methodology/approach: We conducted a bibliometric analysis of 82,121 computer science publications indexed in the Web of Science database and investigated publication, citation, and collaboration patterns of the individual countries.

Findings: Poland has been the most productive country, followed by Russia, the Czech Republic, Romania, Hungary, and Slovenia. Publication rates have increased substantially over the period, but this has not been accompanied by a corresponding increase in the quality of the publications. Hungary and Slovenia are the most influential countries in terms of citations per paper. Artificial Intelligence is the most frequently occurring computer science subject category, with Interdisciplinary Applications the category with the greatest impact. USA, Germany, UK, France, and Canada are the most frequently collaborating Western nations, and papers published in collaboration with USA authors accrue the most citations.

Originality/value: This is the first ever bibliometric study of the whole post-communist Eastern European computer science research as indexed in the Web of Science.

Keywords: Computer science, Eastern Europe, Web of Science, Bibliometrics, Analysis, Citation analysis

Article Classification: Research paper

1. Introduction

The breaching of the Berlin Wall in 1989 was perhaps the most significant event in the break-up of the former USSR's domination of Eastern Europe. In the 25 years since then the Communist Block countries, both those already in existence (e.g., Hungary and Poland) and those arising from the subsequent break-up of the USSR (e.g., Belarus, Moldova, Ukraine and the Central Asia and South Caucasian states) have gone their separate ways socially, economically and scientifically. In this paper, we present a bibliometric study of the development of computer science in fifteen of these countries over this period.

There have already been several bibliometric studies of scientific developments in the former Communist Block (hereafter FCB) countries during this period. Thus, Karamourzov (2012) analysed development trends in the Commonwealth of Independent States and demonstrated the large, and in some cases, near catastrophic, reductions in scientific activity that have taken place. Kozak *et al*. (2014) showed that the break-up of the Block did not result in significant increase in publication counts or in academic collaborations with international researchers. Radosevic and Yoruk (2014) compared the science and social science capabilities of the countries of Central and Eastern Europe with those of the long-established members of the European Union. Allik (2013) contrasted the very different approaches to research excellence that have been taken by the three Baltic states (Estonia, Latvia and Lithuania), Popovic *et al*. (2012) and Ivanovic and Ho (2014) discussed the improving quality of Serbian academic research, and Vanecek (2008) compared bibliometric data for the Czech Republic with six other EU countries. There have also been many published bibliometric studies of computer science, these involving either a comparison of multiple countries (e.g., Fiala, 2012; Guan and Ma, 2004; Ma *et al*., 2008) or a focus on a specific country, e.g., Brazil (Arruda *et al*., 2009), China (Xie and Willett, 2013), India (Gupta *et al*., 2011) and Malaysia (Bakri and Willett, 2011). However, we are not aware of any such studies of computer science that focus on the FCB countries and the work reported here hence fills a niche in the literature. The next section summarises the methods used, and we then discuss FCB publications, citations to those publications, the nature and extent of international collaborations involving these countries, and similarities between their individual research profiles.

2. Data and methods

The study is based on the *Science Citation Index Expanded* and the *Conference Proceedings Citation Index – Science* databases in the Thomson-Reuters *Web of Science* system. A search was carried out in early 2014 for journal articles, proceedings papers or reviews published in the period 1989-2014 in the Research Area COMPUTER SCIENCE, and then noting those FCB countries that had at least 1,000 publications that met these search criteria. In order of decreasing productivity these countries were: Poland, Russia, Czech Republic (shortened to

Czech in some places of the text below), Romania, Hungary, Slovenia, Slovakia, Ukraine, Croatia, Bulgaria, Lithuania, Serbia, Yugoslavia, Latvia and Estonia. Yugoslavia has been included in the list as meeting the publications threshold; however it should be noted that the last of its publications was in 2006, by which time the country had ceased to exist.

In addition to the countries above, searches were also carried out for the publications of the three South Caucasian states which lie on the boundary between Europe and Asia (i.e., Armenia, Azerbaijan, and Georgia), of four Balkan states (Albania, Macedonia, Montenegro, and Bosnia), of Moldova and Belarus, and of two other countries – the Soviet Union and Czechoslovakia – that are now defunct. None of these countries, however, had reached the minimal threshold of 1,000 publications and they were thus excluded from further analysis. (The first FCB country below the threshold was Belarus with 784 publications.) This study concentrates on Eastern Europe, and the Central Asian republics (e.g., Kazakhstan) were hence not considered at all. In total, the 26 countries inspected produced 82,121 publications; the 15 countries chosen for further analysis were responsible for more than 95% of these publications. The full *Web of Science* publication records for the 15 countries were downloaded in March 2014 and saved as plain text files that were then subsequently imported into a relational database for the analyses that are described below. In this context it is relevant to note that, of course, the 2014 publication data are far from being complete and the 2013 publication data are, most probably, incomplete too due to indexation delays in the *Web of Science* database. However, we decided to retain these years in our analysis because 2014 marks the significant 25th anniversary of the fall of the Iron Curtain.

3. Results and discussion

3.1 Publications

In the period 1989-2014, the 15 countries considered here (and the 11 others with a negligible research output) produced a total of 82,121 computer science publications as detailed in

Table I, which lists for each country the numbers of publications (*P*), the numbers of citations (*C*), the mean number of citations per publication (*CPP*), and the normalized CPP ratio (*NCPPR*). It will be seen that Poland is by far the most productive country, followed by Russia, the Czech Republic, Romania, Hungary, and Slovenia. That said, in looking at the figures in the table, account should be taken of how long the individual countries have been in existence. For example, three of the top-ranked countries - Poland, Romania and Hungary - existed in 1989 and have thus been able to produce publications and collect citations throughout the entire period under review; the only other countries with publications as early as 1989 were Bulgaria and Yugoslavia (which had changed its constitution during this period and which, as noted above, had ceased to exist by the end of the period under review). Since older publications have more time to attract citations, the unequal lengths of existence of the individual countries are reflected in *NCPPR* by averaging the yearly citations per paper divided by the mean number of citations per paper for all papers published in the same year.

[Insert Table I here.]

The overall distribution of publications across all 15 countries is shown in Figure 1. Starting with just 457 publications in 1989, the general trend is for a steady increase until 2008-09 when there were more than 7,000 publications, this being followed by substantial drops in 2010 (22%) and in 2011 (a further 17%) before an apparent levelling-off in 2012; the totals for 2013 and 2014 are incomplete since the data was collected in early 2014. Our assumption is that the most obvious reason for the marked drop-off is the world economic crisis, which started in 2008 and which might be expected to affect the subsequent volume of research and the consequent publications within a year or two of that happening. A comparable drop-off after 2009 is seen if all computer science research around the whole world is considered (rather than in just the FCB countries as here). One of the reviewers of this article was interested in the exact development of all computer science production and so we added a second data series with the publication counts of all computer science papers from the whole world (the dashed line). We can see that the trend is quite similar to our data under study even if they were collected more than a year earlier (March 2014 vs. May 2015). However, the overall trend in computer science cannot be the only reason for the variations of FCB countries observed in Figure 1. Figure 2 shows the productivity curves for the six most productive countries, and it will be seen that the drop-off occurred in different countries at different times, presumably as a result of local circumstances. For example, in Hungary the drop-off occurred in 2007, which we ascribe to the worsening financial situation in the early years of the century causing the country's government to implement a strict austerity programme after the 2006 elections.

[Insert Figure 1 here.]

[Insert Figure 2 here.]

Thus far, the 82,121 publications have been considered as a whole. The publications for each country were then sub-divided into the seven *Web of Science* computer science subject categories: Artificial Intelligence, Cybernetics, Hardware & Architecture, Information Systems, Interdisciplinary Applications, Software Engineering and Theory & Methods (note that some publications have been assigned to multiple categories). The sub-divisions are detailed in Table II, where it will be seen that by far the most popular categories are Artificial Intelligence and Theory & Methods. Breaking down these totals by country enables the identification of national areas of particular expertise. For example, Artificial Intelligence figures prominently in the research profiles of Poland and Latvia, with each having almost 40% of their publications devoted to this subject area; conversely, this category is under-represented in the profiles of Bulgaria, Yugoslavia, and Estonia. Cybernetics has the smallest total number of publications in Table II: it is studied most intensively in Russia (with 17% of the country's total publications) and least intensively in Serbia (with less than 2% of its publications). Hardware & Architecture has the next smallest number of publications in Table II: here the strongest focus is in Croatia and the weakest in Russia. Information Systems is the focus of no less than 52% of all of Lithuania's computer science publications, whereas both Russia and Bulgaria have just 16% of their publications in this category. The former high figure is probably due, in part at least, to the fact that the *Web of Science* journals *Informatics* and *Information Technology and Control* are both published in Lithuania and are home to 38% of the Lithuanian publications in this category. Slovenia and Slovakia have the highest and lowest percentages respectively for publications in Interdisciplinary Applications; while Estonia and Croatia have the strongest, and Slovakia and Bulgaria the weakest, presence in Software Engineering. Theory & Methods is dominated by Russia, and least studied in Slovenia and Croatia; 35% of the 5,255 Russian publications in this category appear in the *Journal of Computer and Systems Sciences International*, which is published in Russia. The inter-category variation is exemplified by Figure 3, which shows the research profiles across the seven *Web of Science* subject categories of the six most productive countries.

[Insert Table II here.]

[Insert Figure 3 here.]

The titles of the 20 publications carrying the largest numbers of FCB outputs are listed in Table III, the two parts (a) and (b) corresponding to the periods 1989-2000 and 2001-2014, respectively. Each row contains a publication name, the number of FCB outputs in that period, and the impact factor (where this is available from the 2013 *Journal Citation Reports* database, with NA indicating that a value is not available). Eight of the journals are common to both tables, demonstrating (as one would probably expect) the long-term nature of many of the research interests. We have noted previously that high national publication rates in a particular journal can be related to the place of publication, and this is further evidenced by some of the data in Table III. For example, 33% of the 2001-2014 FCB papers in *MATCH-Communications in Mathematical and in Computer Chemistry* came from Serbia, the country of publication; and a similar comment applies to 68% of the 2001-2014 FCB publications in *Fundamenta Informaticae* that came from Poland; finally, no less than 87% of the 1989-2014 FCB publications in *Kybernetika*, which is published in the Czech Republic, are listed as coming from there, from Slovakia or from Czechoslovakia.

[Insert Table IIIa here.]

[Insert Table IIIb here.]

One might hope that the substantial increases in publication rates evident in Figure 1 would have been accompanied by an increase in the quality of publication. However, a comparison of the mean impact factors, when averaged over those journals in Tables 3a and 3b for which data are available, shows that the mean has dropped from 1.455 for 1989-2000 to 1.302 for 2001-2014. Further analysis moreover suggests that the FCB countries publish only rarely in the most prestigious computer science journals (as denoted by their 2013 impact factors from the *Journal Citation Reports* database). For example, *ACM Transactions on Intelligent Systems and Technology* has the highest impact factor for the journals in both the Artificial Intelligence and Information Systems *Web of Science* categories; however, the 15 FCB countries contributed just 0.93% of the publications in the journal using the search parameters described in the methods section (i.e., journal articles, proceedings papers or reviews; 1989-2014; and *Science Citation Index Expanded* or *Conference Proceedings Citation Index – Science* databases). Very low percentage contributions are also observed for the most prestigious journals in two other categories: 0.40% for *IEEE Wireless Communication* in Hardware & Architecture; and 0.64% for *ACM Transactions on Graphics* in Software Engineering. Better results are obtained with *IEEE Transactions on Systems, Man and Cybernetics Part B-Cybernetics* in Cybernetics (2.39%, where one-third of the FCB publications involve Witold Pedrycz (see Collaborations below)), and with *IEEE Transactions on Evolutionary Computation* in Theory & Methods (2.68%). The highest percentage contribution of 6.11% is obtained with *IEEE Transactions on Industrial Informatics* in the Interdisciplinary Applications category.

3.2 Citations

Turning now to the *C* and *CPP* values in Table I, it will be seen that there are considerable variations in the impact of the research conducted in the 15 countries, with Hungary and Yugoslavia (*CPP* value of 5.6) at one end of a spectrum that stretches down to Latvia (*CPP* value of 1.6) at the bottom. It is hence hardly surprising that when the *CPP* data are sub-divided by subject category, one obtains, as demonstrated in Figure 4, a more heterogeneous set of plots than is obtained from the publication data in Figure 3.

[Insert Figure 4 here.]

There are two ways of studying the relationship, if any, between the subject category and the citation impact. First, by computing the fraction of the total number of citations for a country that are received by the publications in a specific category; second, by computing the *CPP* values in each of the categories. The first approach helps to identify strongly (or weakly) cited categories for an individual country as compared to their impact in the other countries. For example, publications in Interdisciplinary Applications attract more than 60% of all the citations for Croatia, Estonia and Ukraine; while citations to publications in Cybernetics contribute less than 1% of all the citations of Croatia, Estonia and Serbia. The largest *CPP* values were obtained for Yugoslavia, Estonia and Hungary in Interdisciplinary Applications (values of 8.8, 8.4, and 7.9, respectively), Estonia in Information Systems (7.7), and Lithuania in Hardware & Architecture (7.1). It should be noted that this last high value is due in large part to an article by Avizienis *et al*. (2004): this had attracted 666 citations by March 2014, about ten times the number of citations for the second most cited Lithuanian publication.

The distribution of total citations to the papers published in the six most productive FCB countries in the individual years of the period under study is shown in Figure 5. Inspection of the figure reveals three well-marked peaks in the distributions: Hungary in 2001 with 3,442 citations; the Czech Republic in 2003 with 4,420 citations; and Slovenia in 2006 with 2,912 citations. These figures are clear outliers because the mean number of citations per year is 1,464 for Hungary, 1,368 for the Czech Republic, and 893 for Slovenia. The peaks are caused in large part by three heavily cited articles that make very substantial contributions to the total citations accrued in the respective years and countries: Tusnady and Simon (2001) with 884 citations, Zitova and Flusser (2003) with 1,737 citations, and Demsar (2006) with 1,176 citations. These are the fourth, first, and second most cited computer science articles produced in Eastern Europe from 1989 to 2014; the third most cited article is by Pudil *et al*. (1994) with 957 citations, causing another small Czech peak in 1994. Similarly, Figure 6 shows the distribution of citations to papers in the seven computer science categories over individual years, with well-marked peaks being observed for Interdisciplinary Applications (2001 with 7,808 citations), Software Engineering (2003 with 4,277 citations), and Hardware & Architecture (2004 with 1,977 citations). All of these peaks are the result of articles noted above, *viz* Tusnady and Simon (2001), Zitova and Flusser (2003), and Avizienis *et al*. (2004).

[Insert Figure 5 here.]

[Insert Figure 6 here.]

3.3 Collaborations

Many of the 82,121 publications involved international collaborations, with at least 1,000 publications involving each of the five following Western countries (in order of decreasing number of collaborative publications): the USA, Germany, the UK, France and Canada. The basic data for these collaborative publications are shown in Table IV.

[Insert Table IV here.]

The most striking part of Table IV is the right-hand column containing the *CPP* values, with even the smallest value here (9.7 for Canada) far exceeding even the largest values in Table I (5.6 for Hungary and for Yugoslavia) and with the value for the USA as high as 14.8. This differential level of citation has been noted previously by Teodorescu and Andrei (2011) who found that FCB publications involving international collaborators were typically cited about twice as much as those without such collaborations. The importance of international collaborations on the impact of research has been widely noted (Frenken *et al*., 2009; Glänzel, 2001; Guerrero Bote *et al*., 2013) and Table IV demonstrates that this is clearly the case here.

The extent of international collaborations involving the sets of five non-FCB and 15 FCB countries was studied by creating a 20×20 collaboration matrix, in which the *IJ*-th element denoted the percentage of country *I*'s collaborative publications that involved collaborations with country *J*. Some of the resulting degrees of collaboration are quite strikingly asymmetric, most obviously for collaborations between the Czech Republic and Slovakia, where 7.2% of the Slovak publications involved collaborations with Czech researchers, but where only 2.0% of Czech publications involved Slovak researchers. In like vein, Croatia was much more dependent on Slovenia than *vice versa*; and the Ukraine was similarly more dependent on Russia, although it remains to be seen whether this will continue to be so given the current (2014) political unrest in the Ukraine. In Figure 7 there is a "heat map" of the collaboration matrix, only some aspects of which we discuss in the paper, and, for comparison, there is also a heat map of influence of these collaborations in terms of citations. For instance, Slovakia published 7.2% of its research together with Czech, but this research accounts for 20.7% of Slovakia's citations. Similarly, Ukraine's research with Russia (1.4%)

accounts for 15.3% of its citations and Croatia's research with Slovenia (2.4%) accounts for 10.6% of Croatia's citations. In general, an international collaboration is rewarded by more impact, which is clearly shown in the heat maps. In particular, a collaboration with the USA is very advantageous for the FCB countries with the extreme case of Estonia and 44.2% of its citations to the collaborative research with the USA. By contrast, it is least advantageous for Serbia (only 6%) but still better than with the other four Western nations. The only country, for which it was better to collaborate with Western countries different from the USA, is Ukraine whose publications with Germany and the UK had a greater impact (25.3% and 21.6% vs. 15.3%).

[Insert Figure 7 here.]

Poland has the most extensive involvement with non-FCB researchers, with ca. 25% of the joint publications for France, Germany, the UK and the USA being with Poland. Canada is an extreme outlier here, with 51% of its collaborative publications being with Poland. However inspection of the data reveals that almost one-half of these publications involve a single, highly productive scientist, Witold Pedrycz, who works in the areas of fuzzy sets and neurocomputing and who has concurrent affiliations with both the University of Edmonton and the Polish Academy of Sciences. After the USA, Germany has the most extensive range of collaborations, followed in turn by the UK, France and Canada; the many German links may well arise in part from it being by far the geographically closest of these countries to the FCB. An alternative way of visualizing the collaboration relationships between countries is to generate graphs with nodes as countries and edges as collaborations, where the size of the nodes depends on the number of publications and the thickness of the (bidirectional) edges depends on the (relative) number of collaborations. We did produce such "collaboration diagrams", but due to the high number of edges they looked chaotic and showed little additional information so we content ourselves with presenting the heat maps.

Figure 8 shows the percentage of all publications in each of the years 1989-2014 that have involved a collaboration, either involving just FCB countries or involving both FCB and non-FCB countries. Two conclusions can be drawn from this figure: after a long period when the level of collaboration remained relatively constant, the last few years have seen a rapid increase in the percentage of collaboration-based publications; and collaborations that lie solely within the former Communist Block are much less popular than those involving non-FCB countries, presumably because the latter can bring expertise and funding that is not available locally.

[Insert Figure 8 here.]

3.4 Cluster analysis

The discussion thus far has focused on the individual countries; in this section, we investigate potential relationships between them using the methods of cluster analysis (Everitt *et al.*, 2011). This identifies groups, or clusters, of objects in a multi-dimensional space such that objects in the same cluster are close to each other and distant from those in other clusters. There are many different clustering methods available: here we have used the well-known Ward's hierarchical agglomerative method (1963) to cluster the 15 countries. The method results in a dendrogram, a tree structure in which each of the 15 clusters representing the individual countries are successively merged with other clusters to yield finally a single cluster containing all of the countries.

We have used first the research profiles as exemplified for six countries in Figure 3, i.e., the proportion of research publications in each of the seven *Web of Science* subject categories. The profiles here are clearly very similar to each other, and this is also the case for the remaining nine countries, with the result that the cluster analysis shows that all of the countries are grouped within a single cluster at a very small Euclidean distance. Similar comments apply if we consider each country's international collaborations with other countries, both FCB and non-FCB). Marked differences, however, are observed if we instead consider the citations per paper in each of the subject categories. The resulting dendrogram (Wessa, 2014) is shown in Figure 9, where the individual countries are represented by their top-level internet domains, e.g., RS (Republika Srpska) for Serbia). The dendrogram contains two well-separated clusters: one involving Croatia, Latvia, Romania, Russia, Serbia and the Ukraine; and the other involving the remaining nine countries (Bulgaria, Czech, Estonia, Hungary, Lithuania, Poland, Slovakia, Slovenia, and Yugoslavia). It seems that there is an East-West split even within Eastern Europe regarding the citations per paper with the first cluster including more Easterly nations and the second cluster including more Westerly countries. Thus, the Czech Republic, Poland, Slovakia, Hungary, and Slovenia are geographically the most westerly countries in the region and their physical proximity appears to be reflected by being clustered together. Figure 9 also shows that the successor states (or the largest ones at least) resulting from the break-up of a country are still closely related to each other, e.g., the Czech Republic and Slovakia, Russia and the Ukraine, or Serbia and Croatia. Thus, the old relations between FCB countries obviously still persist in computer science.

[Insert Figure 9 here.]

4. Conclusions

Since 1989, the break-up of the Communist Block has resulted in substantial changes in the FCB countries, including changes in the nature of their scientific research. This paper has reported the first comparative study of the extent of these changes in academic computer science, using data from the *Science Citation Index Expanded* and the *Conference Proceedings Citation Index – Science* databases for the period 1989-2014. The main contributions of the study are as follows:

- We have analyzed 82,121 journal articles and conference papers produced by researchers from 15 Eastern European countries in the period 1989-2014 and indexed in the *Web of Science* database.
- We studied the research production and impact of individual Eastern European countries over the years in the entire period under investigation as well as the production and impact of various computer science categories.
- We conducted a cluster analysis of the countries with the aim of grouping them together on the basis of similarities in their publication, collaboration, and citation behaviour.

Based on the key results we achieved, we may conclude that the most productive Eastern European countries in computer science are Poland, Russia, Czech Republic, Romania, Hungary, and Slovenia. However, the publications of Hungary and Slovenia have the most impact in terms of citations per paper. But, in general, even though the total research production of the countries under study has increased substantially over the years, there is no similar effect regarding the impact of the publications produced. And, in addition, despite similar patterns in publication, collaboration, and citation behaviour of Eastern European countries, there is a visible East-West divide in this region with respect to the citations per paper in the individual computer science categories, with the Western part nations' papers being generally more frequently cited.

An obvious limitation of the study is that it focuses on those countries that have at least 1,000 publications in the *Web of Science* database. One might argue that this threshold is too strict and that also other countries should have been included. Another problem is the instability of this part of the world, resulting in the appearance of new countries, the disappearance of old countries, and the existence of countries covering different territories during the period under study. These characteristics make some of the data difficult to measure and to interpret. Finally, much important research in computer science research is published in conference proceedings and these were poorly represented in the *Web of Science* for many years. Therefore, in our future work, we would like to focus also on other bibliographic databases and other scientific fields.

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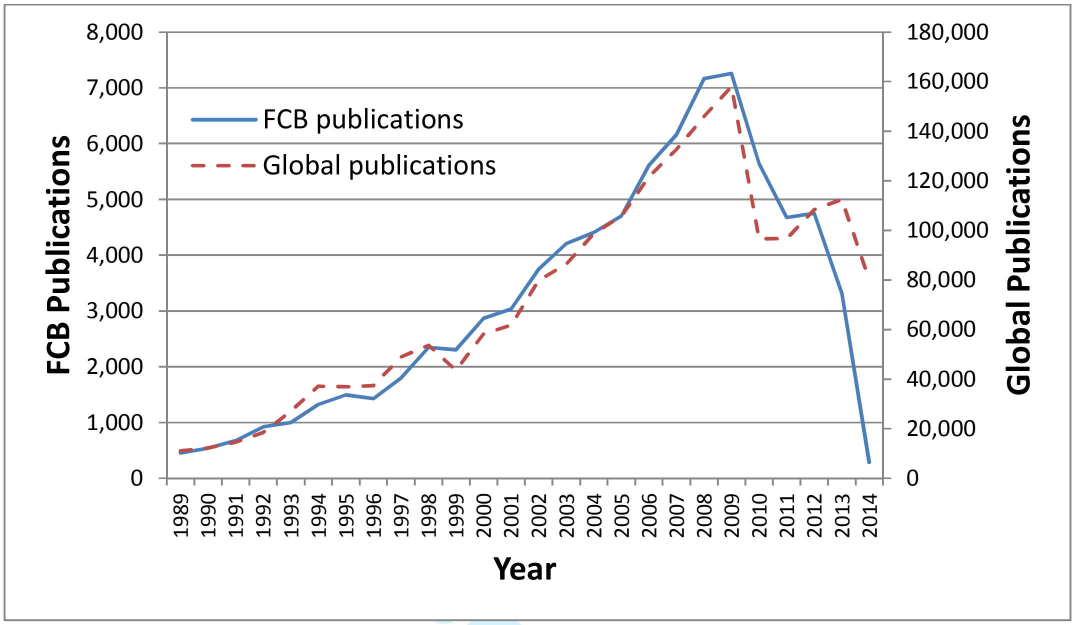

Figure 1. Distribution of FCB countries' publications and of global publications

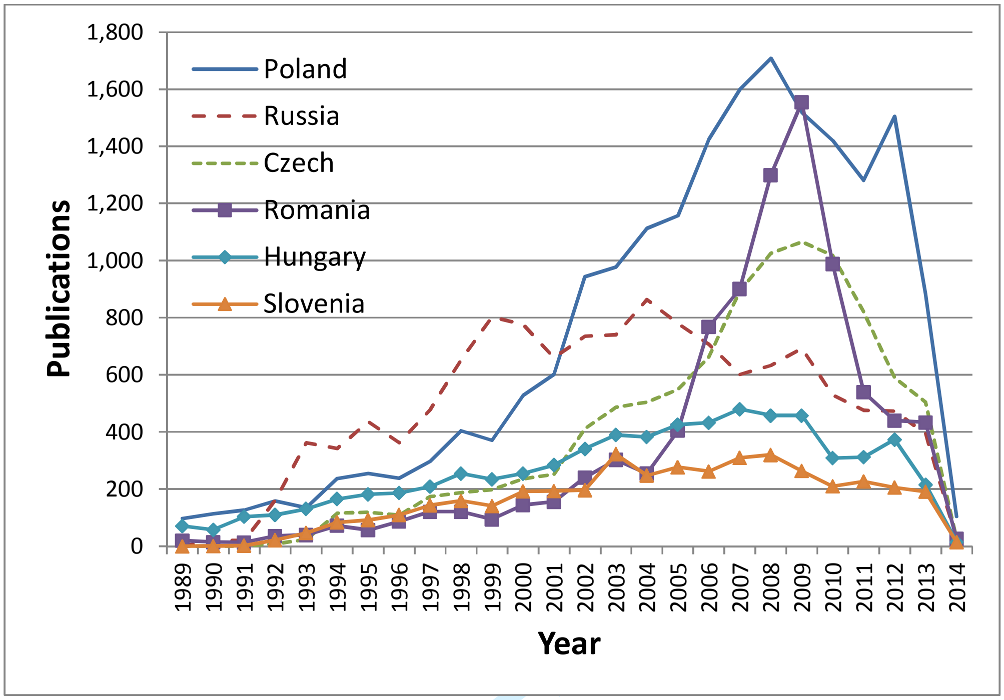

Figure 2. Distribution of the six most productive FCB countries' publications

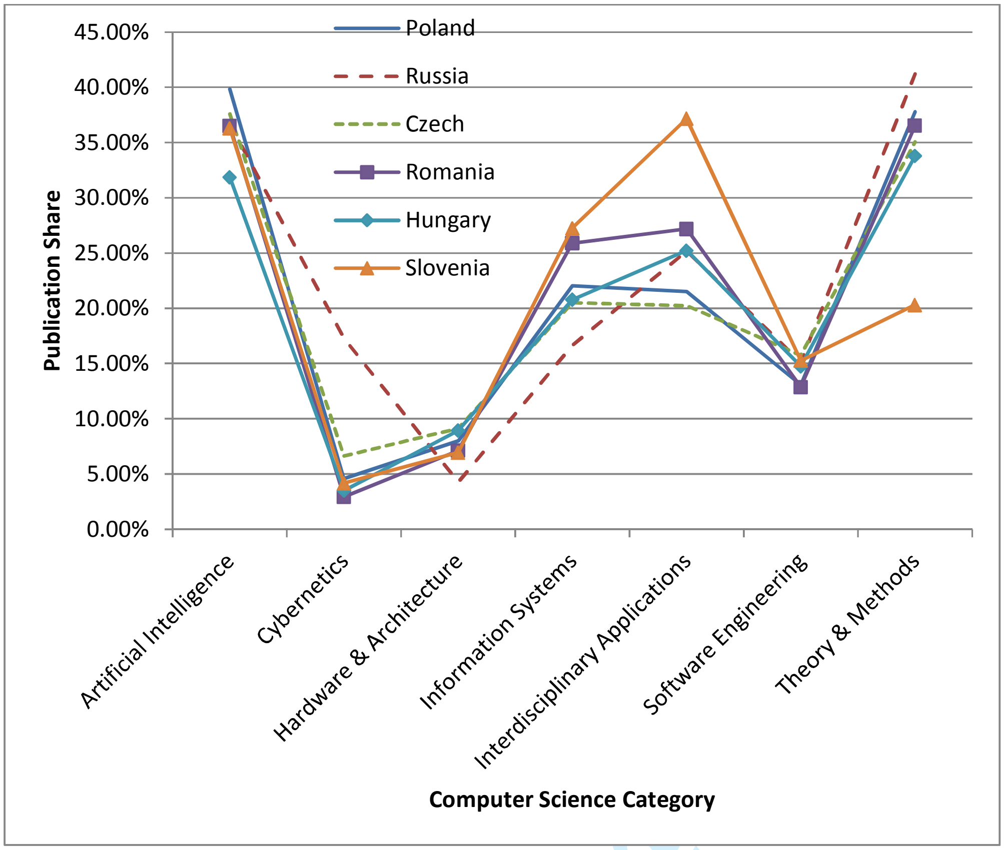

Figure 3. Research profiles of the six most productive FCB countries' publications

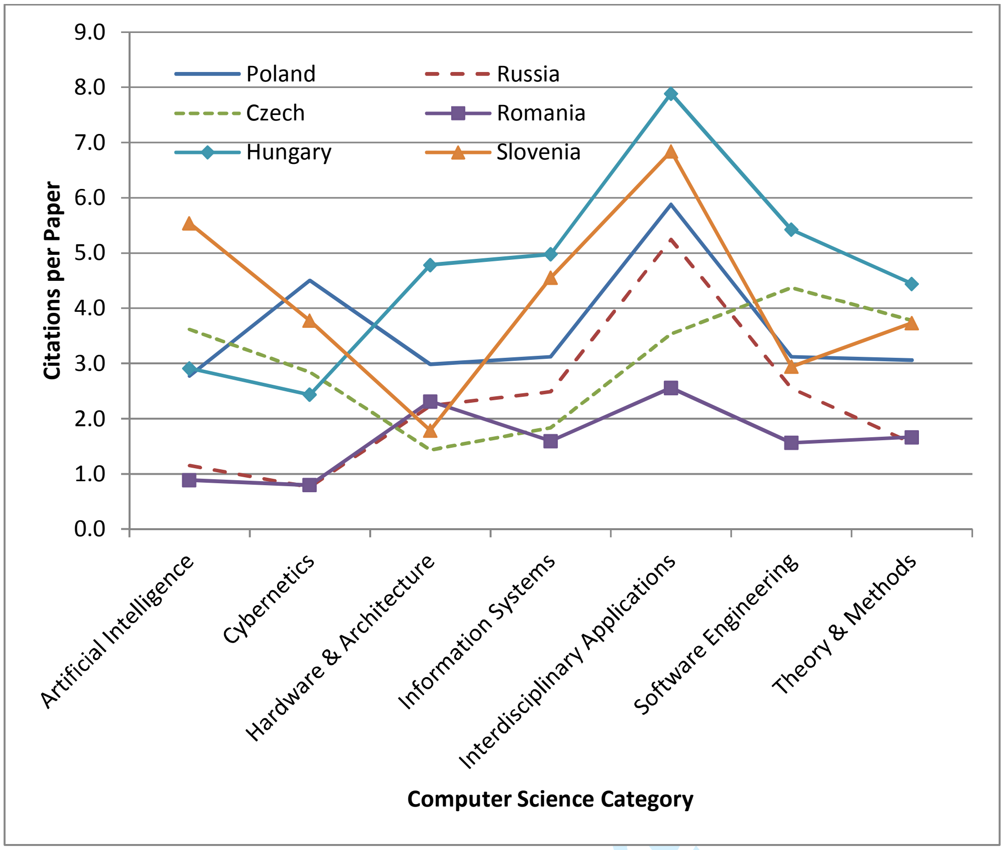

Figure 4. Research profiles of the six most productive FCB countries' citations per publication

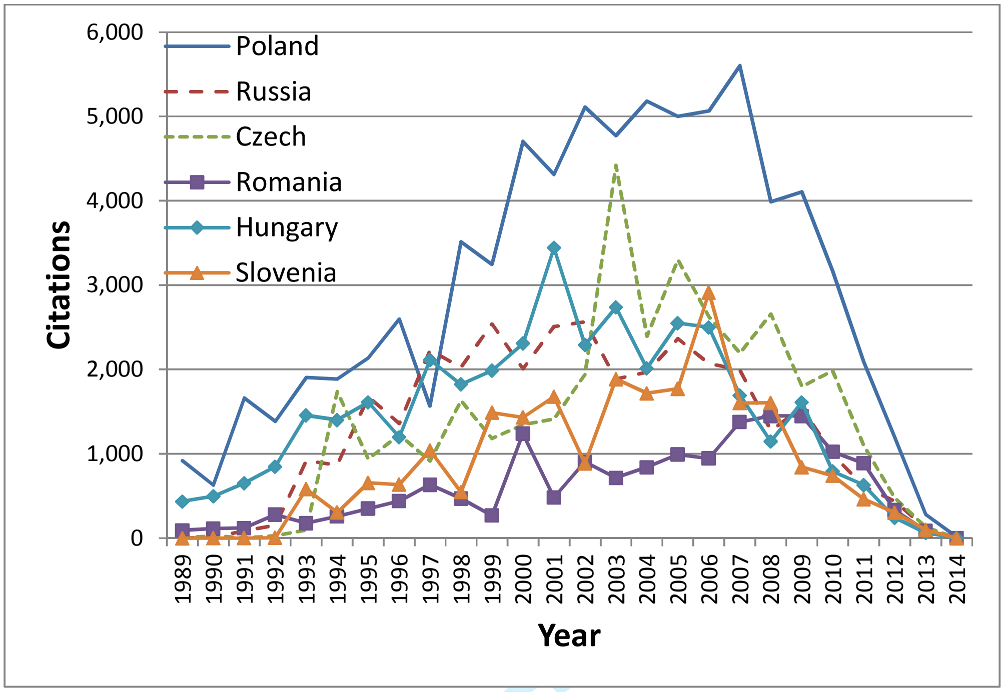

Figure 5. Citations to the papers of the six most productive FCB countries published in individual years

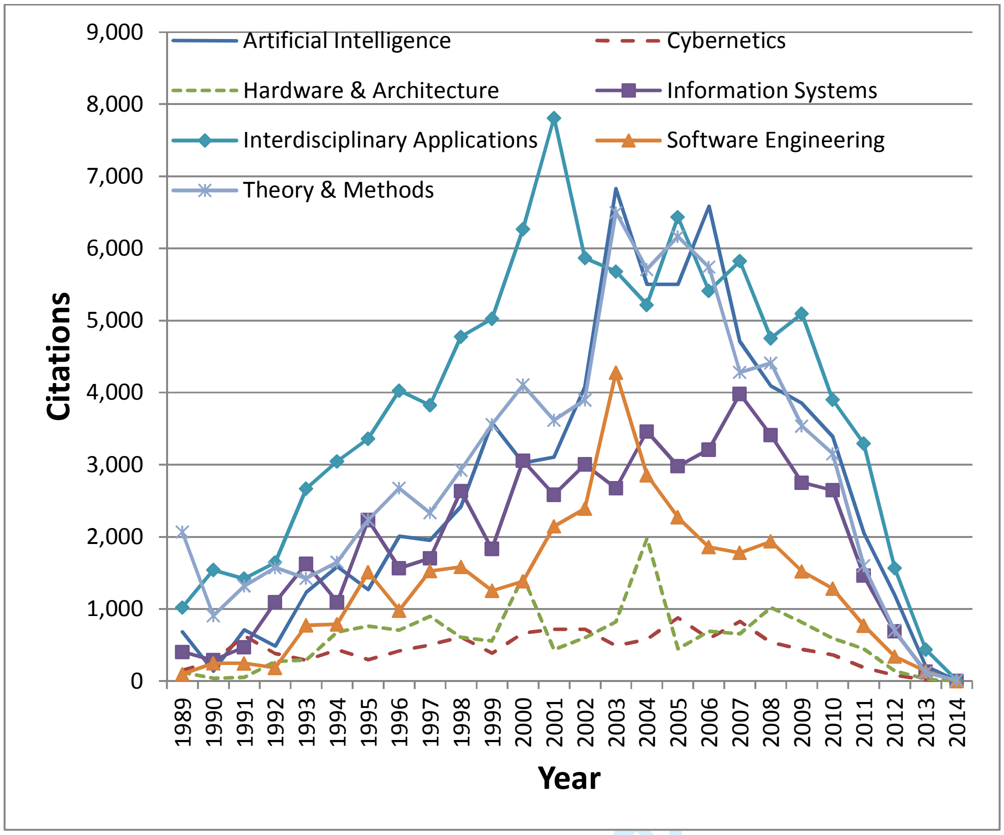

Figure 6. Citations to the papers of FCB countries published in various computer science categories in individual years

	Poland	Russia	Czech	Romania	Hungary	Slovenia	USA	Slovakia	Ukraine	Croatia	Bulgaria	Germany	Lithuania	Serbia	UK	France	Yugoslavia	Canada	Estonia	Latvia
Poland	100%	0.2%	0.2%	0.1%	0.1%	0.1%	3.9%	0.1%	0.1%	0.0%	0.1%	2.4%	0.0%	0.0%	1.8%	1.5%	0.0%	2.8%	0.0%	0.0%
Russia	0.3%	100%	0.2%	0.0%	0.2%	0.1%	4.3%	0.1%	0.3%	0.0%	0.2%	2.5%	0.0%	0.0%	1.6%	2.2%	0.1%	0.8%	0.0%	0.0%
Czech	0.4%	0.3%	100%	0.1%	0.4%	0.3%	3.5%	2.0%	0.1%	0.0%	0.1%	2.6%	0.1%	0.1%	1.5%	1.7%	0.0%	0.7%	0.0%	0.0%
Romania	0.2%	0.1%	0.1%	100%	0.6%	0.1%	2.2%	0.1%	0.0%	0.1%	0.1%	1.4%	0.0%	0.1%	1.1%	1.7%	0.0%	0.5%	0.0%	0.0%
Hungary	0.3%	0.3%	0.6%	0.8%	100%	0.2%	6.2%	0.2%	0.1%	0.2%	0.1%	3.2%	0.0%	0.2%	2.5%	1.7%	0.1%	1.6%	0.1%	0.0%
Slovenia	0.7%	0.2%	0.6%	0.2%	0.4%	100%	4.6%	0.2%	0.2%	1.5%	0.1%	2.2%	0.1%	0.6%	2.1%	1.2%	0.1%	0.6%	0.0%	0.0%
USA	24.5%	18.0%	11.5%	6.7%	14.1%	6.5%	100%	2.6%	2.0%	2.5%	3.8%	6.9%	1.2%	1.6%	5.4%	3.3%	2.2%	3.7%	1.7%	1.1%
Slovakia	1.0%	0.3%	7.2%	0.3%	0.5%	0.2%	2.8%	100%	0.1%	0.0%	0.0%	2.5%	0.0%	0.4%	1.7%	1.6%	0.1%	0.7%	0.0%	0.0%
Ukraine	0.6%	1.4%	0.3%	0.0%	0.1%	0.3%	2.2%	0.1%	100%	0.0%	0.0%	2.2%	0.0%	0.0%	1.7%	1.2%	0.0%	0.6%	0.0%	0.0%
Croatia	0.2%	0.0%	0.1%	0.4%	0.5%	2.4%	2.9%	0.0%	0.0%	100%	0.0%	1.7%	0.0%	0.3%	0.8%	0.7%	0.2%	0.2%	0.0%	0.0%
Bulgaria	0.7%	1.1%	0.4%	0.3%	0.3%	0.2%	5.0%	0.0%	0.0%	0.0%	100%	3.3%	0.0%	0.2%	3.8%	2.5%	0.1%	1.3%	0.0%	0.0%
Germany	24.7%	16.8%	13.7%	6.7%	11.6%	4.9%	11.0%	3.7%	3.1%	2.3%	4.0%	100%	2.6%	2.1%	7.7%	4.8%	1.4%	3.2%	1.4%	1.5%
Lithuania	0.2%	0.3%	0.3%	0.0%	0.1%	0.2%	2.0%	0.0%	0.0%	0.0%	0.1%	2.6%	100%	0.0%	1.6%	0.6%	0.0%	0.3%	0.1%	0.1%
Serbia	0.3%	0.1%	0.5%	0.6%	0.6%	1.4%	2.7%	0.7%	0.0%	0.4%	0.2%	2.3%	0.0%	100%	3.2%	0.9%	0.0%	2.3%	0.0%	0.0%
UK	24.6%	14.6%	10.6%	7.2%	12.2%	6.6%	11.8%	3.5%	3.3%	1.4%	6.2%	10.5%	2.1%	4.1%	100%	6.8%	1.7%	4.1%	1.2%	0.4%
France	23.0%	21.8%	13.7%	12.2%	9.2%	3.9%	8.0%	3.6%	2.6%	1.4%	4.5%	7.1%	0.9%	1.3%	7.4%	100%	0.3%	3.1%	0.9%	0.2%
Yugoslavia	0.1%	0.7%	0.1%	0.2%	0.8%	0.5%	5.2%	0.2%	0.0%	0.3%	0.2%	2.1%	0.0%	0.0%	1.9%	0.3%	100%	1.2%	0.0%	0.1%
Canada	51.1%	9.8%	6.3%	4.6%	10.8%	2.3%	10.8%	1.9%	1.6%	0.6%	2.9%	5.9%	0.6%	3.9%	5.5%	3.8%	1.4%	100%	0.7%	1.0%
Estonia	0.1%	0.2%	0.0%	0.0%	0.6%	0.1%	5.0%	0.1%	0.1%	0.1%	0.0%	2.6%	0.1%	0.0%	1.6%	1.2%	0.0%	0.7%	100%	0.0%
Latvia	0.2%	0.4%	0.3%	0.0%	0.0%	0.0%	3.3%	0.0%	0.1%	0.0%	0.1%	2.8%	0.1%	0.0%	0.6%	0.3%	0.1%	1.0%	0.0%	100%

	Poland	Russia	Czech	Romania	Hungary	Slovenia	USA	Slovakia	Ukraine	Croatia	Bulgaria	Germany	Lithuania	Serbia	UK	France	Yugoslavia	Canada	Estonia	Latvia
Poland	100%	0.4%	0.2%	0.1%	0.3%	0.3%	16.3%	0.2%	0.0%	0.1%	0.3%	7.9%	0.1%	0.0%	4.0%	5.3%	0.0%	6.7%	0.0%	0.0%
Russia	0.8%	100%	1.0%	0.1%	1.0%	0.3%	17.9%	0.1%	2.4%	0.0%	1.0%	10.5%	0.1%	0.0%	7.8%	11.4%	0.1%	3.8%	0.2%	0.0%
Czech	0.4%	0.9%	100%	0.1%	1.2%	0.4%	11.4%	5.2%	0.1%	0.1%	0.5%	8.1%	0.1%	0.3%	9.7%	6.7%	0.0%	1.4%	0.0%	0.0%
Romania	0.4%	0.2%	0.3%	100%	2.0%	0.5%	11.3%	0.2%	0.0%	1.0%	0.3%	3.6%	0.0%	0.1%	2.2%	5.0%	0.2%	3.2%	0.0%	0.0%
Hungary	0.6%	0.9%	1.1%	0.8%	100%	0.5%	20.6%	0.2%	0.1%	0.2%	0.1%	6.5%	0.0%	0.0%	6.5%	3.6%	0.2%	2.4%	0.1%	0.0%
Slovenia	1.1%	0.5%	0.7%	0.3%	0.9%	100%	15.2%	0.2%	0.0%	2.8%	0.2%	5.2%	0.0%	0.6%	4.0%	1.5%	0.6%	0.8%	0.1%	0.0%
USA	27.7%	13.7%	9.0%	4.0%	17.5%	7.9%	100%	2.7%	1.8%	1.9%	2.7%	8.2%	2.5%	0.6%	8.6%	6.9%	3.4%	3.1%	4.1%	0.8%
Slovakia	1.9%	0.5%	20.7%	0.4%	0.7%	0.4%	13.4%	100%	0.9%	0.0%	0.2%	4.7%	0.0%	1.5%	3.8%	4.7%	1.1%	0.8%	0.0%	0.0%
Ukraine	0.5%	15.3%	0.6%	0.0%	0.5%	0.2%	15.3%	1.5%	100%	0.0%	0.0%	25.3%	0.0%	0.0%	21.6%	10.5%	0.0%	3.6%	0.0%	0.2%
Croatia	1.2%	0.0%	0.8%	2.7%	1.5%	10.6%	13.9%	0.0%	0.0%	100%	0.0%	6.4%	0.0%	0.6%	2.6%	2.0%	0.7%	0.6%	1.7%	0.0%
Bulgaria	2.6%	4.1%	2.3%	0.6%	0.5%	0.4%	15.1%	0.3%	0.0%	0.0%	100%	9.8%	0.0%	0.1%	9.3%	2.5%	0.2%	3.6%	0.0%	0.0%
Germany	29.8%	17.8%	14.3%	2.9%	12.2%	5.9%	18.1%	2.1%	6.7%	1.9%	4.0%	100%	2.2%	0.7%	12.1%	9.5%	2.3%	3.1%	1.1%	0.7%
Lithuania	0.7%	0.5%	0.6%	0.0%	0.0%	0.1%	17.5%	0.0%	0.0%	0.0%	0.1%	7.0%	100%	0.0%	14.1%	11.7%	0.0%	0.5%	1.1%	0.0%
Serbia	0.4%	0.3%	2.4%	0.3%	0.3%	3.1%	6.0%	3.1%	0.0%	0.9%	0.1%	3.5%	0.0%	100%	5.6%	2.4%	0.0%	5.5%	0.0%	0.0%
UK	18.6%	16.5%	21.3%	2.2%	15.2%	5.7%	23.8%	2.1%	7.1%	1.0%	4.7%	15.0%	5.4%	1.5%	100%	14.5%	1.6%	3.2%	0.5%	0.7%
France	27.4%	26.3%	16.2%	5.4%	9.3%	2.4%	21.0%	2.8%	3.8%	0.8%	1.4%	13.0%	4.9%	0.7%	15.8%	100%	0.1%	3.0%	0.7%	0.0%
Yugoslavia	0.1%	0.6%	0.0%	0.5%	0.9%	2.0%	21.6%	1.3%	0.0%	0.6%	0.2%	6.7%	0.0%	0.0%	3.8%	0.2%	100%	5.1%	0.0%	0.0%
Canada	50.7%	12.8%	4.9%	5.1%	8.9%	1.9%	13.7%	0.7%	1.9%	0.4%	2.9%	6.3%	0.3%	2.4%	5.2%	4.4%	3.6%	100%	0.9%	0.8%
Estonia	0.0%	1.4%	0.0%	0.0%	1.0%	0.7%	44.2%	0.0%	0.0%	2.5%	0.0%	5.5%	1.7%	0.0%	2.1%	2.6%	0.0%	2.1%	100%	0.0%
Latvia	0.6%	0.1%	0.0%	0.0%	0.0%	0.0%	22.3%	0.0%	0.6%	0.0%	0.2%	8.7%	0.0%	0.0%	7.1%	0.1%	0.1%	5.4%	0.0%	100%

Figure 7. Collaboration share (top) and citation share (bottom) matrix of 15 FCB countries and five Western nations as a heat map

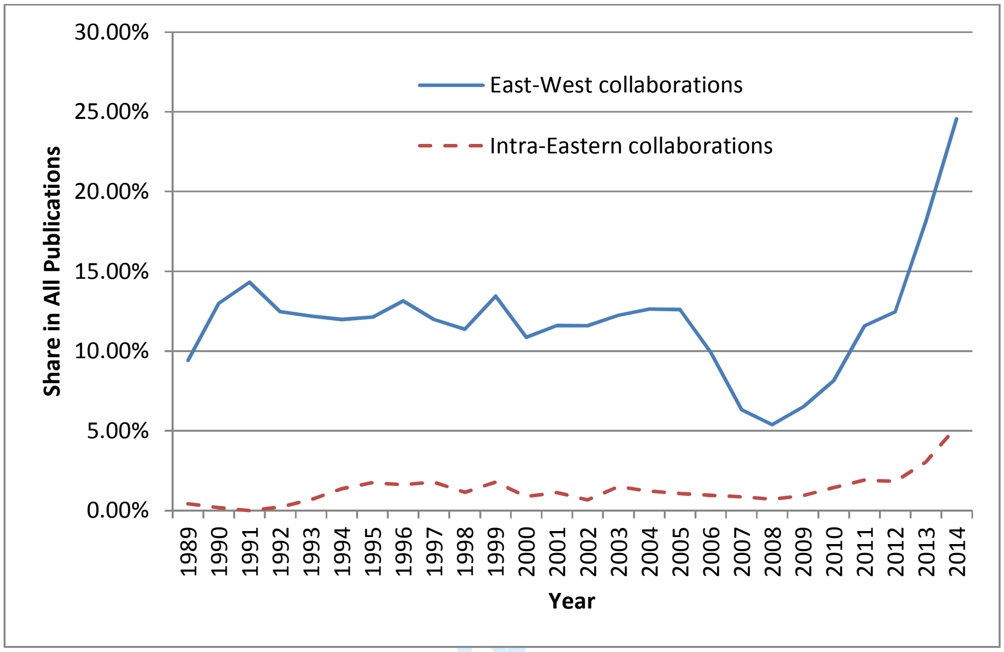

Figure 8. Collaborations between FCB and non-FCB countries, and just within the FCB countries

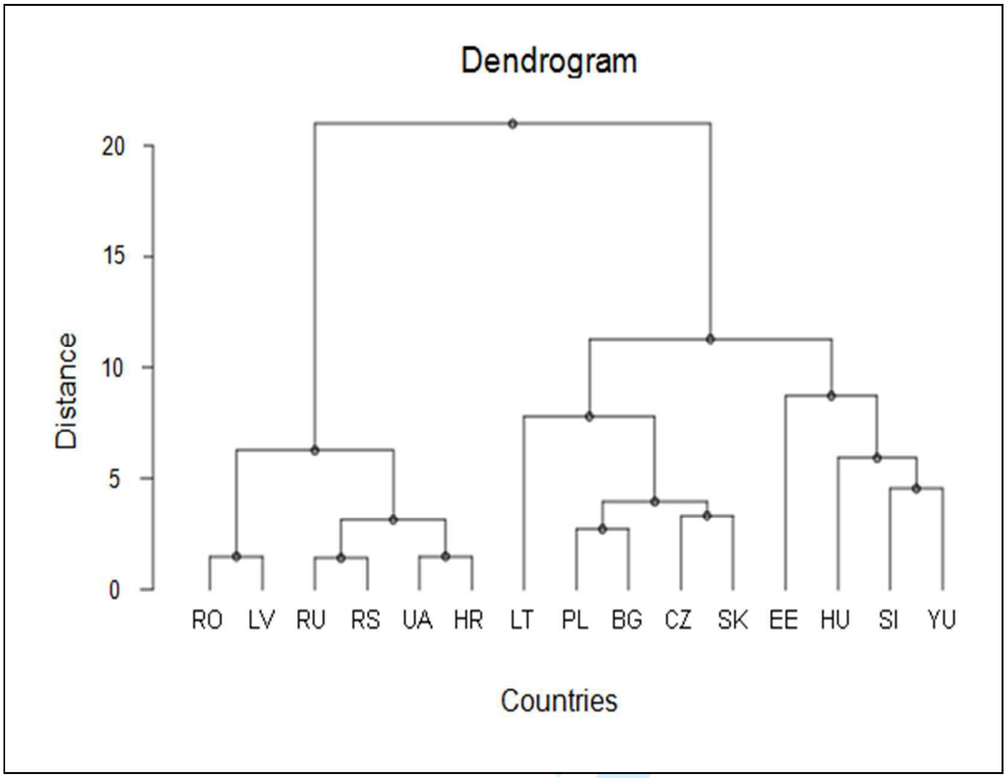

Figure 9. Cluster analysis of 15 FCBs based on citations per publication in the seven *Web of Science* subject categories

Table I. Computer science publications by 15 FCB countries 1989-2014

Country	*P*	*C*	*CPP*	*NCPPR*
Poland	19,200	76,031	4.0	1.33
Russia	12,727	34,234	2.7	0.76
Czech Republic	9,990	35,565	3.6	1.31
Romania	9,134	15,950	1.7	0.79
Hungary	6,843	38,051	5.6	1.38
Slovenia	4,239	23,209	5.5	1.34
Slovakia	2,804	8,937	3.2	1.09
Ukraine	2,717	5,316	2.0	0.67
Croatia	2,548	6,110	2.4	0.85
Bulgaria	2,283	8,124	3.6	0.95
Lithuania	1,864	6,271	3.4	1.38
Serbia	1,764	4,297	2.4	1.05
Yugoslavia	1,262	7,055	5.6	1.15
Estonia	1,019	4,165	4.1	1.17
Latvia	1,000	1,568	1.6	0.55

P: number of publications; *C*: number of citations; *CPP*: mean number of citations per publication; *NCPPR*: normalized CPP ratio.

Table II. Computer science subject category publications by 15 FCB countries 1989-2014

Subject Category	*P*	*C*	*CPP*
Artificial Intelligence	29,858	70,209	2.4
Theory & Methods	28,586	76,231	2.7
Interdisciplinary Applications	20,337	99,941	4.9
Information Systems	19,090	51,016	2.7
Software Engineering	11,786	34,154	2.9
Hardware & Architecture	6,286	15,118	2.4
Cybernetics	5,795	11,451	2.0

P: number of publications; *C*: number of citations; *CPP*: mean number of citations per publication.

Table IIIa. The 20 titles carrying the largest numbers of FCB publications in 1989-2000

Journal	*P*	Impact Factor
Journal of Computer and Systems Sciences International	846	0.265
Lecture Notes in Computer Science	371	NA
Journal of Chemical Information and Computer Sciences	316	4.068
Computers & Mathematics with Applications	314	1.996
Fuzzy Sets and Systems	309	1.880
Kybernetika	300	0.563
Programming and Computer Software	298	0.233
Computer Physics Communications	263	2.407
Compel-The International Journal for Computation and Mathematics in Electrical and Electronic Engineering	224	0.440
Theoretical Computer Science	218	0.516
Computers & Chemical Engineering	213	2.452
Nauchno-Tekhnicheskaya Informatsiya Seriya 2-Informatsionnye Protsessy I Sistemy	199	NA
Computers & Structures	173	2.178
Cybernetics and Systems Analysis	169	NA
Computers and Artificial Intelligence	166	0.319
Automatic Control and Computer Sciences	154	NA
KORUS 99: Third Russian-Korean International Symposium on Science and Technology	153	NA
Avtomatika I Vychislitelnaya Tekhnika	148	NA
MELECON 98: 9th Mediterranean Electrotechnical Conference	147	NA
Computers & Chemistry	136	1.595

P: number of publications.

Table IIIb. The 20 titles carrying the largest numbers of FCB publications in 2001-2014

Journal	*P*	Impact Factor
Journal of Computer and Systems Sciences International	1,222	0.265
Fundamenta Informaticae	611	0.479
Theoretical Computer Science	536	0.516
Computers & Mathematics with Applications	496	1.996
Fuzzy Sets and Systems	496	1.880
Programming and Computer Software	450	0.233
Computer Physics Communications	429	2.407
Experience of Designing and Application of CAD Systems in Microelectronics	428	NA
Kybernetika	407	0.563
Modern Problems of Radio Engineering, Telecommunications and Computer Science, Proceedings	362	NA
Journal of Molecular Modeling	357	1.867
COMPEL-The International Journal for Computation and Mathematics in Electrical and Electronic Engineering	326	0.440
International Journal of Computers Communications & Control	316	0.694
MATCH - Communications in Mathematical and in Computer Chemistry	301	1.829
Mathematical and Computer Modelling	292	2.02
Informatica	273	0.901
Control and Cybernetics	266	NA
EUROCON 2007: The International Conference on Computer as a Tool	265	NA
Information Sciences	253	3.893
Mathematics and Computers in Simulation	253	0.856

P: number of publications. Note that several of the journals in Table 3a have changed their names: the Journal of Chemical Information and Computer Sciences is now the Journal of Chemical Information Modeling; Computers and Artificial Intelligence is now Computing and Informatics; and Computers & Chemistry is now Computational Biology and Chemistry.

Table IV. Non-FCB countries involved in international collaborations

Country	*P*	*C*	*CPP*
USA	3,017	44,727	14.8
Germany	1,891	20,185	10.7
UK	1,383	16,227	11.7
France	1,267	14,814	11.7
Canada	1,039	10,065	9.7

P: number of publications; *C*: number of citations; *CPP*: mean number of citations per publication.