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A Bibliometric Review about Adaptivity

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Abstract

The last decades adaptivity has become an increasingly popular feature within the technological arena and academic publications related to this subject appear more frequently. This article reviews the research on adaptivity in both, technological and broader academic arena, by conducting a bibliometric review of the available academic literature related to the subject. By using bibliometric indexes the results found here can be replicated, complemented and extended in a systematic way, incrementing its utility. The study examines the growth pattern of research in adaptivity, and identifies its top areas; types of publications; and contributing countries and organizations. The review also revealed the value for some of the parameters needed to develop more specialized analysis in adaptivity, such as: scope, timespan, search space and databases. Finally, we propose several analysis to be performed in future works to complement the previous results. This work is, to our knowledge, the first bibliometric review conducted for the subject matter of adaptive behavior.

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Keywords: adaptivity; bibliometric study;

1. Introduction

The idea of an entity capable of modifying its own behavior according to the characteristics of its environment and its own particular goals is not a novelty, it has been around far ago. Several areas of knowledge have shown interest in adaptive behavior, some of them aiming to use some of its features to enhance its performance or as a tool to solve some problems in their domains, and others aiming to study adaptivity as a main feature in their object matter. In this work we propose the application of bibliometric indexes to better understand the presence of academic publications in the different areas of knowledge. As result we present an overview of the development of academic research about adaptivity and we point out some valuable information to assist researchers to locate their work and discover the work done in this subject matter and potential new approaches.

Due to space limitations here we present only some of the basic outputs of the bibliometric indicators, the complete set of outputs are available in `https://sites.google.com/view/bibliometric-adapt-supplement/home`.

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2. Adaptivity

In this section we describe, in general terms, what is our subject matter: adaptive behavior in a broader approach. The section is divided in two subsections: definition (or description) of what is considered as adaptive behavior; and a brief analysis of the etymology of terms related to the study of this phenomenon.

2.1. Description of adaptive behavior

Adaptive behavior, the exercise of adaptivity, is the ability of an *entity*, at any moment, to *decide* performing a self-modification, by *executing* a set of proper actions, of its own features, structure and/or behavior, or even its environment, when facing new incoming events *perceived* in its surroundings while pursuing a particular *goal* in order to *suit more efficiently* the new *context* of its performance [1,2].

The term *entity* can take a wide range of meanings for example: individual, system, structure, agent, being, and so on, encompassing different magnitudes from a single molecule to an interacting group of organisms [3]. The concrete meaning is largely determined by the field of study. The *decision* to effectively change any of its components comes uniquely from its own analysis about the benefits gained in doing so. The direct *execution* of the proper set of actions matching the situation can have indirect repercussions in other available actions that define the behavior of the entity. The analysis mechanism is performed due to stimulus *perceived*, or sensed, in the current situation. The high-level *goal* the entity aims generally is set by an external high-level authority: a leader, a manager, a need or even evolution. The motivation in performing adaptations is a better suiting of the entity and its goal into the new situation. This have a variety of consequences, such as: incorporation/drop of features to take advantage of opportunities, avoidance of threats, or being prepared for facing danger. By being adaptive the entity tries to respond to changes in the *context* in which it performs at that time. This context is defined by the internal features of the entity (its behavior and structure), the characteristics of the external environment (resources, events, objects within) and the channels of interaction between them. While performing such adaptive behavior the entity usually exploits existing knowledge acquired in previous experiences.

2.2. Etymological challenges studying adaptive behavior

Adaptive behavior describes a phenomenon that can be studied, inspected, characterized and dissected from different perspectives. In fact, adaptive behavior has also being called by several names within different areas of knowledge, such as: runtime evolution, dynamic change, runtime/dynamic reconfiguration, autonomic change, and so on. That establishes an etymological challenge for researchers trying to map the scientific work developed in this subject from an interdisciplinary point of view. While doing so, it is important to consider both: the etymological sense of the works used to describe adaptive behavior, and the subject matter of the scientific study. On the first side, analyzing the characterization of adaptive behavior from an etymological perspective allows us to understand the components involved in the phenomenon in general terms, taking off the ad-hoc terminology adopted by different areas. On the other side, the study of adaptivity is gaining attention as a multi-disciplinary concern due to the rising demand for intelligent and more realistic applications. Considering continually changing conditions, critical systems or high-definition simulation of real life situations, are some of the requirements in areas like: IoT, Ubiquitous Computing, Multi-agent Systems, Evolving Systems, Cyber-Physical Systems, Autonomic Computing and others. With such as variety of spaces created to research about adaptivity it is important to correctly differentiate scientific works dealing with adaptive behavior, from those that use some of its features.

3. Bibliometrics

The term was first used by Pritchard [4] and is described as “the application of mathematics and statistical methods to books and other media of communication”. Bibliometric analysis can encompass single documents, authors, research groups, countries or any other defined set. The nature of a bibliometric analysis is, in most cases of comparative kind categorizing the works through bibliographic indexes. In `https://sites.google.com/view/bibliometric-adapt-supplement/home` we provide more information on bibliometric and detail the index used.

In this article we applied bibliometric analysis on adaptivity, aiming to: **(a)** Discovering the nature and evolution of scientific communications regarding adaptive behavior and the scattering order of all cited literature; **(b)** Ascertain the type of reference (direct and indirect) employed in the published output on adaptive behavior and its impact in corresponding mapping of literature; **(c)**Identify the main forms and sources of literature used as a source of knowledge for adaptive behavior; **(d)** Assemble and interpret statistics to demonstrate historical movements, and to determine the research interest of the scientific community.

4. Methodology

In this section we will present the methodology used in this work. The components of this methodology involve two main parts: exploratory search review and bibliometric indexes.

4.1. Exploratory Review

Here we address the configuration for the searches performed: the keywords identifying adaptive behavior, the searches strings and the scientific databases. First, we choose the basic keywords to perform the search. Since we wish to inspect the permeability of academic works about adaptivity we only want to use general terms that successfully identify adaptivity. We will void or filter terms due to: ambiguity (A), domain specificity (D) or inaccuracy in defining adaptivity (I). In our case we work with a triple:

- adaptive: the central term for representing exactly the concept we are looking for. We use the specific term and not its root form, *adapt-*, because the term adaptable which will be retrieved by this root form, as discussed in [5], do not necessarily imply adaptivity;
- self-adaptive: a representative term used in interdisciplinary research that reinforce the idea of auto modification;
- self-managed: adaptivity is a necessary condition for performing self-management or any of its supported self-* features [6,7].

Second, we set up four searches, distinguished by two concepts: search space and type of reference. Regarding search space, two domains are sta: the general space(GS) and the specific space(SS). In the former, we look up for information without regarding any particular area of knowledge. In the latter, we look up for data within the areas related to computation and technology. Regarding the types of reference, we consider two ways of referencing the concept of adaptivity within the publications: direct reference (DR) and indirect reference(IR). We considered a publication has direct reference to adaptive behavior if we found a match for the search keywords in the title of the publication. We understood as an indirect reference the match for the search criteria in the metadata of the publication. The details about which information of the publication compound its metadata depends of the search configuration. In our case the metadata of publications is compound of the fields: author, title, abstract and keywords. Considering these cases we define four searches: Indirect Reference in the General Space (IRGS), Direct Reference in the General Space (DRGS), Indirect Reference in the Specific Space (IRSS), and Direct Reference in the Specific Space (DRSS).

Third, we chose to work with two bibliographic databases [8]: *Web of Science (WoS)* from Thomson Reuters and *Scopus* from Elsevier, both online subscription-based databases widely used in academic research. They provide the following advantages: (i) accessibility through institutional affiliation; (ii) provision of supporting tools for bibliometric analysis within the platform and through several third-party tools that allow either exporting data from WoS and Scopus (e.g. Publish or Perish) or process the information according to the exporting format used by WoS and Scopus (e.g. metaknowledge and library); (iii) sufficient coverage: as pointed out in [9] within the context of natural and formal sciences, WoS or Scopus present an adequate representation of the work within the areas; (iv) reliability: information stored in these databases is recognized as reliable and of high quality. Finally, we build the corresponding search strings and perform the exploratory review in both databases. The search strings used to perform the searches in both the databases are specified in `https://sites.google.com/view/bibliometric-adapt-supplement/`.

4.1.1. Initial Results

After applying the search-strings for each configuration at both databases on November, 17th, 2017, we retrieved some initial results. Table 2 details the number of records for each search.

Table 1: Records retrieved for general space criteria.

Searches	WoS	Scopus
IRGS	439,870	667,293
DRGS	166,732	217,680

Table 2: Records retrieved for specific space criteria.

Searches	WoS	Scopus
IRSS	112,644	108,082
DRSS	52,916	49,656

From those we can observe that WoS outperforms Scopus retrieving works in the specific space searches, while Scopus retrieved until 50% more records in general space configurations. We also confirm that DR searches refined the results to 40%, in average, with respect to the results for IR searches, and searches within the specific space (SS) of computing retrieved in average only 25% of all the records retrieved for the Generic space(GS).

4.2. Bibliometric Indexes

In this work we use some bibliometric indexes[8] to analyze data from three perspectives: frequency of publications, citations and keyword statistics. The analysis on frequency of publications focus on the indicators of historical growth, major areas of research, preferred forms of publication and main journals publishing about the adaptive behavior. We started by gathering the data of scientific works by year in both IRGS and DRGS to plot the growth of publications related to adaptivity within scientific community. Figure 1 shows two particular breakpoints in the growth of publications: (i) the pattern of growth before 1947 are basically the same for IRGS and DRGS: they are sort of stabilized in less then 5 published works; (ii) the pattern changed dramatically around 1947, were the published works triple the previous year. These two particularities are also shown for all searches configurations in both databases, which means that can be treated as a general event. From Figure 1 we can also deduce that there is a tendency for publications related to adaptivity: they are growing consistently since 1991. This suggest that 1991 represents an important year for development, and some works published around this year might add incredible contribution, generating the pattern of a snowball that still remains today.

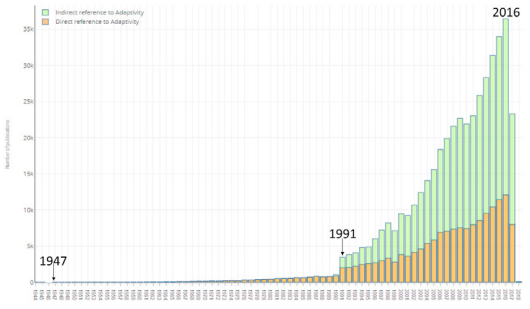

Fig. 1: Growth per year for publications matching the IRGS search

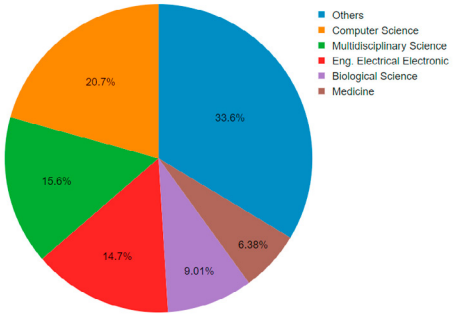

Fig. 2: Distribution of publications per Area of Research matching the IRGS search

Following, we analyze the most active areas, in regards of published academic work, addressing adaptivity. To do so we submit the IRGS data to the WoS Analysis Tool for retrieving the corresponding statistics by area of research. Figure 2 shows the main 5 grouped areas of research that published the scientific works most related to adaptivity. The main area of research is Computer Sci. with 20.7%, followed by Multidisciplinar disciplines with 15.6% and Electrical and Electronic Eng. with 14.7%. More detailed information of this grouped areas and their corresponding values can be found in our supplementary repository in `https://sites.google.com/view/bibliometric-adapt-supplement/`. From this index we can drawn three observations: (i) Computer Sci. is the most active grouped area of research publishing about adaptive features by a large margin; (ii) adaptive behavior reveals its multidisciplinary nature and permeability between areas of research in a steady way, being the second major

group; (iii) the three main areas perform almost the same pattern of growth along the years showing that they do not only hold the historical majority, but they actually propel the research in subjects related to adaptivity in the present.

In order to analyze the preferred forms of publication, we continue working with IRGS to plot Figure 3 that confirms the statement made in[9]: most of the publications in natural science appear in Journals and Conferences. Articles are the main publication type with 57.2%, followed by Proceedings papers with 37.4%, which means that filtering a search by these types of publication ensures a coverage of more than 90% of information. Table 3 shows the top 10 source titles for IRSS retrieved with the Analyze tool available from WoS platform. Here again we observe a balance between Journals (5) and Conferences (5).

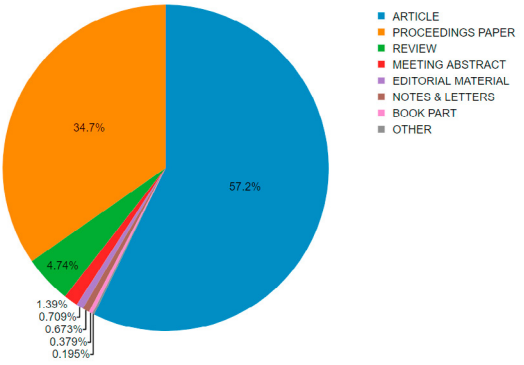

Fig. 3: Growth of publications per Area of Research matching the IRGS search

Table 3: Top 10 publication sources from IRSS configuration in WoS

Type	Source Titles	Records	% of total
J	Lecture Notes in Computer Science	8455	7.568%
J	Lecture Notes in Artificial intelligence	1823	1.632%
C	Proceedings of SPIE	1369	1.225%
C	Int. Conf. on Acoustics Speech and Signal Processing ICASSP	1296	1.160%
J	Neurocomputing	1160	1.038%
J	Journal of Computational Physics	1013	0.907%
C	IEEE International Joint Conference on Neural Networks IJCNN	887	0.794%
J	Communications in Computer and information Science	885	0.792%
C	Proceedings of SPIE	855	0.765%
C	IEEE International Conference on Systems Man and Cybernetics Conference Proceedings	846	0.757%

Information in Table 5 represent the top 10 organization affiliated to research works on adaptivity, and Table 4 lists the top 10 countries developing such research. Both tables reflect, in general terms, the global interest in subjects related to adaptivity within computer and technological venues.

Table 4: Top 10 Countries from IRSS in WoS

Countries/Territories	Records	% of total
USA	25305	22.405%
PEOPLE'S REPUBLIC OF CHINA	23689	20.974%
JAPAN	5643	4.996%
GERMANY	5460	4.834%
ENGLAND	5439	4.816%
INDIA	4693	4.155%
CANADA	4675	4.139%
TAIWAN	4519	4.001%
FRANCE	4499	3.983%
SOUTH KOREA	4415	3.909%

Table 5: Top 10 Organizations from IRSS in WoS

Organizations	Records	% of total
UNIVERSITY OF CALIFORNIA SYSTEM	1990	1.762%
CHINESE ACADEMY OF SCIENCES	1682	1.489%
CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS	1337	1.184%
TSINGHUA UNIVERSITY	1058	0.937%
NANYANG TECHNOLOGICAL UNIVERSITY	1030	0.912%
NANYANG TECHNOLOGICAL UNIVERSITY NATIONAL INSTITUTE OF EDUCATION NIE SINGAPORE	1023	0.906%
STATE UNIVERSITY SYSTEM OF FLORIDA	858	0.760%
INDIAN INSTITUTE OF TECHNOLOGY IIT	777	0.688%
SHANGHAI JIAO TONG UNIVERSITY	747	0.661%
NATIONAL UNIVERSITY OF SINGAPORE	741	0.656%

In our supplementary material located at `https://sites.google.com/view/bibliometric-adapt-supplement/`, we present the corresponding rankings of author using analytic tools to complete the bibliometric method. However, further work is needed in order to develop better indicators for productivity in such cases, which is a big challenge for many reasons (e.g. norms for the attribution of work, author's name standardization).

5. Conclusion and Future Work

According to the applied indexes we present the following conclusions. From the configuration of the searches we learned that it makes a significant difference to apply searches only by DR, the visibility of some interdisciplinary works depend on it. Etymological challenges and the multidisciplinary nature of the subject difficult mapping some works that end scattered with indirect references. According to our results the works retrieved by DR represent the 40% of the works retrieved by IR. In the same way, searching in a specific space (SS) restrict our results up to 25% compared with a general search (GS). Following the reviewing process we learn that conducting the searches

in WoS and Scopus offered an adequate coverage for the subject matter we are interested in researching, both in width (diversity of areas) and depth (computer related areas). From the growth index, we conclude that adaptivity experienced a consistent growth in the last seventy years. A future work is to study this growing pattern to understand if it accompanies particular areas or if it performs an independent development. In fact, the growing pattern in the three main groups in Fig. 2 is very similar, with peaks in 1947 and 1991. These suggests that some events preceded the two main peaks, analyzing this information could help to identify some of the most representative and pioneering works of this interdisciplinary subject. From the type of publication, the main sources of scientific communications in the case of adaptivity came from articles published in Journals (57.2%) and Conferences' Proceedings (37.4%). These results confirm the statement on[9], however, these also confirms the scarcity of literature in extended formats, such as: books, book chapters, white papers or technical communications. The interest in such formats is because they are indicators of the consolidation on the main topics about a subject matter, and the maturity of research. Following that interest, a future work is to analyze the growing publications in the subject from the point of view of emergence of new venues on the subject or the incorporation of new tracks or special issues in existing ones. This last analysis helps mapping the growth in research interest for adaptive behavior from emerging technologies, such as: IoT, Ubiquitous computing, multiagent systems, cyber-physical systems and others. From indexes related to top countries and organizations publishing about adaptivity we conclude that leading research comes from United States of America followed closely by People's Republic of China. However, within the top ten we can observe representation of America, Asia and Europe, confirming that the subject has gained global interest.

Some future efforts that can be done based in the information analyzed in this work are:

- Application of some other classic indexes, such as: Bradford's Law[10], Lotka's Law and Zipf's Law to complement the bibliometric's overview[8].
- Further analysis of citation patterns (shooting stars, sleeping beauties) to identify significant scientific works.
- Further work must be done to consider indicators for "contribution" either when analyzing publications, authors, or institutions. For example, addressing the interactions and exchange of information within technological frameworks, WoS has starting developing indicators for informetrics for such platforms, known as Webometrics, such as: usage counts. Alternative metrics and webometrics[8] to capture the diffusion of a single research product in online tools and environments. Altmetrics estimate impact outside the academy, impact of influential but uncited work, and impact from sources that are not peer reviewed.
- Application of bibliometric analysis for keywords and topics that help identifying alternative descriptioins in different fields of knowledge and emerging topics.

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