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Identifying the evolutionary process of emerging technologies: A chronological network analysis of World Wide Web conference sessions

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ABSTRACT

The significance of a computer-based approach in roadmapping processes will increase in accordance with the ever-larger number of scientific publications and enhanced computing technologies. This article proposes a method to analyse chronological changes in research topics as observed from proceedings papers and conference sessions using a text-mining technique, which enables us to detect, identify, and analyse the evolutionary process of emerging technologies in the many rapidly growing research fields. Chronological networks of conference sessions from World Wide Web conferences between 2002 and 2011 are used to visualize the scientific and technical streams formed by the session sequences. The chronological networks demonstrate the evolutionary process of 'Social Networks', 'Monetization' and 'Semantic Analysis' studies. In the evolutionary process of emerging web-based technology, the convergent session nodes that recapitulate past research topics and the divergent session nodes in the networks play significant roles in promoting dynamic interactions among research topics. The proposed method is distinctive in that it is prospective: the session titles reflect future perspectives, including researchers' expectations for pioneering new research fields within a scientific community. This article also discusses the characteristics of a textual method for scientific publication analysis in terms from the aspect coverage, data, links and stability.

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1. Introduction

Science-based innovation shapes emerging technology, which has the potential to create new industries or transform existing industry [1]. An emerging technology is fundamentally different from the incremental improvement of established technology. An emerging technology often causes technological discontinuity and has disruptive impacts on existing industries, markets, and firms. Strategic research and development (R&D) investment in emerging technologies

can effectively enhance industrial competitiveness, attracting significant attention not only from industrial and business executives but also from policy makers and administrators at the national level. Although it is reasonable to assume continuity, equilibrium, rationality, and optimality for the incremental development of existing technology, these assumptions are not appropriate for emerging technology [1]. Thus, simple extrapolation based on these assumptions makes no sense for emerging technology. To complicate matters, it is extremely difficult even for experts to detect and identify emerging technologies from rapidly changing R&D forefronts. Meanwhile, various science and technology (S&T) roadmaps describing structural relationships among

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science, technology, and applications have been used for strategic R&D in both private and public sectors [2]. Roadmapping techniques integrate an expert-based approach, in which collective knowledge is created, and a computer-based approach that analyses scientific publications, even for emerging technology with disruptive impacts [3,4]. Although the expert-based approach will still be required for the roadmapping process, the significance of the computer-based approach will increase as the number of scientific publications becomes ever vaster and as computing technologies are enhanced. Therefore, this article aims to improve the efficiency and effectiveness of the roadmapping process in the computer-based approach and proposes an objective and quantitative method to detect, identify, and analyse the evolutionary process of emerging technology in rapidly growing research fields.

Undoubtedly, emerging technology has had certain disruptive impacts, which have been changing our lives dramatically. Information and communications technology (ICT) is the most notable representative case in recent years as web-based technology has considerably changed personal and business communications. Hence, for this article, we chose to focus on certain influential web-based technologies that are widespread in current commerce, manufacturing and trade, and personal communications. To detect, identify, and analyse the evolutionary process of emerging web-based technology, we take up the top-ranked international conferences at which the latest cutting-edge papers have been presented. First, this article proposes a method for analysing chronological changes in research topics as observed from proceedings papers and conference sessions, employing text-mining techniques. Second, this article investigates the evolutionary processes of web-based technologies from the analysed results obtained from the top-ranked international conferences on the World Wide Web (WWW). Our main reason for employing academic conferences for our investigation is that they represent a much more rapid dissemination of research outcomes and a higher share of proceedings papers compared to journal articles in computer science [5,6]. Moreover, academic conferences are considered to be specifically designed to advance the frontiers of knowledge within a scientific community. We also assumed that the abstraction levels of the research topics represented by conference session titles would be suitable for analysing the evolutionary process of emerging technology.

This rest of this article is organized as follows. Section 2 briefly reviews related studies on the quantitative methods used to analyse scientific publications concerning a computer-based approach in the roadmapping process. Section 3 describes a visualization method for chronological changes in research topics based on text-mining techniques. Section 4 shows examples of chronological networks from conference sessions and presents an argument concerning the evolutionary processes of emerging research topics. Section 5 discusses the characteristics of the proposed method, and Section 6 outlines conclusions and contributions.

2. Literature review on the scientific publication analysis

Scientific research stimulates technological innovation that accelerates economic growth [7,8], which, in turn,

attracts significant attention from both public and private sectors for strategic R&D at the national and enterprise levels. The application of S&T roadmaps has been expected to support decision-making, in both the public and private sectors, in terms of strategic R&D from the perspective of promoting S&T innovation [2–4]. For example, a roadmap describing structural relationships between patents and technologies has been used in strategic decision-making for collaboration and cross-licencing among firms [9]. In general, the S&T roadmapping process integrates an expert-based approach, aimed at creating collective knowledge from meetings, panels, and workshops, with a computer-based approach that focuses on analysing scientific publications, represented by journal articles and patents [2]. Nowadays, scientific research outcomes are presented primarily as scientific publications that are digitally archived in databases. Although the expert-based approach will still be necessary for the S&T roadmapping process, the significance of the computer-based approach will increase as computing technologies are enhanced and as the numbers of scientific publications become exponentially larger. It is difficult to examine a vast number of scientific publications categorized into various disciplines even for experts. The aim for the computer-based approach in the S&T roadmapping process is mainly to detect, identify, and analyse scientific publications for emerging technology. Scientific publication analyses are here classified into bibliometric, textual, and hybrid methods. Moreover, we further classify the obtained contents into the research topics and trends described below.

2.1. Bibliometric and textual methods

2.1.1. Bibliometric method

Bibliometric analysis employs traits of scientific publications, such as citation, author, and affiliation. In particular, co-citation analysis is useful for detecting and identifying research topics. Co-citation relationships connecting different documents introduce a hierarchical structure [10] and enable the creation of co-citation clusters that contain similar documents [11–14]. Thus, co-citation clusters of documents have been used to detect, identify, and analyse emerging research frontiers [15–21]. In this process, an influential article describing an emerging research topic makes a hub in the co-citation network. Although co-citation analysis is a powerful and sophisticated technique based on the network structure, constructing the linked data that connects the articles is an expensive process, as is identifying the cited articles. It also takes a certain amount of time to index cited articles in databases after article publications. This peculiarity of co-citation analysis would be a disadvantage in an investigation of rapidly changing and growing research fields.

2.1.2. Textual method

Textual analysis, an alternative method of bibliometric analysis for investigating scientific publications, enables researchers to unveil implicit mutual links between articles in disparate disciplines that would be isolated in terms of such bibliometric traits as co-citation and co-authorships [22]. Instead of such explicit and clear connections, invisible and obscure connections can be discovered in textual analysis, constituting a distinctive difference between bibliometric and

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