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An analysis of the structure and evolution of the scientific collaboration network of computer intelligence in games

R. Lara-Cabrera, C. Cotta *, A.J. Fernández-Leiva

Department of "Lenguajes y Ciencias de la Computación", ETSI Informática, University of Málaga, Campus de Teatinos, 29071 Málaga, Spain

HIGHLIGHTS

- We analyze the collaboration network of computational intelligence in games.
- Recent percolation into a giant component and decreasing centralization is shown.
- Sub-linear preferential attachment is observed for new nodes.
- Collaborations are exponentially distributed and fidelity is strong among coauthors.
- Central nodes are projected into keywords to identify hot topics and their relation.

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ABSTRACT

Games constitute a research domain that is attracting the interest of scientists from numerous disciplines. This is particularly true from the perspective of computational intelligence. In order to examine the growing importance of this area in the gaming domain, we present an analysis of the scientific collaboration network of researchers working on computational intelligence in games (CIG). This network has been constructed from bibliographical data obtained from the *Digital Bibliography & Library Project* (DBLP). We have analyzed from a temporal perspective several properties of the CIG network at the macroscopic, mesoscopic and microscopic levels, studying the large-scale structure, the growth mechanics, and collaboration patterns among other features. Overall, computational intelligence in games exhibits similarities with other collaboration networks such as for example a log-normal degree distribution and sub-linear preferential attachment for new authors. It also has distinctive features, e.g. the number of papers co-authored is exponentially distributed, the internal preferential attachment (new collaborations among existing authors) is linear, and fidelity rates (measured as the relative preference for publishing with previous collaborators) grow super-linearly. The macroscopic and mesoscopic evolution of the network indicates the field is very active and vibrant, but it is still at an early developmental stage. We have also analyzed communities and central nodes and how these are reflected in research topics, thus identifying active research subareas.

1. Introduction

Games have long been seen as an ideal test-bed for the study of artificial intelligence (AI) [1]. In the past, much of the academic work on AI and games focused on traditional board games, such as checkers and chess, and these games

* Corresponding author. Tel.: +34 952 13 7158.
E-mail addresses: raul@lcc.uma.es (R. Lara-Cabrera), ccottap@lcc.uma.es (C. Cotta), afdez@lcc.uma.es (A.J. Fernández-Leiva).

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were in turn used to check the goodness/efficacy of AI techniques. Although this traditional focus is still being used, there is now also a growing body of work on applying computational intelligence (CI) to game development (including video games) with the aim of improving the game itself. CI comprises a collection of nature-inspired methods – such as evolutionary algorithms, artificial neural networks and fuzzy logic – for the resolution of complex problems, and can be applied to optimize game development from different perspectives: for instance, from the user's point of view, current players demand, not only outstanding graphics, but also other non-visual features that CI can help to significantly improve such as intelligent/adaptive behavior of non-player characters (NPC), an interesting narrative, or more attractive contents (in the form of, for instance, levels, maps, weapons, armor, terrains, music or even the game rules themselves) and many more. In addition, from the industry's point of view, CI is starting to be viewed as a mechanism to improve the process of game development as well as a tool to extend the commercial life of games. Regarding the first issue, CI is being used to automatically generate game content, such as terrains, maps or even music [2], whereby the automation of this process would lead to a reduction in the production costs as the content would not be entirely hand-created and thus human intervention might be reduced. Moreover, CI techniques applied to achieve this objective in one particular game might presumably be adapted to a similar game belonging to the same genre and this would also reduce the expense of implementing new games. With regard the latter issue, the capacity of CI to produce automated NPC behaviors as well as multimedia content is interesting (and promising) as, in theory, it would be natural to extend a successful (i.e., a best seller) game by procedurally creating new content. This new content in turn would produce a new (commercial) version of the game (the recursive application of this idea sculptures the concept of infinite game) which represents a way of extending the earnings at a minimum cost. Moreover, the industry perceives CI as a tool from which it is possible to gain additional benefits as it can be used to extract interesting players' data that can be employed, for instance, to evaluate player satisfaction (e.g., via emotional analysis) or to construct specific games according to the profile of the users.

However, the application of CI techniques to game development goes beyond the idea of just generating pure entertainment and also covers the purpose of solving hard (and, in many cases, socially accepted) problems; this is for instance, the case of the so-called "serious games". These games prioritize additional objectives than of being simply fun such as training, learning, evaluation, management, marketing, or advertising among others. Serious games have already been implemented in a wide number of heterogeneous areas such as education, health care, politics, or defense [3] and CI has already been applied successfully to the construction of serious games—see Ref. [4].

In general, one can be certain that CI will have a great impact on game development and for this reason the application of CI to games is currently attracting increasing interest from both industry and academia. The consequence of this interest is that this field is a burning issue that seems to have undergone a huge transformation in recent years. To study this transformation, we have embarked on an analysis of the social network of researchers working on CI in games (CIG). Social network analysis – see Ref. [5] for a survey – although an old discipline, has recently been given new impetus and tools from the field of complex networks. A review of complex networks is presented in Ref. [6]. The study of all kinds of networks has been an extremely active research topic in the recent past, following the introduction of models for power-law [7] and scale-free networks [8], which, in turn, has induced the study of many different phenomena in this new light. The particular class of network the study of which is addressed in this work is a co-authorship network [9]: nodes in these networks are paper authors, joined by edges if they have written at least one paper together. Note that the co-authorship data is a social network since collaborating in a research study usually requires that the coauthors become personally acquainted. Thus, studying the ties, their structure, and their evolution enables a better understanding of the factors that shape scientific collaboration. In this sense, this network analysis has been done in many other fields, like mathematics [10,11], evolutionary computation (EC) [12–14], computer-supported cooperative work (CSCW) [15], social sciences [16] and physics, biomedicine and computer science [17,18], to cite some examples.

This work analyzes the collaboration network of the CIG community on three different scales – macroscopic, mesoscopic and microscopic – aiming to discern the status and distinctive features of the community, the rules governing scientific cooperation within it, and the direction in which it is heading as well as trying to identify which seems to be some of the most active research topics in the area.

2. Materials and methods

The bibliographical data used for the construction of the scientific-collaboration network has been obtained from the *Digital Bibliography and Library Project* (DBLP[1]) bibliography server. This database, maintained by the DBLP Team at the University of Trier, provides bibliographic information on major computer science journals and proceedings. It lists more than 1.9 million publications and several thousand computer scientists (as of March 2012). Besides this wide coverage of computer science, the DBLP database provides an easy to use application programming interface (API) to obtain filtered results. The results can be filtered by author, venue, date, keyword, etc. These results are encoded into XML or JSON files, which can be easily parsed by a scraping program.

1 http://www.dblp.org/db/.