Extracting and visualizing research impact semantics

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***Abstract*—Citation lists and metrics applied on them are considered a leading indication of a researchers scientific impact. In this work we consider the publication outlet where citing papers are published in order to extract a deeper understanding of a researcher's scientific impact. The results are obtained in the form of distributed impact metrics, which we then visualize in a suitable and intuitive manner. We report on preliminary results and outline our ongoing and future work towards the development of an integrated system and of reusable widgets, respectively, that implement the proposed ideas.**

I. Introduction

For long referencing of scientific works has been used as a measure of research impact, the underlying assumption being that referenced works form the scientific basis upon which the referencing works are built. Therefore each unique reference implies the existence of yet another new research effort that the original work has had impact on.

The counterarguments to this approach are many, some clearly being quite valid. For example, most citations are found in the introduction or related work sections, merely identifying the referenced papers are similar and not necessarily as works whose findings have been exploited to achieve new results. Moreover, it is not rare for a catchy title to contribute significantly to the number of citations achieved, at times perhaps more so than the quality of the content itself, and many authors have conceded to having referenced works they have not even read, simply because others had also cited them in a similar context. And of course, there are those papers that list many references, this paper itself intentionally being such an example, unavoidably listing some works that have not been really considered, and those that list few references, sometimes omitting works that may have been considered indirectly or even directly.

Still, to this day, the list of citations is considered a leading indication of scientific impact and metrics such as citation count are used even in the evaluation of researchers applying for lecturing and tenured positions. Efforts are being made, of course, to optimize the quality of information extracted from the list of citations. The filtering of citations to remove citations in the considered researchers latter papers, as well as citations from the papers co-authors, is a first step (removal of self-citations). Then, in this enhanced/filtered list of citations, different metrics can be applied aiming to extract a more fair and accurate measure of the impact. These metrics, each one of which has its strengths and weaknesses, examine solely the existence of scientific references. What they fail to do is examine the context of references.

In this work we consider the context of citations in order to extract a deeper understanding of scientific impact. Specifically, we use the publication medium (specific journal, conference etc) as an indication of the scientific discipline to which each paper belongs and use this information in order to partition the citation space. We are then able to examine how conventional citation metrics are distributed in the space of scientific disciplines. We should underline here that our approach does not constitute an alternative citation metric. What we do is identify semantically different partitions of the citation space, upon which any of the conventional citation metrics may be applied. For example, one may calculate the h-index of a researcher's impact per scientific field. As a result, we can see upon which disciplines each researcher is making an impact and we can even discriminate between different types of impacts, such as focused (inter-discipline) or broader (intra-discipline). In order to maintain the ability to assess a researcher's impact with a single look we propose a suitable visualization approach for the richer impact metrics we are calculating. Finally, we outline how this will lead both to an integrated stand alone software platform as well as to widgets that can be added to commercial or personal web pages.

The structure of the remainder of the paper is as follows. In section II we review conventionally used citation metrics. In section III we discuss citation context and how it affects a citation. In section IV we present two characteristic examples that illustrate the type of insight that could be extracted from citation records. Continuing, in section V we outline our approach towards the semantic analysis of citation records and in section VI discuss the intuitive visualization of the acquired research impact information. Finally, section VII outlines our plans for the development of an integrating system implementing the ideas presented in the paper and section VIII lists our concluding remarks. Intentionally, our list of references is partitioned into core and additional references, the first listing works relevant to the paper's contribution and the latter works considered in the paper's examples.

II. Citation metrics

Despite their inherent weaknesses, citation lists are used to this day as one of the most trusted indications of scientific impact. An important driving factor for this is that they are fully quantitative and objective, and can be computed in an automated manner with little or no human intervention. In

order to overcome the weaknesses of the count of citations as a metric, a long list of more elaborate metrics have been proposed. Some of the most commonly used ones are the following.

A. Average number of citations per paper

This metric aims to compensate for the fact that some authors publish more and may appear to have higher impact when only the total number of citations is considered, where in fact each of their works is cited sparingly. It also partially compensates for differences in the number of years researchers have been active.

B. Average number of citations per author

This metric aims to compensate for the fact that single author papers and cooperative works do not indicate the same degree of ownership/contribution and therefore should not be linked with to the same amount of personal impact. Thus, the count of citations for each paper is distributed equally to the contributing authors. Variations are possible, such as crediting a greater part of the contribution to the leading author, or gradually reducing the amount of contribution credited based on the author's position in the author list.

C. Average number of citations per year

This metric aims to compensate for the fact that researchers that have been active for longer inevitably have produced more work. By averaging over the count of years the metric calculates a more fair rate of citations received, which allows for the comparison of veteran and new researchers.

D. h-index and similar indices

A scientist has index h if h of his or her N_p papers have at least h citations each and the other $N_p - h$ papers have $\leq h$ citations each [1]. Various proposals to modify the h-index in order to emphasize different features have been made. For example, there is a variation that considers the number of authors in each paper [2] and another that averages the h-index over the years of activity [3]. In [4] the h-index is partitined into $h1$, $h2$ and $h3$, discriminating between different types of authors such as the perfectionists and the mass producdrs.

The g-index is a well known extention of Hirsch's h-index, where citations count is averaged [5] and the e-index is the square root of citations in the h-set beyond h^2, i.e. beyond the theoretical minimum required to obtain a h-index of h which makes it useful for the comparison of authors with the same h-index [6].

E. s-index

The s-index, playfully defined in [7], is based on the notion of entropy and seems to provide a better quantification of a researcher's impact than the h-index, but only for researchers with large publications records and citation lists.

F. i-10 index

The i-10 index, used in Google Scholar, equals to the number of articles with at least ten citations[8].

III. Referencing context

What the metrics of the previous section fail to consider is the context of each citation. Here we take a look at two relevant contextual aspects and discuss their applicability for the definition of richer citation metrics.

A. Role of referenced work

Not all references in the bibliography section of each paper have the same role. In the current paper, for example, the first part of references lists works that are relevant to the work presented herein, whilst the second part lists works that have merely been examined as part of the citation analysis examples. Whereas both types of references are considered equally in conventional citation metrics, it is clear the the works in the second part of the list have not had a scientific contribution to the current work.

In order to overcome this, it would be useful if we could consider the role of each referenced work in the examined work. CiteSeer^X uses a similar definition for citation context, but this citation context is only presented to the user as additional information and is not considered in any way in the calculation of citation metrics [9].

Clearly, this would require a human, an expert in fact in the topics of the considered work, to study the paper in question and assess the impact each citation has in it. In addition to impossible to tackle due to the resources required, this also introduces a subjective nature which citation metrics aim to avoid. Therefore such a deep consideration of context is not possible.

A lighter version of context examines the part of the text where the citation is referenced. Citations, for example, in the introduction and the section on related work typically have little or no impact on the considered work, citations in the results are typically used as benchmarks whilst citations in the description of the proposed methodology have most probably been used as a methodological basis and are the ones with the highest actual impact. Unfortunately, this is also inapplicable in the general case as it requires all references to be listed in the paper and sections to be clearly identified as related work, methodology or results, which is often not the case.

Consequently, it seems unlikely that this type of contextual information will be used in generalized and automated citation analysis.

B. Scientific scope

In the previous subsection we looked at the importance of each citation for the considered work. Here we focus on the scientific scope of the citation.

Although not always the case, there are those works that are cross-disciplinary in nature, or that simply rely on ideas from different fields. And although it is debatable how important it is to know the scientific scope of each referenced work in a paper, the reverse is clearly more interesting. Specifically, by examining the scientific scope of the referencing papers we can see which fields of science have been affected by a given paper.

The practical question here of course being how to identify the scientific scope of a paper. Keywords are useful but not standardized and are not used in all publications. Titles can be misleading. Textual analysis is not yet mature enough to guarantee almost perfect results when applied on abstracts that may be related to literary any given scientific field. Our suggestion is that the publication medium itself provides a good indication of the scientific scope. When a paper is considered, either by a journal or by a conference, relevance is also examined together with scientific quality. Therefore, the editorial process guarantees that, for example, all papers published at IEEE Transactions on Image Processing are related to image processing and all papers presented at SMAP are related to its listed topics.

Almost all edited publications come with clearly defined scopes and lists of relevant topics, and for those that do not it is relatively easier to produce them manually since this needs be done once for each publication medium and not separately for each paper. Therefore, the automated and objective (i.e. without considering the subjective opinion of a human expert examining the specific paper) consideration of the scientific scope of a given published paper is feasible.

Our suggestion is that it is also interesting in the scope of citation analysis, as it provides richer insight to the paper's impact.

IV. Two indicative examples

In order to explain what type of insight we are looking at, we are listing here details from the citation records of two important researchers, Dr. Cynthia Whissel and Dr. Theodore Simos.

A. Cynthia Whissell

Cynthia Whissell is a professor in the Psychology Department at Laurentian University and she is a psychologist. In her own description of her research interests she lists language and the way language conveys emotion [19]. Therefore, based on studies, place of work and title, as well as on her own description of herself, Dr. Whissell works in psychology and lingustics. Naturally, one would expect the impact of her work to be in the same fields.

The analysis of her work using Publish or Perish quickly identifies paper *The dictionary of affect in language* [20] as her seminal work, having received more than 5 times more citations than any other of her publications. Based on paper title, abstract and even content, this paper is also in the field of psychology and linguistics. Taking a further step and examining where this work appears we find that it is included in a book titled *Emotion: Theory, Research, and Experience*, again very much in the field of psychology, as expected. Similar observations can be made when examining her other works, concluding that there is nothing to imply that her work and expertise might be relevant to other scientific fields.

Taking a closer look a the papers referencing her work, though, there are quite a few surprises. For example, there is this paper:

> S. Soroka, M.A. Bodet, L. Young, B. Andrew, *Campaign news and vote intentions*, Journal of Elections, Public Opinion and Parties, no. 19(4), pp. 359-376, 2009.

Not only the title and the publication medium, but also the content of the paper itself are clearly focused on politics. Linguistic and psychological aspects are briefly considered in the analysis, but only as tools and not as the core subject of the work. Still, a close examination reveals that the role of Whissell's paper is fundamental in the design and application of the work in question. To put this simply, Soroka et al's paper proves that Dr. Whissell has had a direct impact in the scientific field of political analysis.

This paper is neither an outlier nor an exception. In fact, in the first few pages of citations to Dr. Whissell's seminal work we find proof of impact in psychology [21] [22] [23], biology [24], affective computing [25] [26] [27] [28], artificial intelligence [29] [30] [31] [32] [33] [34] [35] [36], multimedia and image processing [37] [38] [39], speech and liguistics [40] [41] [42] [43], management [44] [45] [46] [47] [48] [49], music [50] [51], gender [52], politics [53] [54] [55], bilingualism [56] [57] and more.

As a conclusion, Dr. Whissell's work has a very broad impact in science and is not limited to psychology and linguistics.

B. Theodore Simos

Theodore Simos is a professor in the Department of Informatics and Telecommunications of the University of Peloponnese. He holds a first degree in engineering and a PhD in mathematics, his research and teaching is in mathematics and he describes himself as a researcher of mathematics [58]. He has been included in Thomson Reuters's list of highly cited researchers, claims more than 2000 citations and has an h-index of 37.

A closer look at the complete list of confirmed citations for his work, conveniently available at [58], reveals that almost all of the citing works are published in journals and conferences in the fields of mathematics, computational chemistry and computational physics, i.e. in theoretical and applied mathematics.

As a conclusion, Dr. Simos's work has a very deep impact in mathematics but little or no impact outside that field.

V. Semantic citation analysis

We have already mentioned that the automated and most importantly the objective nature of citation analysis metrics makes them such excellent tools for the assessment of research impact, particularly in competitive settings such as the comparison of candidates for tenured and tenure track positions. Clearly, for our approach to be useful these properties need to be maintained. Therefore we need to describe a system that can apply these ideas without case by case set up or other intervention.

A. Hierarchies and associations

The core element that needs to be developed is the classification of publication media to scientific disciplines. And as the pool of publication media changes (new conferences are being organized, new journals are being founded, existing conferences and journals alter their scope etc.) this association cannot

Fig. 1. Bar representation (with color in the electronic version of the paper)

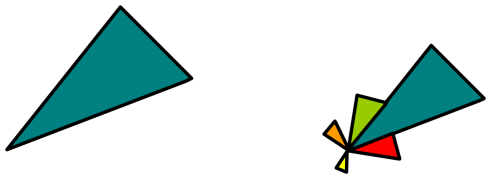

Fig. 2. Area representation (with color in the electronic version of the paper)

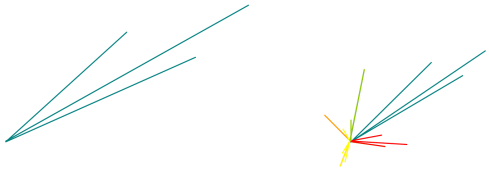

Fig. 3. Second level of field classification (with color in the electronic version of the paper)

be static. But, since these changes are not extremely rapid, the adaptation of the association needs not necessarily be fully automated. For example, it is ok if human input/verification is needed once when a new conference publication is entered in a citation index.

The list of scientific fields, on the other hand, is almost static. Therefore a reasonable first step is to acquire this hierarchy. Existing hierarchies exist that may be considered as a basis, as for example the ones found in [10] or [11].

What is most interesting is the classification of journals and conferences to the chosen hierarchy. Partial journal lists exist that can be used as a basis [12], and citation indices themselves can be used as a source for more complete listings, but then it is clearly a semi-manual effort that will be required to initialize the system. As already mentioned, scope descriptions are already available for most established publication media, and therefore automated supportive tools will not be hard to implement.

It appears that this classification cannot be crist/hard and that a softer approach with multiple associations and degrees should/could be considered; multi- and cross- disciplinary publication media are not rare, with this very workshop being such an example including in its scope topics that range from multimedia and semantics to social media.

B. Metrics

We have outlined the association of publication media to disciplines, and therefore by extension the association of published works to specific scientific fields. The question remains, though, which metrics should be used to meaningfully quantify a researcher's impact.

It is our view that existing citation metrics are more than adequate in quantifying the impact of a researcher's work, they have only been applied too broadly. Thus, our proposal is to use the aforementioned classificaiton scheme to partition citations into semantically relevant groups (disciplines, sub-disciplines and so forth) and then to apply the conventional metrics on these groups.

As a result, for example, instead of a single citation count or h-index, a researcher can have citation counts and h-indices per subject/discipline.

VI. Visualization

We have seen in the examples of the previous sections that a more careful analysis of citation records based on the citation context, and specifically based on the citations' publication media, may reveal differences in the breadth and scope of researchers' impact. Yet, by calculating multiple metrics instead of a single one per author, we lose an important strength of the conventional citation metrics: being able to assess a researcher's impact with a single number.

In order to overcome this, we now look at intuitive ways to visualize the multiple values that we calculate using a single graph. Thus, it will still be able to have a view, in fact a clearer view, of a researcher's impact with a single look. Typically, such lists of numbers would be displayed using bars, as in Fig. 1. In the figure we see the visualization of the hypothetical research impact of two researchers, one with a focused impact (such as Dr. Simos) and one with a broader impact (such as Dr. Whissell). This is certainly an approach that conveys all the information in a single image, but the truth is that one needs to carefully look at the bars and read the legend in order to identify the discipline each individual bar is associated to. Therefore the representation is not particularly intuitive, although using colors to identify disciplines might enhance it.

A more intuitive approach is to depict values not as length but rather as area. The distribution of the area can then be used to depict the disciplines it is related to, as in Fig. 2 where each direction/color is associated with a different discipline. In the provided example we see how roughly equal areas are distributed differently, in sync with the paper's running example. Thus, any user who has become familiarized with this depiction will be able to get a very clear idea of its meaning with a single look.

Similarly, more detail may be depicted if the analysis is not limited to top level but is extended to more detailed discipline classifications, as for example in Fig. 3, although it remains to be examined via experimentation whether this would be more intuitive and preferable to a simple numerical representation.

VII. Implementation

The key output of the proposed methodology is the replacement of unique numerical citation analysis metrics with visualized sets of metrics. Therefore, our implementation plan

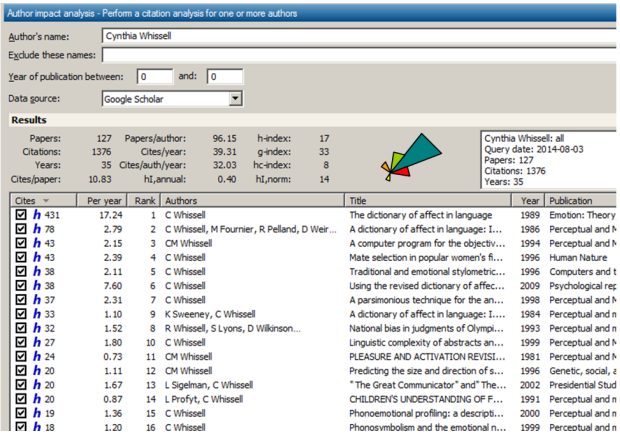

Fig. 4. Publish or Perish interface with visualization (with color in the electronic version of the paper)

is to develop/provide enhanced alternatives to the existing citation analysis tools.

A. Integrated tool

Publish or Perish is probably the leading citation analysis software tool, used by numerous researchers in the estimation of their scientific impact [13] . Ideally we would hope to develop an extended version of this tool incorporating our visualized semantic analysis of citation records. A major obstacle in this direction is the fact that Publish or Perish software is not open source. In order to overcome this we are forced to start from an open source alternative, such as JabRef [14], and re-engineer all the missing functionality. In Fig. 4 we depict how we envision the integrated application.

This is part of ongoing work, currently conducted at the Knowledge and Uncertainty Research Laboratory of the Department of Informatics and Telecommunications at the University of the Peloponnese.

B. Widgets

We also foresee the integration of our approach in web-based tools that provide citation record information, such as researchers' pages on Google Scholar [15], Research Gate [18], Scopus [16], Web of Science [17], CiteSeer^X [9] etc. To this end, we plan to develop widgets implementing the visualization of research impact analysis results and make them available for integration. Such widgets, when available, could also be added to researcher's hope pages as a quick and intuitive visualization of their impact on science, as indicated in the mockup in Fig. 5.

This is part of our future work.

VIII. Conclusion

Citation indices and metrics applied on them are a key indicator of research impact. In this work we use publication context, i.e the medium in which each paper has been published, in order to partition the citation indices into distinct scientific disciplines. This allows us to apply conventional metrics separately in each partition of the citation space, thus acquiring a deeper understanding of a researcher's impact.

Fig. 5. The widget added on a researcher's home page (with color in the electronic version of the paper)

This produces a list of values, one per scientific field. In order to maintain the ability to assess a researcher's impact with a single look we described a suitable visualization approach. This work is not yet completed, and in the closing sections we have outlined how this will lead both to an integrated stand alone software platform as well as to widgets that can be easily added to commercial or personal web pages.

Among other things, our approach allows us to discriminate between different types of impacts, such as focused (inter-discipline) or broader (intra-discipline). We do not advocate in favor of one or the other, we simply provide the tools to make the distinction readily available.

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