MACS 30200
Literature Review

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April 24, 2017

Computer's have been a formal part of scientific work since the 18th Century (Grier, 2013), but the modern day electromechanical machines developed by Turing (Turing, 1937) and many others (Abbate, 2012)(Abbate, 2000) are a much more recent innovation, of the last century (Bauer and Rosenberg, 1972). The introduction of these devices to communities around the world (both metaphorically and literally) has had major impacts on the culture (Lessig, 2007), technology(Abbate, 2000) and rate of development (Bauer and Rosenberg, 1972). Much work has been done to study these effects, but it has been primarily focused on either the macro cultural effects (Pfaffenberger, 1988) or the economic/business usage (Landauer, 1995).

By comparison the usage of computers by scientists has been overlooked by researchers (Lab, 2017). This oversight has many reasons, but one of the most significant is the lack of available data. The primary methods for large scale analysis of the culture or structure of scientific work involve bibliometric techniques (De Bellis, 2009) using large standard datasets(e.g. Boyack et al., 2005; Börner, 2010, 2015; Sugimoto et al., 2013; Shi et al., 2015; Evans and Foster, 2011; Skupin et al., 2013). These dataset are generally lacking information about the computational aspects of the work, e.g. the Clarivate Analytics Web of Science (WOS) does not have any such field (McLevey and McIlroy-Young, 2016) and as such research into this dimension is difficult. Recent developments in natural language processing (NLP) have shown that complex concepts can be extracted reliably from text for a wide variety of tasks (Evans and Aceves, 2016), with some very similar to that done here (Foster et al., 2015).

Information Extraction

To extract the information about software usage from the available data requires complex NLP techniques and the best methodologies change quickly(Evans and Aceves, 2016). As we are primarily concerned with the classification of meta-data for a record relating it to a new software tool or not, in theory there are a large number of available techniques, as this is a simple binary classification problem (James et al., 2013)(Jurafsky, 2000)(Murphy, 2012). We have considered most of the available techniques:

- Classified based on a simple regular grammar, e.g. regex
- Word collocation frequencies (Manning et al., 1999)
- Term frequency–inverse document frequency vectors with an SVM or other classifier (Collobert et al., 2011)
- Word2Vec vectors with an SVM or other classifier(Mikolov et al., 2013)(Collobert et al., 2011)

The the current state of the art for natural language processing is the usage of deep neural networks for information extraction requiring more than simple word level similarities(Manning et al., 2014). As this is the state of the art there is no simple set of rules to follow, but there are some guidelines (Goodfellow et al., 2016). These have lead us to the use of a recurrent neural network (RNN) (Mikolov et al., 2010) for the classification, although the exact specifics have been determined with cross-validation techniques (James et al., 2013). The main features to consider are the type of regularization (Goodfellow et al., 2016), what representation of words to use (most likely Word2Vec (Mikolov et al., 2013)), what non-textual data will be included as there are in the WOS data set over 60 possible fields for each record (McLevey and McIlroy-Young, 2016) and what values the hyperparameters take(Goodfellow et al., 2016). This tuning is highly specific to the data, framework (in this case TensorFlow (Abadi et al., 2016)) and model and the parameters are provided in the supporting material.

Data Analysis

Once the records with new software tools have been identified, we can use the existing theory of bibliometrics to look at the network structure. The literature standard approaches are to look at the structure of these nodes in the citation and authorship graphs (de Solla Price, 2002)(Larivière et al., 2006)(Borgatti et al., 2009). This can be a computationally intensive task but tools exists that make it

more practical (McLevey and McIlroy-Young, 2017) so once the records have been labelled the analysis techniques are no longer novel.

The literature is silent on basic features of scientific software usage, and even when limited to only new releases there is no existing data. Thus simple measures such as per domain counts/frequencies and basic graph measurements such as the centrality will be new contributions.

The other main question of what causes tools to be successful, has not been answered for scientists. There has been some work in the business domain (Xin and Levina, 2008)(Hsu et al., 2009). The adoption of new tools by businesses is theorized to follow a sigmoid pattern, with successful new entrants having three stages of usage: First they are used by early adopters and have small market penetration. Then they reach a "take off point" and the large majority of users will adopter their tools. Finally there will be slow growth in adoption again as only the laggards are left as new users (Xin and Levina, 2008). This is based on adopters having a Gaussian distributed chance of adopting the tool and notably this diffusion model does not require that the software have any costs for the users and allows for network effects, thus this signature is considered in our modelling.

There also has been work done examined open source projects (Mockus et al., 2002) which agrees with the theory (Raymond, 1999) of open source that success is derived from openness and collaboration. This would predict that successful tools would come from highly connected groups who are working successfully with the community. This may show up as high connectedness in the co-authorship network correlating with success.

What leads to success has also be been studied in the context of ideas in the scientific literature (Acharya, 2004) (McLevey et al., 2016) or of individuals(Sinatra et al., 2016). In both cases the main measure of success is the cumulative count of citations, which we can also examine on a per paper and a per author basis. We can look for the predictors of success for a new software tool by examining its citations over time and us this as our measurement for the signature. Notably Sinatra et al. (2016) show a that success very unpredictable and can happen years after the paper is published. If the software records have patterns matching this model then the diffusion model may not be a good fit.

References

Abadi, Martín, Ashish Agarwal, Paul Barham, Eugene Brevdo, Zhifeng Chen, Craig Citro, Greg S Corrado, Andy Davis, Jeffrey Dean, Matthieu Devin, et al. 2016. "Tensorflow: Large-scale machine learning on heterogeneous distributed systems." *arXiv preprint arXiv:1603.04467* .

Abbate, Janet. 2000. *Inventing the internet*. MIT press.

Abbate, Janet. 2012. *Recoding gender: women's changing participation in computing*. MIT Press.

Acharya, Amitav. 2004. "How ideas spread: Whose norms matter? Norm localization and institutional change in Asian regionalism." *International organization* 58:239–275.

Bauer, Walter F and Arthur M Rosenberg. 1972. "Software: historical perspectives and current trends." In *Proceedings of the December 5-7, 1972, fall joint computer conference, part II*, pp. 993–1007. ACM.

Borgatti, Stephen P, Ajay Mehra, Daniel J Brass, and Giuseppe Labianca. 2009. "Network analysis in the social sciences." *science* 323:892–895.

Börner, Katy. 2010. *Atlas of Science: Visualizing What We Know*. Cambridge: MIT Press.

Börner, Katy. 2015. *Atlas of Knowledge: Anyone Can Map*. Cambridge: MIT Press.

Boyack, Kevin, Richard Klavans, and Katy Börner. 2005. "Mapping the Backbone of Science." *Scientometrics* 64:351–374.

Collobert, Ronan, Jason Weston, Léon Bottou, Michael Karlen, Koray Kavukcuoglu, and Pavel Kuksa. 2011. "Natural language processing (almost) from scratch." *Journal of Machine Learning Research* 12:2493–2537.

De Bellis, Nicola. 2009. *Bibliometrics and citation analysis: from the science citation index to cybermetrics*. Scarecrow Press.

de Solla Price, Derek J. 2002. "The pattern of bibliographic references indicates the nature of the scientific research front." *Social Networks: Critical Concepts in Sociology* 4:328.

Evans, James and Jacob Foster. 2011. "Metaknowledge." *Science* 331:721–725.

Evans, James A and Pedro Aceves. 2016. "Machine translation: mining text for social theory." *Annual Review of Sociology* 42:21–50.

Foster, Jacob G, Andrey Rzhetsky, and James A Evans. 2015. "Tradition and innovation in scientists' research strategies." *American Sociological Review* 80:875–908.

Goodfellow, Ian, Yoshua Bengio, and Aaron Courville. 2016. *Deep Learning*. MIT Press. `http://www.deeplearningbook.org`.

Grier, David Alan. 2013. *When computers were human*. Princeton University Press.

Hsu, Maxwell K, Stephen W Wang, and Kevin K Chiu. 2009. "Computer attitude, statistics anxiety and self-efficacy on statistical software adoption behavior: An empirical study of online MBA learners." *Computers in Human Behavior* 25:412–420.

James, Gareth, Daniela Witten, Trevor Hastie, and Robert Tibshirani. 2013. *An introduction to statistical learning*, volume 6. Springer.

Jurafsky, Daniel. 2000. "Speech and language processing: An introduction to natural language processing." *Computational linguistics, and speech recognition* .

Lab, Knowledge. 2017. "The Impact of Programming Languages and Datascience Frameworks on Thinking, Software, and Science." Technical report, The University of Chicago. Unpublished.

Landauer, Thomas K. 1995. *The trouble with computers: Usefulness, usability, and productivity*, volume 21. Taylor & Francis.

Larivière, Vincent, Yves Gingras, and Éric Archambault. 2006. "Canadian collaboration networks: A comparative analysis of the natural sciences, social sciences and the humanities." *Scientometrics* 68:519–533.

Lessig, Lawrence. 2007. *CODE VERSION 2.0*. codev2.cc.

Manning, Christopher D, Hinrich Schütze, et al. 1999. *Foundations of statistical natural language processing*, volume 999. MIT Press.

Manning, Christopher D., Mihai Surdeanu, John Bauer, Jenny Finkel, Steven J. Bethard, and David McClosky. 2014. "The Stanford CoreNLP Natural Language Processing Toolkit." In *Association for Computational Linguistics (ACL) System Demonstrations*, pp. 55–60.

McLevey, John, Alexander Graham, Reid McIlroy-Young, Pierson Browne, and Kathryn S. Plaisance. 2016. "Knowledge diffusion and status boundaries: A statistical network analysis of the relationships between philosophy of science and the sciences." Sunbelt XXXVI (Annual meetings of the International Network for Social Network Analysis). Close to publication.

McLevey, John and Reid McIlroy-Young. 2016. "metaknowledge documentation." `http://networkslab.org/metaknowledge/documentation/metaknowledgeFull.html#WOSRecord`.

McLevey, John and Reid McIlroy-Young. 2017. "Introducing metaknowledge: Software for computational research in information science, network analysis, and science of science." *Journal of Informetrics* 11:176–197.

Mikolov, Tomas, Martin Karafiát, Lukas Burget, Jan Cernockỳ, and Sanjeev Khudanpur. 2010. "Recurrent neural network based language model." In *Interspeech*, volume 2, p. 3.

Mikolov, Tomas, Ilya Sutskever, Kai Chen, Greg S Corrado, and Jeff Dean. 2013. "Distributed representations of words and phrases and their compositionality." In *Advances in neural information processing systems*, pp. 3111–3119.

Mockus, Audris, Roy T Fielding, and James D Herbsleb. 2002. "Two case studies of open source software development: Apache and Mozilla." *ACM Transactions on Software Engineering and Methodology (TOSEM)* 11:309–346.

Murphy, Kevin P. 2012. *Machine learning: a probabilistic perspective*. MIT press.

Pfaffenberger, Bryan. 1988. "The social meaning of the personal computer: Or, why the personal computer revolution was no revolution." *Anthropological Quarterly* pp. 39–47.

Raymond, Eric. 1999. "The cathedral and the bazaar." *Philosophy & Technology* 12:23.

Shi, Feng, Jacob Foster, and James Evans. 2015. "Weaving the fabric of science: Dynamic network models of science's unfolding structure." *Social Networks* 43:73–85.

Sinatra, Roberta, Dashun Wang, Pierre Deville, Chaoming Song, and Albert-László Barabási. 2016. "Quantifying the evolution of individual scientific impact." *Science* 354:aaf5239.

Skupin, André, Joseph Biberstine, and Katy Börner. 2013. "Visualizing the topical structure of the medical sciences: a self-organizing map approach." *PloS one* 8:e58779.

Sugimoto, Cassidy, Vincent Lariviere, Chaoqun Ni, Yves Gingras, and Blaise Cronin. 2013. "Global gender disparities in science." *Nature* 504:211–213.

Turing, Alan Mathison. 1937. "On computable numbers, with an application to the Entscheidungsproblem." *Proceedings of the London mathematical society* 2:230–265.

Xin, Mingdi and Natalia Levina. 2008. "Software-as-a-service model: Elaborating client-side adoption factors." .