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Web Science: Understanding the Emergence of Macro-Level Features on the World Wide Web

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Abstract

In this monograph we consider the development of Web Science since the launch of this journal and its inaugural publication 'A Framework for Web Science' [44]. The theme of emergence is discussed as the characteristic phenomenon of Web-scale applications, where many unrelated micro-level actions and decisions, uninformed by knowledge about the macro-level, still produce noticeable and coherent effects at the scale of the Web. A model of emergence is mapped onto the multitheoretical multilevel (MTML) model of communication networks explained in [252]. Four specific types of theoretical problem are outlined. First, there is the need to explain local action. Second, the global patterns that form when local actions are repeated at scale have to be detected

and understood. Third, those patterns feed back into the local, with intricate and often fleeting causal connections to be traced. Finally, as Web Science is an engineering discipline, issues of control of this feedback must be addressed. The idea of a social machine is introduced, where networked interactions at scale can help to achieve goals for people and social groups in civic society; an important aim of Web Science is to understand how such networks can operate, and how they can control the effects they produce on their own environment.

Contents

1

Introduction

> The web of our life is of a mingled yarn, good and ill together.
>
> *All's Well That Ends Well*, act IV scene iii

This monograph is a distillation of the last seven years' work in the development of *Web Science*. The idea of the interdisciplinary or multi-disciplinary science of the Web has been under refinement since the Web Science Research Initiative (WSRI) was unveiled in late 2006; a series of theoretical and methodological papers [44, 45, 87, 147, 158, 269, 274, 316, 318, 323] has been published expanding on many themes, supplemented by an increasing body of work carried out by an increasingly enthusiastic and coherent cohort of researchers and students. The Web Science Conference has become a growing annual event — 2013 saw the fifth — and is now recognised as an ACM conference. Web Science courses proliferate at undergraduate and graduate levels, and attention to the curriculum is growing all the time [87, 370].

We believe that it is timely to revisit the theme of the foundations of Web Science, already explored at some length in the inaugural article of this journal [44], but now informed by consideration of some of the significant Web Science research now available. This monograph will explain the motivating issues for Web Science, and show not only how research has addressed the gap between the micro-level processes and the macro-level Web-scale phenomena to which they give rise, but also why research is still needed to do that.

1.1 Scale, Emergence and Control: Social Machines

In particular, we need to place Web Science research in the context of *emergence*, the notion that phenomena visible at larger scales emerge out of interactions that occur at smaller scales, usually at much lower levels of complexity. As explained in the original papers, the otherwise mysterious or under-theorised appearance of macro-level effects can have very large social repercussions (especially given the very large numbers involved — at least 4.45 billion webpages in the indexed Web as of October 2013 (http://www.worldwidewebsize.com/), 2.4 billion people online worldwide as of June 2012 (http://www. internetworldstats.com/stats.htm), a billion active Facebook users [205], 400 million Tweets a day as of March 2013 (http://www.youtube.com/ watch?feature=player embedded&v=Bl-FpuehWGA), 139.7 million blogs on Tumblr as of October 2013 (http://www.tumblr.com/ about), 71 million Wordpress sites as of October 2013 (http://en. wordpress.com/stats/), and 52 billion published and linked Resource Description Framework (RDF) triples in OpenLink Software's Linked Open Data Cloud Cache as of March 2012 (http://www.w3.org/wiki/SweoIG/TaskForces/CommunityProjects/LinkingOpenData)). For more data on the relationship between the Web and particular nations, see the Web Foundation's Web Index project (http://thewebindex.org/).

It is clear from these very large figures that scale is a major part of the picture for the Web. There are indeed actors, organisations and systems which are very influential, but the scale of the Web precludes straightforward narratives about online developments. The macro-level effects that we see in the online world depend less on the contributions of specified individuals and technologies, than on the convergence of billions of individual decisions to use technologies (often in ways unintended by their designers). Granted the importance of a Mark Zuckerberg or a Jimmy Wales, even such central actors still derive their power from the concerted actions of their billions of users (actions which in turn are also influenced by other structural factors, such as legal constraints, financial and other incentives, network benefits and social norms). The picture is also complicated by the complex relationship between 'online' and 'offline'; it is no longer tenable to assume that there are two different kinds of space, the 'virtual' and the 'real' or 'physical'. Rather, many activities have both online and offline component parts. Finally, the Web is of course evolving and being engineered over time [147], from a web of documents to a web of data, and from a web of people to a network of social networks.

The result, as pointed out by Berners-Lee [41], is a cycle of innovation and reaction that, thanks to the scale, has immense social consequences while lacking policy levers for control. A Web resource is often designed with local interests and assumptions in mind, but the Web itself has many hundreds of millions of users, and billions of pages and connections, so any system can result in emergent phenomena undreamt of by the original designers, whose social assumptions can hardly be expected to be accurate in the general case. Figure 1.1 shows an idea being implemented with some technical work and a set of social

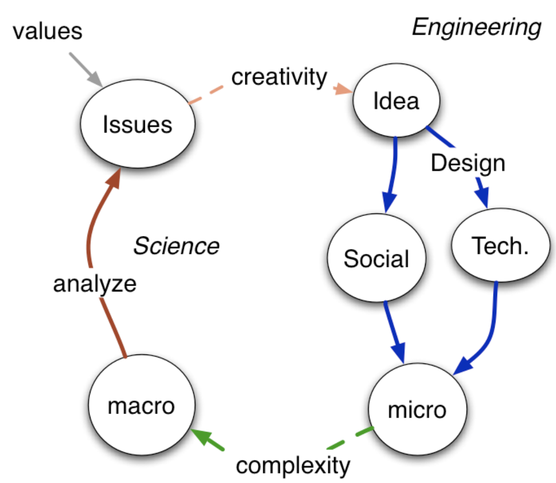

Fig. 1.1 A cycle of engineering and science (from Ref. [41]).

assumptions, to produce a micro-level adjustment to the Web environment, but if enough users take up a system, there will be a marked and noticeable change in macro-level perceptions. It may be that older patterns of behaviour change, or that they are supplemented by new behaviours, or that new users swell the online community (for example, consider the growth of the blogosphere, and how this has changed not only the Web, but also the media, journalism, politics, commerce and social interaction). However that may be, the end result is in effect a new Web understood at the macro-level, as a result of micro-level engineering [269].

This cycle is meant to be illustrative of the difficulties and challenges, rather than a strict ethnographic account of innovation in information technology. In the figure, the micro-level design, when implemented at scale, produces unintended consequences, for which, more often than not, a technical fix is required, and so another idea is born and so we go round the cycle again. The Web Science problem is to marry these episodes of engineering and analysis under a single conceptual framework, and then to achieve a greater level of control of the issues that emerge once the idea is implemented and applied, a marriage which has been referred to as 'philosophical engineering' [314], in which the neat, specifiable world of the realist needs to be reconciled with the scruffier, underdetermined constructed world that defies classification and prediction, and which most of us would perhaps recognise more readily.

Figure 1.2, following David De Roure, gives a sense of different interaction modes of computing. Web Science is concerned with scale — in

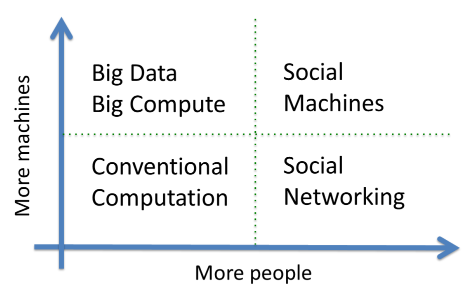

Fig. 1.2 A matrix showing the affordances of scale (adapted from Ref. [99]).

other words, its domain consists of all but the lower left quadrant. Wherever there are more machines, to produce the big data paradigm at upper left, or more people, as in the social networking paradigm at lower right, distribution is inevitable, and hence Web or Web-like technologies will be necessary to handle interaction at scale. The aim of Web Science is not simply to track or monitor the development of such areas, but rather to enhance the technological affordances, and, in time, move technologies upward and toward the right, ultimately to reach the fourth quadrant. We unpack this compressed image later, via Figure 6.1 in Section 6.5.2.

This fourth quadrant is termed as 'social machines' [40, 156], which will be discussed in more detail later in Section 6.5. Yet this concept is implicit in the interpretation of Web Science as a means for understanding the emergence of phenomena at scale, abetted by digital technologies and open networked communications. Computers have always been sociotechnical systems, embedded in organisations, or serving the purposes of users for work or leisure. However, thanks to the spread of interactive read/write technologies (e.g., wikis, photo-sharing, blogging) and devices and sensors embedded in both physical and digital worlds (e.g., GPS-enabled hand-held devices), people and machines have become increasingly integrated. Terms such as 'augmented reality' and 'mediated reality' are in common use [189], and the embedding of computation into society via personal devices has led to the idea of social machines and/or social computation as an abstract conception in which people and machines interact for problem-solving. The 'components' of the machine may be people or computers; the 'routines' or 'procedures' could be carried out by humans, computers or both together.

Social machines are rapidly becoming a focus of computing research [47]. 'Programming the global computer' or 'global ubiquitous computing' has been recognised as a grand challenge for computing [201], while peer-to-peer technologies flexibly link people and computers, as explored in projects such as SOCIAM (http://sociam.org/), OpenKnowledge (http://www.openk.org/) and the Social Computer community (http://www.socialcomputer.eu/). As Web Science begins to unravel the mysteries of scale and control, it will intuitively become the theory and practice of social machines. The aim will be not just to understand the emergent phenomena, but rather to develop means, methods and tools for controlling large-scale phenomena, at least partially. Hence via another route we once more reach the conclusion that analysis and engineering must sit alongside each other within Web Science. The problem is sharpened by the desideratum that 'programming the social computer' must be achievable from *within* the social computer — the methods of Web Science should output policy for governments and large organisations, but will also democratise control by allowing people to develop social machines to achieve their own smaller-scale, local, idiosyncratic purposes.

1.2 A Research Roadmap: Essential Perspectives

In its short history, Web Science has developed a community, and a diverse set of theories and methods, has begun to gather evidence, and is working to enable designers and policymakers to ensure that the Web's effects on society are broadly beneficial, while preserving the invariant general principles that ensure the good health of the Web itself. Scale is important: large linked networks of resources, infrastructure, people and ideas will foster innovation. Secondly, 'good enough' works: bottom-up mechanisms with significant margins for error will foster large user communities. And thirdly, open standards rule [147]. When these principles come together, emergent phenomena can develop at scale.

Dutton [114] has argued that Web Science has a computational bias, inclined to support the efforts of engineers, as opposed to the more social and political orientation of the wider field of Internet Studies. Indeed, this is an important role for Web Science, as 'programming' social machines by designing in desired macro-level effects is conceptually hard to do; a system or tool designer can typically understand and aim for specific micro-level effects, but theories and tools for determining what will emerge at scale out of many such individual actions are sorely lacking [273]. Emergence, explicitly or implicitly, has featured prominently as Web Science has tried to map, connect and theorise the micro and the macro into a coherent account of how social machines emerge when large quantities of computers are deployed by large numbers of networked people. It is unlikely that deterministic theories of social machines will be developed, but it is to be hoped that a greater understanding of the structuring factors and the relative contributions of certain types of structure will result from such analysis.

In order to achieve that, the Web needs to be understood from a variety of perspectives (cf. [44, 45, 158, 314]); no single perspective will encompass the range of relevant phenomena. The research roadmap of Web Science must emphasise at least five relevant perspectives.

- **Computational.** With the emergence of the linked data Web and Semantic Web a key challenge is how to find, browse, explore and query data, rather than documents, at scale (cf. [44], pp. 7–52).
- **Mathematical.** Billions of Web pages are dynamically generated, existing for the period of a particular query or transaction; modelling this transient or ephemeral Web is an urgent requirement (cf. [44], pp. 53–71).
- **Social.** The dynamics and drivers of people's use of newly emergent forms of the Web remain unclear. Yet these will have implications for our understanding of key sociological categories, such as kinship, gender, race, class and community, and vice versa, as they play out online (cf. [44], pp. 73–98).
- **Economic.** Web 2.0/Web 3.0 create many opportunities for users to generate content and share it in self-forming networks, and these need to be modelled in economic terms of incentives and rationality (cf. [354]).
- **Legal/regulatory.** The law, currently reactive to hyperfast Web evolution, should surely lead the intellectual agenda and interact and respond to economic, social and technological influences. The present intellectual property, data protection, torts and policing regulatory regimes, established in the offline world, have to be fit for purpose in the Web 2.0/Web 3.0 environment (cf. [44], pp. 99–109).

These are the kinds of issue studied by the Web scientist, bridging many disciplines. It is worth noting that even if there is a computational/engineering bias in Web Science, social studies (represented by the final three of the five perspectives) are a vital part of the Web scientist's toolbox. As Dutton puts it, Web Science and Internet Studies both "assume that macro-level societal implications can flow from the micro-level decisions made about the Web's protocols" [114, p. 16]. A recent outline of a series of research questions to accompany a social scientist's examination of any Web phenomenon, concerning its relations with analogous offline phenomena, its characteristics, threats, opportunities and effects on other existing activities and relationships [346, p. 69], would not be out of place in a Web Science primer.

1.3 Integrative Research Themes

Another approach to scoping Web Science is to describe the research challenges that aggregate the above perspectives. Although many disciplines quite properly include the study of the Web in their scope, there are certain themes that seem especially characteristic of the Web and its role in communication and practice.

- **Collective intelligence.** Light rules of co-ordination between collaborators can lead to the emergence of large-scale, coherent resources (such as Wikipedia). We need to understand, from a technical point of view, how to enable collective intelligence, as well as to outline the socio-economic reasons for which individuals participate in collective endeavour, the legal frameworks governing the resources created, the policy levers that work in this space and the ethical limits to the use of such policies.
- **Openness.** The Web is a complex mixture of open, public areas and closed, private zones. There are arguments for both: for instance, innovation can be fostered both by information and data sharing, and by protected intellectual property rights. We need to understand which stance is appropriate when. Is openness compatible with the security requirements of e-health applications, for example?

- **Dynamics.** The Web is changing at a rate which may be greater than our ability to observe it; we need to instrument the Web, log it and identify trends.
- **Security, privacy and trust.** All economic, social and legal interactions are based on certain assumptions: that individuals can verify identities, rely on the rules and institutions governing the interactions, and be assured that certain information will remain private. These assumptions are challenged by the Web [50], yet — as recent security revelations concerning the US NSA and the UK GCHQ show (http://www.theguardian.com/world/the-nsa-files, and Ref. [162] for an early academic attempt to place these revelations in perspective) — trust in the infrastructure and in the treatment of one's communications and data will always be an extremely important factor in the growth and development of the Web.
- **Inference and information processing.** The amount of information on the Web is enormous and growing exponentially (it is a major challenge to measure it, never mind to assess how much of it is useful or original). In addition, it comes in a huge range of formats from a vast number of disparate sources. Given this radically decentralised heterogeneity, methods are needed to browse, explore and query the Web in contextually sensitive ways at scale.

It should be clear that each of these themes expresses problems requiring answers from each of the disciplinary perspectives from the research roadmap in Section 1.2. Note also how emergent effects are important factors in these themes. How does collective intelligence emerge from the aggregation of individual contributions? How does openness affect the incentives for innovators, and the take-up (network effects) of their innovations? How do we describe, model and influence the feedback loops between the micro and the macro? How do privacy and trust survive visibility to networks which are much wider, and much more informationally retentive, than social networks which are not digitally mediated? How will the inferences an individual is able to make affect his/her behaviour online — or in other words, how does inference affect micro–macro feedback? In each theme the micro–macro distinction is foregrounded.

1.4 Structure of this Monograph

In this monograph, we review the state of Web Science in 2013–2014 within two research frameworks designed to enable the study of multilevel phenomena. In Section 2, we set out these frameworks, the concept of emergence in the philosophy of science [173], and the Multitheoretical, Multilevel Analytic theory of social networks [252]. Each of these frameworks determines a four-part classification of emergent phenomena, which can be mapped onto each other, and Sections 3–6 will explore these four classes in turn. Section 7 will then bring the four themes back together again in a conclusion.

Sections 3–6 will each be illustrated by a series of exemplary study areas. It goes without saying that Web Science encompasses a wide range of possible objects of study, and so no paper such as this one could possibly be comprehensive. Certain problems, methods or research programmes will be outlined and briefly discussed — these issues have been chosen in order to illustrate certain of the perspectives of the research roadmap above (Section 1.2), or the research themes of Web Science (Section 1.3), as described at the beginning of each of these sections. Before that, however, the rationale for the structure of this monograph will be provided, with some considerations about the overarching theme of emergence.

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