Journal of Universal Computer Science, vol. 23, no. 11 (2017), 1057-1069
submitted: 1/9/16, accepted: 26/11/17, appeared: 28/11/17 © *J.UCS*

Prospects and Challenges for the Computational Social Sciences

Giangiacomo Bravo
(Linnaeus University, Sweden
giangiacomo.bravo@lnu.se)

Mike Farjam
(Linnaeus University, Sweden
mike.farjam@lnu.se)

Abstract: Computational social sciences (CSS) refer to computer-enabled investigations of human behaviour and social interaction. They include three main components — (i) computational modelling and social simulation, (ii) the analysis of digital traces of online interactions, (iii) virtual labs and online experiments — and allow researchers to perform studies that were even hard to imagine a few decades ago. Moreover, CSS favour a more systematic test of theories and increase the possibility of study replication, two factors holding the potential to help social sciences reach a higher scientific status. Despite the huge potential of CSS, we follow previous works in identifying several impediments to a larger adoption of computational methods in social sciences. Most of them are linked with the humanistic attitude and a lack of technical skills of many social scientist. Significant changes in the basic training of social scientist and in the relation patterns with other disciplines and departments are needed before the potential of CSS can be fully exploited.
Key Words: computational social sciences, sociology, social simulation, experiments, big data
Category: E.0, I.6, J.4

1 Introduction

Social sciences may appear to the casual observer as deeply rooted in a somewhat old-fashioned intellectual tradition, often — even if not necessarily — based on qualitative studies and leading more to long-enduring philosophical debates than to the progressive knowledge accumulation typical of the natural sciences. Although that may represent a fair pictures of the hard core of some disciplines, it is not the whole truth. First there are significant differences both across and within disciplines. Second, and more importantly here, new approaches to the study of human behaviour and social interaction have emerged in the last 20–30 years. The common ground for most of them is an intensive use of information and computation technologies, which is why they are known as *computational social sciences* (from now on CSS).

Although an increasing number of computer-enabled social science works have been published since at least the mid 1990s, the CSS were first defined as such in 2009 by a position paper published in the *Science* journal by an interdisciplinary group of scholars led by David Lazer [Lazer, 09]. In their definition, the CSS include three main components: (i) the analysis of digital traces of online interactions, (ii) virtual labs and online experiments, and (iii) computational modelling and social simulation. These new methods hold the promise to add to the scientific status of social sciences as they allow to observe the behaviour of large number of people for extended periods of time, to carry-on carefully designed experiments (e.g., to rigorously test theories), and to build formal models of complex systems involving non-equilibrium and non-linear dynamics. In addition, CSS will have practical impacts both in terms of knowledge production (e.g., better understanding of the drivers of social dynamics) and on the society as a whole (e.g., better scenario-producing tools to support policy-making) [Conte, 12] [Shah, 15] [Squazzoni, 12].

On the other hand, the risk that academia will not fully exploit the potential of CSS is real. This, in turn, risks to put the expertise needed to answer contemporary social question into the nearly exclusive domain of companies (e.g., Google, Facebook) and government agencies (e.g., NSA), which have already set themselves on the frontiers of big data and online interaction research [Bakshy, 15] [Goel, 15]. Lazer and colleagues identified several reasons that are driving this process [Lazer, 09].

1. Sociological theory has been largely developed informally and with little use of quantitative data, and especially without the terabytes of data currently available. As a consequence, existing paradigms are little able to capture the emergent phenomena highlighted by empirical research within the CSS, a fact leading to a disregard of such findings by many theory-oriented scholars.

2. The distance between the computer science departments and the social science ones is often large, whit institutional and cultural obstacles preventing (although probably less today than a few years ago) the institution of long-term structured collaborations.

3. This distance also means that a knowledge gap exist preventing potentially interested social scientist to effectively run CSS studies, as they neither possess the required technological skills themselves nor have access to easy-to-use infrastructures for data collection and analysis.

In addition, we identified two further impediments to larger adoption of CSS protocols in standard sociology and social science departments.

4. The lack of an acceptance of a truly scientific “modelling culture” within social sciences. Many scholars do not recognize the implicit modelling work behind much social theory and actively reject the explicit/formal modelling

typical of CSS, e.g., in the form of agent-based models or network structural models [Epstein, 08] [Squazzoni, 12].

5. The rejection of experimental methods in the study of human behaviour and, more generally, a widespread "exemptionalist" perspective suggesting that methods coming from the natural sciences cannot be fruitfully applied in the social sciences [Falk, 09] [Webster, 07].

The main goal of this paper is to illustrate the developments that occurred since the publishing of Lazer *et al.*'s article and re-assess the potentialities and risks for CSS. Its core message is that computational methods are still under-represented in social sciences and that a basic understanding of these methods will instead nicely complement the current standard toolbox of the social scientist. We will first present some interesting, recent examples of works covering different aspects of CSS. Then the relation with other social science fields will be assessed through a textual analysis on a sample of abstracts drawn from the *Scopus* database. Finally the current challenges for CSS will be presented and discussed.

2 Selected CSS examples

This section briefly discusses selected examples of the three CSS sub-fields identified by [Lazer, 09]. For a broader discussion, the interested reader can refer to [Golder, 14] for big data and online experiments and to [Macy, 02] or [Squazzoni, 12] for social simulation.

2.1 Big data

The vast amount of data available due to modern information technologies allows social scientist to check hypotheses on large groups and in situations inaccessible a few decades ago. One such hypothesis with regard to social networks is that it is advantageous for nodes (humans, firms, etc.) in a network to be connected to a diverse set of other nodes (e.g. friends from different groups). This hypothesis is based on graph theory and has been tested only in small groups such as school classes. Eagle et al. tested the hypothesis with the help of data from (almost) all mobile and landline calls within the UK during one month [Eagle, 10]. They analysed calls between $>$ 32,000 communities (district subdivisions) and combined them with a measure of economic prosperity. They find that communities linked (via calls) to a set of communities that is diverse with regard to the prosperity measure are more prosperous than those connected to a homogeneous set of communities. Eagle and colleagues' work shows that social scientist, thanks to big data, can test theories not just in small groups or samples but straight at the population level as well.

In another study, Bessi et al. used data from > 1 million Facebook users in order to compare consumption patterns among users who "like" (a formal action on Facebook) contents related to either (a) science or (b) conspiracy theories [Bessi, 15]. They found that "conspiracy likers" were more involved in spreading the contents they like than "science likers". On the other hand, discussion on conspiracy-related contents took place mainly within the conspiracy community itself — hence creating the so-called "echo-chambers" — while science contents were discussed also by users outside the science community. Furthermore, Bessi et al. analysed how both groups reacted to obviously false content generated by parodistic content providers and found that conspiracy likers commented and liked the parodistic content far more often than science likers did. This research is in line with theories in social science about the need of humans with extreme beliefs for what is often referred to as *cognitive closure* [Leman, 13].

2.2 Online experiments

Experiments in a laboratory allow scientist to study a phenomenon under controlled conditions, manipulating only one aspect at a time. This control over external factors can hardly be achieved outside the laboratory, but usually comes with high costs per observation and low external validity, i.e., a discrepancy between the artificial lab setting and the real-world phenomenon one is interested in. As shown in the two examples below, online experiments can be a useful compromise between control over external factors and relatively low costs per observation.

Salganik et al. [Salganik, 06] studied an artificial music market with >14,000 teenagers — a number unseen in lab experiments. In the baseline condition, users chose from a list of songs and listened to them. In the social information condition users received additional information on how often a song was downloaded by others. Additionally, all songs got rated by independent subjects with respect to perceived quality. Salganik et al. found that the social information led to a much higher variance in downloads per song and the correlation between the quality of a song and its success in terms of downloads was lower compared to the baseline condition. This study demonstrates that it is hard to predict the success of a product in markets where social influence is occurring.

Massive multiplayer online games (MMOGs) are played by hundreds of thousands, if not millions, of players socially interacting in ways similar to daily off- and online-interaction. Since the action space of players in games is small compared to real world, it is relatively easy to objectively quantify social behaviour in MMOGs. Since interaction is digital and stored in databases needed for the gameplay, all players' actions can be observed and recorded at basically no cost. Thurner et al. studied the emergence of norms and rules within a community of gamers and analysed data for > 1,700 players over a course of > 1,000 days

[Thurner, 12]. They were looking for typical sequences of actions and found that punishment actions were often followed by written communication, probably clarifying reasons for punishment. Furthermore, despite the lack of formal rules of how gamers should behave, players self-organized according to rules and norms of good conduct, resulting in reciprocal and pro-social behaviour.

Since many markets are becoming online markets and much of our social interaction is becoming online interaction, these online experiments demonstrate a clear potential to generate big data of important phenomena in a close to realistic setting.

2.3 Social simulation

Thanks to the increase of computing power, social scientists cannot just analyse and access amounts of data inconceivable a few decades ago but also generate such data from models. These models can be used to simulate social interaction according to a theory, to test its implications, or even to predict the effect of certain interventions. An example of the latter is the work by Balcan et al. [Balcan, 09], who studied the 2009 H1N1-influenza pandemic. They built a model of influenza transmission on a global scale with a spatial resolution of 10×10 miles and a temporal resolution of a day. They combined this model with data on population density and airline travel across regions and trained the model with the (incomplete) data that were available regarding the outbreak at certain places. They used the resulting model to estimate parameters of the influenza in the past (e.g., spreading rate) and to estimate the effect of interventions at various times and places.

Axtell instead presented a state of the art model with regard to the simulation of labour markets [Axtell, 16]. He used an agent-based approach (i.e., modelling the agents that interact, opposed to the results of their interaction) and simulated 120 million workers who invest their labour in a way that maximizes their own payoff. Agents were facing the dilemma that their labour led to the highest payoff when they cooperated with others in a firms, but they were best off when they free-rode on the effort of the other agents working in the same place. This led to a constant dynamic of agents leaving a firm because of too many free-riders and starting new firms with other cooperating agents. Note that this constant dynamic of entering and leaving agents is very different from how macroeconomic phenomena are usually modelled. The model managed to replicate a remarkable number of properties observed in real labour markets without most of the (problematic) assumptions usually made in macroeconomic modelling. Many of the properties of the model even numerically resemble those observed in the US labour market (which it aims to simulate).

3 Textual analysis of CSS and sociology titles and abstracts

The examples above showed some remarkable CSS works but do not represent the whole field. In order to get a more comprehensive picture of it, we performed a textual analysis on the titles and abstracts of CSS papers published since the appearance of Lazer et al. article [Lazer, 09]. Data were downloaded from the Scopus database on August 15, 2016. The query included all works including the "computational social science" expression in the January 2009–August 2016 period and resulted in 249 items. The number of CSS works raised from 6 in 2009 to 57 in 2014, with a subsequent small decline in 2015 (52 works) and 32 works in the first half of 2016. The most common publication outlets were computer science and interdisciplinary journals, such as the *Lecture Notes in Computer Science*, *PNAS*, *Royal Society Open Science* and *PLoS One*. The only social science journal among the top ones was the *Annals of the American Academy of Political and Social Science*.

The first thing to notice, is the small number of works using the CSS expression. Besides the over 50,000 works that can be found using "social science" and "sociology" as keywords (see below), it is worth noting that even papers that could be legitimate considered CSS did not use that label in most cases. For instance, a query for the 2009–2016 period using "agent-based model" as keyword returned over 1500 items, while one for "social media" returned over 13,000 items. This suggests that CSS is not yet an established label to identify the growing number of papers that could legitimately pertain to the field. It may also be that scholars pertaining to specific disciplines consider the label too broad or maybe not especially appealing to their community. For instance, some authors could use computational *sociology* instead of the more generic term *social sciences* to better specify the target audience for their works, as done, e.g., by [Macy, 02] and [Squazzoni, 12].

Keeping in mind this limitation, it is interesting to analyse the network of relations among the most frequent terms in the CSS-works dataset. We used a *visualization of similarities* (VOS) approach [van Eck, 10] [Waltman, 10] to map and cluster the terms found in the corpus including titles, keywords and abstracts (Fig. 1). This resulted in four clusters. The first one (red in the picture) was clearly linked with methodological questions in the analysis of big data and, more generally, in the development of CSS research. The second one (green) referred to network analysis and the study of group dynamics. The third (blue) included terms derived from works based on social media data. The last one (yellow) instead included terms linked to the modelling and simulation of social processes.

It is also interesting to understand how CSS integrate with more traditional social sciences. To compare them results with a more traditional way of studying the society, we performed a second query on the Scopus database using "soci-

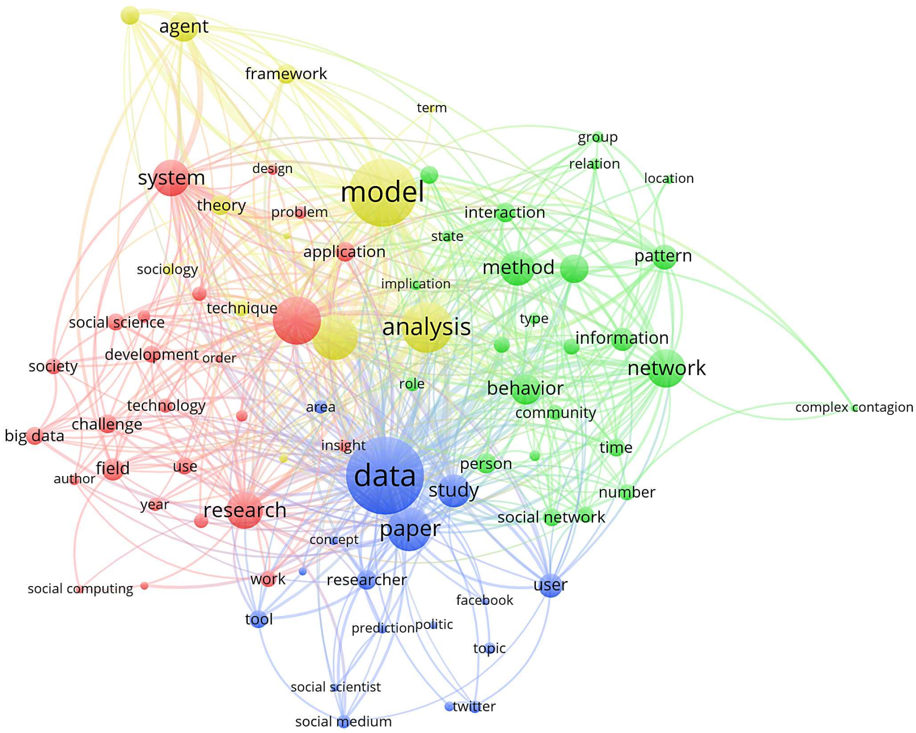

Figure 1: Relations among the most frequent terms in the CSS corpus. Map produced using the VOSviewer software, version 1.6.3.

ology" as keyword. The specific discipline was chosen as example of a "typical" social science[1] and produced over 24,000 records. The number of sociological works increased from 2695 in 2009 to 3575 in 2015 and the most common outlets were well established sociological journals.

Due to limitation imposed by Scopus, the abstract of only the most recent 2000 papers in this group could be downloaded. With them, we performed the same type of textual analysis done on the CSS corpus, which resulted in the term network showed in Figure 2. Three cluster were found here. The first two highlighted the traditional divide between qualitative/theory-focused (red) and quantitative/empirically-focused (green) sociology. A third cluster (blue), approximatively placed between the previous ones, included terms linked with

[1] Although differences certainly exist among the different social sciences, limitations imposed on Scopus queries led us to the decision of focusing on a single one, here used as example. The focus on sociology is motivated on the growing interest for CSS within the discipline.

applications to specific domains, and especially to gender issues. It is worth noting that this grouping is similar to what was previously found through manual recoding of the papers published in small samples of British [Payne, 04] and Nordic-countries journals [Erola, 15].

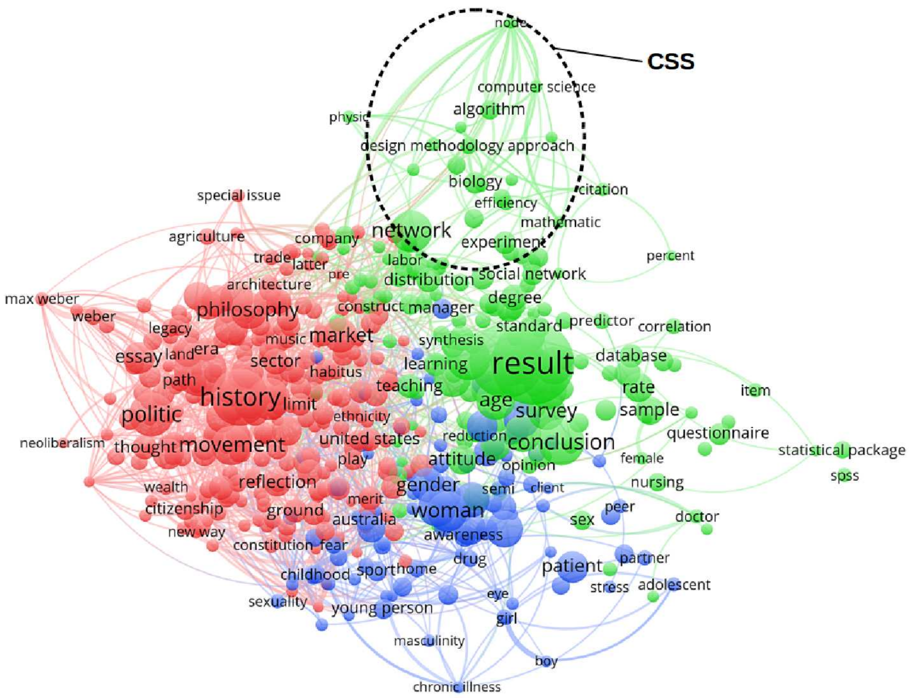

Figure 2: Relations among the most frequent terms in the sociology corpus (titles and abstracts). The dashed ellipse indicates the possible location of CSS within the term network. Map produced using the VOSviewer software, version 1.6.3.

The CSS found little space in this picture, even if several terms linked to network analysis and, to a lesser extent, to other computational methods can be found at the periphery of the term network (upper part of Fig. 2). It is also worth noting that the references to other disciplines within the qualitative cluster pointed towards history, anthropology and philosophy, while the ones in the CSS area included mathematics, physics, biology and computer science. The other parts of the network included few references to other disciplines, with the partial exception of statistics which is (although infrequently) mentioned within the non-CSS area of the quantitative methods cluster.

4 The challenges ahead

The analysis above showed a slow but continuous development of CSS in recent years. Still, the pace of spreading of the CSS label within the scientific community seems slow, which may lead to a severe underestimation of the actual size of the field: recall that 13,000 works used "social media" in their titles of abstracts, while only a few hundreds explicitly mentioned the CSS. On the other hand, some signals point out toward a certain institutionalization of the filed, the most notable being the recent institution of regular *International Conference on Computational Social Science* (IC^2S^2) events — the first one took place in Helsinki (Finland) in 2015, the second one in Evanston (IL, USA) in 2016 and the third one in Köln (Germany) in 2017 — which have attracted several hundreds of participants per year. However, these conferences are dominated by computer scientists, physicists and engineers, while only a minority of their attendants comes from the social sciences, and especially from the ones that should be more interested in these developments, e.g., sociology and political science.

The limited participation of social science scholars in the IC^2S^2 events looks fully consistent with the first two of the challenges identified by [Lazer, 09], which have made it easier for computer scientists, experimental psychologists and even physicists to enter the field than for sociologists and other social scientists. However, this is probably only part of the story. Our textual analysis highlighted a gap within sociology, which probably exists in other disciplines as well. It may only seem like a linguistic issue but, in our experience, it is not just a matter of style but reflects a real divide between a "positivist" and an "interpretivist" approach in the study of social behaviour, which often leads to difficult communication, misunderstanding, and even suspect between the different research traditions. Moreover, we think that the underlying cause of this divide has no easy fixes because it is deeply rooted in the basic attitude — i.e., humanistic vs. scientific — that the different scholars bring into the study of the society: something that looks consistent with the different links to other disciplines that can be found within the various clusters in Figure 2.

At the same time this divide points towards a crucial role that the CSS concept (and label) can potentially play. It can indeed work as a bridge linking currently isolated clusters of disciplines, which often study different angles of the same social phenomenon but are not able to benefit from findings in other clusters due to academic, theory or language barriers.

Despite CSS holding roots in a significant 20^{th} tradition of empiric and quantitative social science research represented, for instance, by Lazarsfeld, Coleman and Converse, many contemporary social science scholars still hold, implicitly or explicitly, an exemptionalist perspective — i.e., the belief that humans are exempt from the laws of nature because of their capacity of cultural adaptation [Wiktionary, 16]. Although exemptionalism is deeply rooted in humanistic thinking, starting with Galileo, it has been systematically challenged by scientific evidence [Buchanan, 07] [Kanazawa, 04]. Nevertheless, one of its corollaries — known as interpretivism and implying that theories and methods used to study human societies should be qualitatively different from the ones employed to do research on the rest of nature — remains important, if not dominant, in several of social sciences. As a consequence, many scholars tend to prefer qualitative and philosophical discourses about the society, such as social critique or symbolic interpretation, to the computationally-intensive methods typical of CSS.

Although not necessarily bad in itself, the strong preference for qualitative methods clearly represents an obstacle for a wider adoption of computationally-intensive methods within several social science disciplines, and especially in sociology. The CSS perspective often challenges classical (and current) sociological theories, which were typically built starting from few exemplary cases or, at best, relatively small survey samples. The issue here is that many of the informal and descriptive theories used in sociological debate could now be tested thanks to improved modelling techniques (e.g., agent-based modelling), large amounts of observational data (i.e., big data), and carefully designed online experiments. However, descriptive theories built on few cases are not always able to produce falsifiable predictions and, even when they are, they often cannot bear a careful quantitative scrutiny [Bruinsma, 13] [Prior, 13] [Willer, 09], although others have been confirmed by rigorous experimental data [Keizer, 08]. This does not mean that the CSS do not require or allow theory building and qualitative methods, as sometimes suggested [Anderson, 08]. Quite the opposite, the new kind of big and unstructured data provided by the CSS need well developed theories for their interpretation, as traditional tools to asses the significance of the relationship among variables become of little use when applied to millions or tens of millions of observations or when texts are analysed [Conte, 12] [Holme, 15]. At the same time, we believe that the kind of theory needed by social sciences today should be truly scientific, i.e., (i) able to produce testable predictions and (ii) consistent with the available data or rejected after a careful empirical scrutiny.

In addition, some practical issues linked to the prominence of a humanistic approach in current sociology and other social sciences are, in our opinion, the low capacity to manipulate large amounts of data, the lack of a serious modelling culture, and the limited use (or rejection) of experimental methods by many researchers. This also depends on the current formulation of university programmes, especially at the bachelor level, which tend to focus more on (classical and modern) social theory than on methods, and in most cases simply ignore CSS. At the very least, students should be made aware during their education of the existence of CSS, so that they could eventually familiarise themselves with computational methods in their elective courses. We acknowledge that the situation is slowly changing with the introduction of innovative programmes in several universities, but in our opinion the real breakthrough will only occur when computational methods will be included in the basic methodological training of all social scientists, complementing the traditional qualitative and quantitative approaches.

5 Conclusions

The CSS hold the promise to significantly impact the way that research is done within the social sciences and, perhaps, to help addressing some of the "big problems" of today by allowing practitioners and policy makers to better plan their interventions on the basis of improved empirical evidence and more reliable models [Conte, 12] [Lazer, 09]. However, within the academia significant barriers not only hinder the full realization of the CSS potential but also risk to leave the "big data" to the monopoly of large companies and intelligence agencies. In addition to the ones identified by Lazer et al. [Lazer, 09], we proposed the lack of a truly scientific culture and the consequent limited use of formal modelling (including computer modelling) and experimenting (including online experiments) as significant obstacles for the development of the CSS within some of the traditional social science disciplines. The risk here is a growing marginalization of those fields (or sub-fields) that choose to remain closed into their ivory-tower philosophical debate, while a company-dominated applied social research develops outside the academic walls [Watts, 17].

We instead believe that academia should actively participate in and possibly lead the change. This most likely implies some modifications of the current approach in teaching an research within the mainstream social sciences. In our opinion the most important are:

1. To create awareness among the students of the existence and potentialities of CSS, introductory course in computational methods should be introduced in standard social science programmes at the bachelor level.

2. To enable students to apply specific CSS techniques that require a deeper computational background, more advanced elective courses need to be offered to the interested students, specifically taking into account their non-computational background.

3. To train researchers in CSS methods, new dedicated graduate training programmes should be developed.

4. Different publication cultures across disciplines need to be taken into account to enable scientific exchange within the CSS. For instance, many natural and computer scientists tend to publish important work in conference proceedings while in many social sciences such proceedings are considered less

prestigious, while monographs remain an important source of academic prestige. To overcome such obstacles one could allow for sub-field specific tracks on CSS conferences without mandatory publication in the proceedings and more freedom to publish elsewhere.

5. To overcome the existing technical gap and allow interested social science scholars to design and implement CSS projects, technical infrastructures both open and sufficiently easy to use without advanced computer science knowledge should be developed.

6. To allow for the realization of innovative, larger-scale CSS projects, institutional infrastructures (e.g., dedicated research centres) should be developed allowing social scientists to communicate and work together with scholars from computer sciences, physics, mathematics and other scientific disciplines.

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