PLANNING FOR SOCIAL ENVIRONMENTS:

Social Capital in the Context of Critical Realism and the Dynamics of Complex Systems

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Overview

This report is the first chapter of a dissertation project that examines how one might better understand the social infrastructure of our communities. The difficulties of measuring intangible social structures require ongoing experimental projects. Some of these experiments will lead to insight, others will identify dead ends. This current effort builds on existing work and proposes how that work could be applied in new ways.

Measuring phenomena as intricate and difficult as those arising from human interactions at neighbourhood scales requires careful methodological and conceptual framing. A strategy that balances directive progress with permissive exploration is needed. Critical realism provides a philosophical framework within which to situate qualified knowledge development arising from complex systems insight. In turn, network science provides a vital set of mathematical and analytic tools and strategies that are directly applicable to social capital phenomena. Around and through this open approach to exploration, novel methodologies such as the relationship between social capital and spatial use in urban areas can be considered for their potential to assist urban planners in understanding and evaluating the social impact of past, present, and future plans as a means of increasing the sophistication and effectiveness of urban planning strategies and evaluations.

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Planning and the Measurement of Social Capital

Social capital as a subject of formal research is relatively new, although the subject of social structures is not (Aristotle 2012; Tocqueville 2001). Amid significant and wide-ranging academic interest in social capital, agreement on measurement and consensus about the scope of what is included in social capital remains elusive. This need not be a significant worry as science has always proceeded from partial understanding, competing theories, and unclear boundaries (Brody 1970; Chomsky 1996; Serres 1995). There are dozens of varying definitions of social capital, but for this paper, the phrase "social capital" is intended to refer to the invisible network of social ties that enables individual agents to make use of the social resources of their networks,. Social capital is a phenomenon whose effect is significant (Coleman 1988; Kawachi, Kennedy, Lochner, and Prothrow-Stith 1997; Ostrom and Ahn 2003) despite the difficulty of definition and measurement.

Increasing our understanding of the social infrastructure of urban communities at the scale of neighbourhoods is particularly important for planners. This local scale is related to a significant number of phenomena that are vital to well-being, such as mental health, longevity, educational achievement, economic performance, and belonging (Bethune 2014; Dunkelman 2014; Pinker 2014).

National and regional social trends are made visible through instruments such as the General Social Survey so that we can learn about how people spend their time, how they perceive their neighbours, what they think of the organizations in their communities, and so on. While this scale of analysis is of some use to planners, it is much less valuable in the context of community-level design and decision-making. This is particularly true for social capital, where local conditions are paramount given that the relational ecology of citizens is particularly important (Bechard and Marchand 2006).

Neighbourhood-level social-capital measurement requires a data-collection approach that is sufficiently economical for deployment across cities at neighbourhood levels. Saturation surveys (outside of a census) are generally not feasible given cost and complexity, but the increasing ubiquity of mobile devices that collect geographic positioning systems (GPS) data (N. Cohen 2011) means ever-larger data sets are at least potentially available for emerging data-analysis approaches (Pentland 2014). For example, it would be expensive to collect a representative sampling at neighbourhood levels for an entire city with the additional burden of mapping the social networks of participants. Participant surveys, though common as a form of data generation, continue to face the problems that are inherent with respondent-driven instruments (Bernard, Killworth, Kronenfeld, and Sailer 1984). Despite the difficulties and expense, this approach to gathering data is an important facet of social-capital research to date (Australian Bureau of Statistics 2004; Lochner, Kawachi, and Kennedy 1999). Novel methodologies that grow out of the proposed open exploration could lead to more effective and reliable measures (such as novel behavioural methods that combine machine learning and the duration of time/location overlaps to detect relational ties [Crandall et al. 2010; Eagle 2005]). Understanding and making effective use of these emerging data-science methods is an important task for current social-capital research in planning contexts.

Research in social capital requires strategies that can respond to the complex and overlapping social phenomena of relationship networks and perception. The lack of agreement on definitions (Friesen 2013a) suggests that the field may still be early in its development (Kuhn 1996). A review of existing scholarship demonstrates, for example, that trust and social ties are key elements across definitional differences (Carpiano and Fitterer 2014; Chow and Chan 2008; Richey 2007; Veenstra 2002). Planners could more readily understand the impact (negative or positive) of their plans and decisions if neighbourhood levels of trust and social-network characteristics could be measured economically and consistently over time. The range of phenomena that contribute to social capital (Dugundji, Scott, Carrasco, and Paez 2012; Kwan 2007; J. R. Logan 2012; van der Gaag 2002) suggests a need to establish a framework suitable for the variations but coherent enough for planners who are interested in understanding the social infrastructure of their cities at the scale of communities. We know lower levels of trust lead to increased relational fragmentation, social isolation, and hence decreased levels of social capital (Bethune 2014). Social fragmentation can increase pressure on municipal resources through increased litigation, greater involvement by police or municipal enforcement in disputes, low voter turnout and volunteering, and low levels of informal interaction with consequent increased health-service demands (Browning, Feinberg, and Dietz 2004; McDoom 2014). Recent work in Holland points to increased social capital as an effective means of lowering the costs of public health service while improving positive results for patients with Parkinson's disease (Tod et. al. 2016).

Framework for Social Capital Measurement

A Government of Canada expert report that reviewed social capital from a policy perspective considered measurement approaches at *macro* (structural including national-regional such as General Social Survey), *meso* (local communities, neighbourhoods, Census Tracts), and *micro* levels (individuals or immediate networks of individuals) (Franke 2005). Findings suggested that more time and effort have been invested in designing and carrying out macro-level international and national research programs (Chung, Choi, and Lee 2014; Garcia, Martinez, and Radoselovics 2008; Gesthuizen, van der Meer, and Scheepers 2009; van Oorschot and Arts 2005) along with highly contextual micro-level ethnographic or site-specific research projects where behaviour of a specific group, type of individual, or social unit is being examined (Boneham and Sixsmith 2006; McPherson, Smith-Lovin, and Brashears 2006). The meso scale, which is particularly relevant to planners, represents an important research and policy opportunity. The meso level of social structure is strategic for improving research and policy tools that planners can use in developing strategies for city building that more fully integrate social implications in decision-making and resource-allocation processes including a much better understanding of the social impact of decisions.

Complex phenomena with unclear or highly diverse causal mechanisms may feature significant clusters of interacting systems and causal dynamics that cannot be understood in isolation from each other (Gunderson and Holling 2002; Kuhn 1970). Where this is the case (e.g., human health and environmental conditions), scientists can often gain insight into the higher-order phenomenon by understanding the dynamics of subsystems of phenomena. Early social-capital research and theory explored key causal factors such as trust and cultural norms (Bourdieu 2008; Coleman 1988; Paldam 2000). Untangling the complex nature of these causal factors in neighbourhood social phenomena is ongoing (Chung, Choi, and Lee 2014) and reflects long traditions of deliberations that concern planning theory and complex phenomena (Jacobs 1992; Lindblom 1959). This insight is critical for ongoing research.

Progress in social-capital research may, as a result of these challenges, require significant time frames (Ostrom and Ahn 2003) and a fuller consideration of the nature of the problems encountered. The proposed Social Imaging Study framework has been designed with an awareness of these dynamics including the ways in which they involve the contested relationship between natural and social sciences (Gadamer 1960; Putnam 1988; Rorty 1998), challenges regarding the efficacy of theory in guiding research (Kuhn 1970; Thomas 1997), and the degree of confidence we can have in research results, particularly social-science results, as true (or complete) representations of reality (Derman 2011; Rorty 1979).

Structuring Social Capital Research

The idea of an open and exploratory approach to research has been explored in the field of architecture through the concept of an armature (Hu 2014; Kojima 2014). An armature is a structure that acts as a point of focus for something to develop rather than acting as an external constraint that fences something in. Armatures are commonly used in sculpture, model building for animation in stop-motion film, and architectural design processes. From an urban vantage point, a road can act like an armature along which vendors, gas stations, parks, and other structures develop over time. By contrast, a formal suburban master plan develops out of a fully proscribed set of terms where dynamics about the future are assumed or projected based on known patterns (Allmendinger 2009; Fainstein and Campbell 2011; Fischler 2000). The nature of social capital lends itself to a directed but open approach where new insight can be gained from new data sets designed to explore the complex phenomena involved. I will employ a carefully structured research strategy with sufficient flexibility to allow for novelty and discovery on the way (Alexander 2003a; Westley, Zimmerman, and Patton 2006; Wheatley 2006).

The armature approach is reflected in the structure of this chapter. Movement from left to right (figure 1) reflects a framework that scales from meta-philosophical considerations to particular phenomena that can be investigated empirically. This simplified logic supports an approach to social-capital research methods and strategies that advance explanation without succumbing to totalizing or reductive traps (Abbott 2009; Kuhn 1970).

Critical Realism → Complexity Science → Networks → Social Capital → Spatial Data

Figure 1. Progression of thought from critical realism to spatial data

For the current project, critical realism is employed as a meta-theoretical framework within which complex systems and behaviours are both expected and partially understood. Network analysis provides a formalized means of understanding those complex systems that are driven by both the structure (topology) and processes (dynamics) of various elements and components (including nested systems of systems) (Albert and Barabási 2002; R. Cohen and Havlin 2010), in this case social interactions in space and time that constitute the social infrastructure of cities (Friesen 2013b). Following this logic, each of the elements of the proposed armature is examined more closely below.

Critical Realism

Critical Realism → Complexity Science → Networks → Social Capital → Spatial Data

Critical realism holds promise as a primary framework for orientation in this challenging space and can improve social-capital theory and shape further research.

The particularities of critical realism are oriented around four key general concepts and commitments, within which we can extend our understanding of social capital: regularity in scientific knowledge, historical knowledge, human agency, and emergence.

First, for knowledge to be generated, shared, and built on, some degree of *regularity in scientific knowledge* is required. It is possible and common for knowledge gained through research to be shared with and understood by other people given that reality exists apart from our mental interactions with it (Mir and Watson 2001, 1170). In this regard, science may be thought of as a cultural practice with rules and practices that guide how that knowledge is generated, evaluated, shared, and disputed (Kuhn 1996). The subject of inquiry is the world around us at all scales, including individual and collective expressions of human society. The approaches to different subjects vary widely, but even the most isolated forms of inquiry reflect a dependence on pre-existing knowledge, culture, instruments, and theories (R. K. Logan 2007). Critical realism asks, "what must be true about reality for scientific experiments to be intelligible" (Steinmetz 1998, 176)?

Critical realism affirms this characteristic of scientific knowledge but qualifies the overreach of naturalism by arguing that neither reductivism (explanation of primary elements constitutes a full description) nor scientism (only what qualifies as scientific knowledge is valid knowledge) is adequate (Putnam 1988). Advancing research about social capital for meso-level urban settings will require ongoing commitments to meaningful synthesis of a wide range of research approaches and removal of artificial barriers between fields of inquiry (Bhaskar 1978, 2; Scheffer et al. 2015). The deep causal complexity of social-capital factors requires a commitment to disciplined but provisional conclusions that traverse narrow disciplinary boundaries (Fairfield 2003; Feyerabend 1970; Gadamer 1960; Taylor 2004).

The regularity of scientific knowledge permits us to accumulate knowledge beyond the intellectual and temporal limits of individual human beings—what we know can be passed on, added to, refined, or changed within cultural and formal structures. Traditional science has believed, at various points, that in principle this process could be totalizing and exhaustive, and would lead to complete knowledge of the world and ourselves. This encyclopedic aspiration was seen in, for example, statements of some nineteenth-century scientists who believed that all that was left for science to discover in their time was decimal places and details (Badash 1972). Scientific knowledge, like other forms of knowledge, is always partial and can shift significantly with new discoveries. Our most sophisticated and intensive efforts to explore, experiment, and formalize knowledge have led to a realization that what we know, in both degree and kind, is very partial indeed, even in the most formalized fields of science. Significant causal complexity and the deep interrelatedness of all phenomena suggest that there are in-principle limits, not something that will be remedied by better research or more sophisticated computation. Even where causal assumptions are made or patterns are noted, the non-linear nature of interacting dynamics results in a temporal reality that is never free of contingencies (Steinmetz 1998; Taleb 2010). This is something that planning has increasingly recognized as a permanent feature of the dynamic processes it operates within (Allmendinger 2009, 18–23), including in the evaluation of complex phenomena such as social infrastructure.

Second, *historical knowledge*, including social patterns that we can perceive through statistical data, direct experience, and cultural knowledge, have always been used to guide decisions about the future. From a critical-realist perspective, cognitive abilities such as reason, logic, deduction, induction, and related analytic devices enable us to synthesize information and improve our judgment. However, historical knowledge, however complete, cannot lead us to predictive certainty (Reed and Harvey 1992, 357). Prediction premised on causal, linear processes has yielded important knowledge, but much of the world around us—both social and natural—is not linear. Deep contingencies give rise to interconnections of non-linear interacting systems at all scales, and critical realism insists that in any setting (natural, social, or otherwise) there exist "constellations of causal factors" (Steinmetz 1998, 172). Highly controlled laboratory settings provide the most significant degree of prediction, generating critical knowledge of how causal-mechanical interactions operate, but these settings also have limits (Feyerabend 1970).

Third, critical realism recognizes that one of the logical consequences of partial knowledge (historical and future) is that *human agency*—the ability to act independently of external constraints—is limited. Our expectations about what may be gained in studying social-capital phenomena must consider that knowledge gained is always incomplete. Two events or conclusions that appear the same could have different causes. Single-causal mechanisms, given the nature of reality, are in principle not possible (Alexander 2003b; Steinmetz 1998, 173). Our experience suggests that individual humans have a degree of choice—what to wear, what to eat on a given day—but that choosing is more limited than we might initially think. While we may choose to eat whatever we want, our location, resources, biological limits, and many other factors narrow what appears to be an open choice down to a very narrow range—for example, we may not walk to Australia however much we will it. Acknowledging limits is not equivalent, however, to acceptance of determinism. Though we may exercise options within limits, we do have an ability to act on the phenomena and systems around us and to understand them to some degree. Progress in research, including social phenomena, is therefore possible and meaningful, and knowledge leading to action can be developed, examined, modified, and pursued further. Determinism is an important complement to agency (Caro, Sandoval-Hernandez, and Luedtke 2014). The structures—natural, social, cultural—out of which the natural world, human life, and consciousness arise are in many instances highly regularized; we expect to find our apples beneath, not above, the trees. We very usefully speak of laws, principles, constants, and other causal terms. In the human sphere, something as seemingly benign as learning to speak reflects an important degree of determinism—our minds, thinking, and perception are highly shaped by the distinctive analytic features of human language and all that comes with it (Gilson 1988). That shaping occurs in us long before we are conscious of its effects such that, while we may try and consciously reject it, we can never uninstall the linguistic frameworks we grew up in or fully undo their effect on us (Chomsky 1996; Martinich 1996). Language requires individuals: without them there is no language, as evidenced by extinct languages. And there is no language if there is only one individual: verbal communication is a function of collective process in development, use, and modification (Kripke 1996). A language broken into pieces for analysis is no longer human language, however useful such a reductive process might be for other purposes (Gilson 1988). Social phenomena (and language represents a cluster of social phenomena) can be partially understood through elements, but only functioning wholes can provide robust explanation (Chomsky 1996).

Critical realism recognizes and holds in creative tensions the demands of both agency and determinism from the individual human to our wider societies and social structures, recognizing that society exists as something that profoundly structures who we are but that we can study, learn about, act on: "Society may thus be conceived as an articulated ensemble of such relatively independent and enduring structures; that is, as a complex totality subject to change both in its components and their interrelations" (Bhaskar 1978, 13).

Fourth, critical realism allows for *emergence*. One of the important results of the tensions of agency and determinism is that law-like functions at one level can give rise to novel phenomena at higher orders. This observation is often referred to as emergence. Emergence in a critical-realist context is "the relationship between two [structural levels of reality] such that one arises diachronically (or perhaps synchronically) out of the other but is capable of reacting back on the lower level and is causally irreducible to it" (Steinmetz 1998, 173). The implication is that even where we might find law-like behaviour by looking at isolated lower-order interactions (e.g., the conservation of energy in the atomic structure of hydrogen), the explanation provided by that law does not encompass all aspects of behaviour that occurs at higher orders.

Emergence complicates our efforts to sort out direct causal arrows. Even in physical systems, when elements interact they can produce novel features that are not present in the elements (eg. “wet” is a property of millions of water molecules (Humphreys 2016; Richardson, Snowden, and Allen 2006). Social interactions extend this complexity by including not only physical interactions of individuals but states of mind and perceptions (eg. trust). The relations between parts, elements, people, natural entities, and everything else around us is deeply complex at a causal level. Critical realism seeks to understand how law-like behaviour on the one hand is related to less understood or unexpected causal effects on the other. In some cases, we may see a social cause and resulting effect (eg. a lie leading to loss of trust) without understanding all aspects of the intervening changes in mental or physiological states. These dynamics are important for social capital research. At the meso level of social structural analysis such as investigations of social capital at neighbourhood levels, these patterns and regularities amid potentially wide variations are a persistent challenge.

Complexity Science

Critical Realism → **Complexity Science** → Networks → Social Capital → Spatial Data

The critical-realist framework suggests what may be known and how at a general level. Complexity science is concerned directly with the causally difficult phenomena we experience and are part of. This includes the social systems and structures that arise from and shape human interactions at all scales, including meso-level neighbourhood contexts in urban settings. When Jane Jacobs wrote *The Death and Life of Great American Cities* in the early 1960s, complexity science as we know it today was still in its infancy. Cybernetics had been around since the 1940s when Norbert Weiner began to explore what constituted the various dynamics of purposeful systems (Moray 1963). Jacobs identified an important 1958 review essay on scientific progress and complexity by Warren Weaver that signalled growing awareness of complex-systems consequences generally and what such thinking might mean in the context of cities and their functions (Jacobs 1992, 428–48). Charles Lindblom, writing a year or so ahead of Jacobs, reached similar conclusions about the limits of administrative planning, in principle: Despite desires and efforts, accounting for and projecting all of the variables, planning into the future as a way of controlling outcomes was simply not possible (Lindblom 1959). Cities are not machines, Jacobs argued, because they are characterized by non-linear processes, implying irreducibility. Like natural systems of energy and motion, social structures and human systems seem to hold order and chaos in tensions reflecting both predictability and novelty (Byrne 1998; Lewin 1999; Simon 1962; Waldrop 1993).

Understanding these dynamics is an important feature of our efforts to understand social structures generally and social-capital measurement in particular. There are several key features that are particularly relevant. Whether or not complex systems are deterministic (Goldspink 1999), they are certainly not linear (Feigenbaum 1983). As discovered by Edward Lorenz while running data on weather-prediction models, even where the environment is a computer operating system running algorithms, very slight variations of initial conditions can yield remarkably different outcomes (Lorenz 1963). In lab experiments and other attempts to create closed systems, this *sensitivity to initial conditions* can be problematic since a failure to control even a small variable affecting a phenomenon (e.g., number of decimal places used) can lead to unexpected or erroneous outcomes. In quasi-closed systems like networks of sensors or operating systems, these unwanted nudges make prediction (and troubleshooting) difficult. This sensitivity is operative even in the case of a simple push-button switch that will “bounce” and be randomly open or closed owing to micro states if a limit strategy is not coded into the software or built into the electronic circuits (Margolis 2012, 155–58). In open systems like societies and other human social structures, the avenues for sensitivity are numerous indeed, and formal repeatability is not possible. Given the sensitivity of systems to these inputs, the deep complexity and non-linearity of an open system appears to make predictability impossible in principle. As Taleb argues in *The Black Swan*, "Almost every event in social life is produced by rare but consequential shocks and jumps; all the while almost everything studied about social life focuses on the "normal," particularly with "bell curve" methods of inference that tell you close to nothing. Why? Because the bell curve ignores large deviations, cannot handle them, yet makes us confident that we have tamed uncertainty. I term this GIF, Great Intellectual Fraud."(Taleb 2010, xxiv) This is an important caution that must be taken seriously where statistical analyses assume normal distributions. Where the spatial and social data are analyzed and compared, traditional statistical methods will be used in addition to the distinctly different approach represented by machine learning methods rooted in random forest approaches (Breiman 2001).

Feedback in systems refers to the characteristic of a system to recursively make use of its own outputs as new inputs. When the feedback amplifies existing signals, it is referred to as positive (regardless of whether it is desired—e.g., feedback in a sound system is very irritating but would be considered formally positive given that it amplifies a system signal). Negative feedback, on the other hand, mutes a system's given direction or process. Feedback of this sort is not characteristic of linear systems but is common in social systems at all scales (Simon 1962). An example of this can be found in research on innovation in organizations where corporate processes designed to promote high margin products internally will "kill off" innovative new products that fail to meet that margin even if those new products could, over time, dramatically outperform existing products (C. Christensen 2011; C. M. Christensen, Baumann, Ruggles, and Sadtler 2006). The built-in logic of corporate processes constitute a feedback mechanism that "mutes" anything that does not fit within it. Universities and other common types of organizations such as municipal bureaucracies function in a similar way (Blais 2010; C. M. Christensen and Eyring 2011). Living systems typically interact with both higher-order and lower-order systems, thus incurring a degree of novelty and a means by which even small changes within or adjacent to one system are fed back into that system, generating high sensitivity to initial conditions, as noted above (Batty 2012; Buchanan 2000).

In social systems, such as those that constitute the conditions for social-capital formation and function, agents within the network of the system can and do change and influence it from within. When a higher-order system influences the sub-systems that form it or with which it interacts, it is referred to as *supervenience* (Murphy 1997, 22–23). The above-noted example of corporate processes generating feedback loops optimized for one type of product profit margin at the expense of another would be an example of supervenience—formal company policy or embedded policy in the form of corporate culture rewards certain types of agent (employee) behaviour and punishes divergent behaviour. Top-down causation is a means by which the characteristics of a larger system constrains the range of motion or the function space of a smaller or lower-order system of interactions.

From a social systems vantage point, individual are constrained by various expressions of the group as seen in rules, formal laws, cultural norms, and expectations. Norms are the result of countless preceding individual decisions and interactions, foundational mechanisms that lead to cultural practice. These collective properties supervene on individuals and limit their range of options (Trofimova 2000). From a network perspective, the topology of the larger structures plays a significant role in determining the range of motion possible for the lower-order systems (Sekara, Stopczynski, and Lehmann 2016). Emergence, as described earlier, is an important feature of complex systems (Kim 1999). Complex systems are composed of networks. Entities or actors plus relations between them leads to phenomena such as social capital. In support of the central hypothesis of this project, social capital is not possible where there are only individuals with no connections at all. After three hundred years of dissecting everything into molecules and atoms and nuclei and quarks, [scientists] finally seemed to be turning the process inside out. Instead of looking for the simplest pieces possible, they were starting to look at how those pieces go together into complex wholes. (Waldrop 1993, 16)Complex systems are the result of dynamic interactions among elements. The tightly coupled nature of these systems means that at given times, any variation within the network of relations can cause a cascading set of influences to occur in all the connected sub-systems and super-systems. When a system is linked in this way, it is said to be at a *critical state*—any perturbation can lead the system toward a chaotic state before moving to a new state of equilibrium. This can be seen experimentally in, for example, the phase change of ice to water and mathematically through computer-enabled iterations of simple equations with tunable variables (May 1976). These dynamics enable the various orders of interacting systems to adapt to both internal and external signals, to receive feedback not only in a loop but also as novel information or influence from the environment (external variables). Historical reflections on social systems affirm that they appear to reflect this phenomena of criticality (Buckley 1968; Collins 2000; Thomas 1997). If we are going to increase our understanding of and possible agency within social systems, we will need to account for complex-systems dynamics in research design, models, and interpretive frameworks (Byrne 1998).

Networks

Critical Realism → Complexity Science → **Networks** → Social Capital → Spatial Data

Complex systems reflect elements interacting at various scales to yield novel behaviour. These emergent phenomena depend on how elements are related to eachother and a great deal of formal insight on this aspect of systems has come through the development of the science of networks. Networks provide the linkage between critical realism, complex systems, and the empirical aspects of social capital being investigated in this study.

The means by which we can begin to understand many complex systems is through the simplification of complex dynamics through the use of nodes and edges. Nodes are the entities that constitute a system (people, books, papers, and so on), and edges are the relationships that connect the entities (trust, social ties, citations, and so on). The structure of nodes and edges gives a topology that can be studied and modelled in ways ranging from simple visualizations to highly complex mathematical and statistical analysis (Snijders 2011).

A second critical aspect of network analytics is the dynamics that occur on the network structures. This is most readily understood as the nature of the dynamics that inform the relationship between networks and systems of nodes. In the case of social networks, friendship, neighbourhood, and family ties form systems of nodes and ties that are complex but analyzable. Even a few dozen nodes with very simple dynamic qualifiers can become highly complex very quickly and surprisingly difficult to analyze. The advent of mathematics supported by computation has enabled significant growth in the application of network analysis to a wide range of phenomena, though one of the significant boundaries is the in-principle non-computable problems owing to exponential increases in computational calculations (Newman 2010).

The highly complex realities that arise from topology and dynamics interactions require critical assessment of how much detail can be included in analysis. In planning environments, transportation has made significant use of network analysis to understand the dynamics of how people and vehicles move on road, sidewalk, and other spatial structures and the role these structures play in large-scale social and cultural dynamics (Little 2002; Omrani 2015; Papinski, Scott, and Doherty 2009). In the case of social-capital investigation where trust, relational connections, and proximity all interact in significantly subtle and powerful ways, network analysis becomes an obvious and important means of investigating the dynamics of social structures. The social infrastructure of cities is a highly complex network of relationships among people, groups, associations, institutions, and a myriad of other structures (Bettencourt 2013; Portugali 2011; Zhou, Sornette, Hill, and Dunbar 2005). The challenges of understanding these structures are compounded by their virtual invisibility in most cases and may include ongoing expert debate over the use of statistical methods for spatial analysis (Dubin 1998; LeSage 1997) and the relationship of standard statistics to machine learning approaches (Breiman 2001). These are important elements of the challenges that social-capital analysis in urban contexts have begun to take on and will need to continue to invest in. For this study, the two primary applications of network science are respondent-driven descriptions of their social networks (close friends, acquaintances, and relatives) and mathematical descriptions of their travel patterns analyzed within ArcGIS.

Social Capital

Critical Realism → Complexity Science → Networks → **Social Capital** → Spatial Data

Community-level measurement of social capital represents well the kinds of problems that critical realism is suited to meaningfully approach. Complexity science operating out of a critical-realist approach provides a framework where specific techniques can be employed. In the case of social-capital investigations, this could include network descriptions of social ties, spatial networks (GIS), statistical analysis (R), and dynamic modelling (NetLogo) as examples (Papinski and Scott 2011; Savitz and Raudenbush 2009; Snijders 2011). Social capital is a complex set of phenomena where there is no singular mechanism, no clear boundary between dynamics, and where interacting mechanisms, agents, and other variables are at best partly understood and often unknown (Janssen, Holahan, Lee, and Ostrom 2010; Ostrom 1986, 16).

It is not necessary to understand all of the underlying mechanisms of social capital in order to make provisional assertions about meaningful knowledge of social resources held among a number of actors—we can gain insight about social dynamics without proof of a causal link (Cushing and McMullin 1989) between a given variable and social capital.

Measurement approaches in this study are designed to detect possible correlations between device-generated spatial data (Abarbanel, Brown, Sidorowich, and Tsimring 1993) and social-capital survey data (Weinberger 2012). Correlation, therefore, is a viable and more frequent option in testing hypotheses, while more formal causation (of the sort imagined in mechanistic interactions of the Newtonian variety—this much change in *x* always causes this much change in *y*) is more effective for physical systems without agency. Inference and probability rather than causation and certainty must inform hypothesis formulation in order to be consistent with a critical-realist approach that is operationalized using complex-systems approaches. The partial nature of knowledge and causes means that any given phenomenon can be scrutinized empirically from a variety of non-exclusive angles (Mir and Watson 2001, 1171). Fragmented or incomplete knowledge is very important and is the primary means by which we understand the dynamics of physical and social worlds.

The variety and nature of human social interactions in high-density locations like cities is extremely complex, and new forms of synthetic research design and analysis will undoubtedly lead to new insights about these phenomena (Dandekar 2005).

Spatial Data

Critical Realism → Complexity Science → Networks → Social Capital → **Spatial Data**

GPS data provides the concrete linkage between human behaviour and the survey data (social capital) that can be analyzed using network science. This is consistent with our understanding of complex systems in the context of a critical-realist philosophical framework. Recording the movement patterns of humans in their home territories provides an opportunity to examine how individual agency interacts with constraining structures related to geography, income, education, institutional experience, and a range of other perceptions.

Knowledge can be legitimate as both *homeostasis* (stationary stability) and *homeorhesis* (evolutionary stability) (Sieweke 2014), and has two direct implications for designing spatial-data collection methods that explore complex social-capital phenomena.

First, it means that it is possible to learn from other phenomena that are better understood than the one in question—we understand a complex phenomenon by using a known measurement method that corresponds to that complex phenomenon. This learning is facilitated through an interplay of deduction, induction, abduction (Hintikka 1998), and replication (Mir and Watson 2001, 1171). Deduction is most suited to settings where defined logical relationships between all variables are possible such as in mathematics, controlled laboratory settings, formalized philosophical argumentation—contexts where we are filling gaps in knowledge within a well-known space (Carnap 1970). Induction is better suited to the exploration of phenomena that are not as well-known as it better serves an exploratory mode where understanding (generalization) grows through observation of instances and patterns (Chomsky 1996). Proceeding in this way, explanations may be partial but useful and need not require direct cause-and-effect conclusions or logical formalisms (Henkin 1967, 72; Mir and Watson 2001, 1172) . By collecting data about movement patterns and calculating the distinct features of each participant, I will explore how these generalizations relate to social-capital levels gleaned from the Social Capital General Social Survey (SCGSS) data.

Second, critical realism affirms the possibility of acquiring real knowledge of the external world, including other human beings, through observation and experience (Acemoglu, Johnson, and Robinson 2004; Bhaskar 1978). This does not require formal comparison in the sense of logical deduction but may proceed through induction whereby signals (data) can be identified, collected, and analyzed in a regular way (Abarbanel, Brown, Sidorowich, and Tsimring 1993; Assad 1999). Collecting spatial data is a valid means of affirming that something might be known about a mind-independent reality: “While science is indeed a social production process, it is also knowledge 'of' things which exist and act independently of science" (Steinmetz 1998, 175). This process includes the comparison of lesser- to better-known phenomena, which allows the scaffolding of hard-won and incomplete provisional knowledge to increase.

Social capital in particular requires integration and synthesis, in this case comparing survey and spatial data so that new knowledge, a "third way" is possible: "Wisdom requires us to invent a third curriculum, which will weave the warp of the rediscovered humanities to the woof of expert exactitude" (Serres 1995, 184). This third way is consistent with the practice of scientific progress and the approach I have outlined. We don't select theories based on deduction, having seen them all and then deciding on the best—the options would quickly run a greater number than all the atoms of the universe. I would suggest that we choose theories based on coherence, whether intuited or consciously identified, between sets of problems and sets of possible solutions spaces. Our inquiry is aimed at correlations or probable causations rather than mechanistic certainty (whatever that is). (Putnam 1988, 128)

Critical Realism and Complex Systems for Planning Policy

The foregoing discussion of the progression of critical realism, complex systems, networks, social capital, and spatial data leads logically to a consideration of the implications for planning, municipal policy, and civil-society development. Social structures arising from relationship networks and spatial use constitute and may even give rise to the physical form of our cities and communities. Planning faces an increasingly fragmented theoretical and practical working space since the fading of rational comprehensive assumptions. This difficulty is compounded by the significant range of professional, social, political, cultural, and land-use issues that planning endeavours to engage and order (Fainstein and Campbell 2011) . The value of the current research will be increased if it can support meaningful integration rather than increased fragmentation. Planning is by its very nature an undertaking that operates at the intersection of a significant number of competing interests and enterprises—engineering, policy, ecology, sociology, commerce, and many others. It is critical, therefore, that new research and practice enable diverse but coherent integration in order to make progress on perennial challenges (e.g., relationship between transportation, land use, and social policy) (Irwin 2010).

The division of practice and theory in planning is also coherently bridged through recognition that the systems of social interaction and resulting structures have independent existence in a critical-realist philosophical framework. There are patterns for planning practitioners to identify and learn alongside theorists who develop additional questions for investigation (Putnam 1988, 109). These patterns merit scientific investigation that can lead to new knowledge and understanding even if the systems display stochastic features. The Social Imaging Project, therefore, is not an esoteric exercise. Science, and with it a science of cities, will continue to grow fresh impetus, not as a reductive, oversimplifying enterprise but as a knowledge-driven process of gathering intelligence, identifying patterns of systems, proposing potential solutions, and beginning creative undertakings. The science of cities requires a conception of theory, hypothesis, and testing that is focused on synthesis of diverse and new data sources that avoids reductive analysis (Serres 1995). Based on reductive paradigms of investigation, it is likely that the public appetite for the knowledge we desperately need will wane and we will fail to meet the demand for increased ingenuity. The experimental method is neither a self-contained nor a self-sufficient technique for discovering causal laws. The strict controls which scientists use to elicit nature's law-like properties produce only limited, idealized knowledge. Positivist canons can suffice only in the closed domain of the experimental setting. These law-like regularities with their clarity and order often disappear when taken from the laboratory and used to explain outcomes in the open world of everyday life (Reed and Harvey 1992, 356).

Cities and the social structures that constitute them are certainly part of "the open world of everyday life." Developing a more integrated, sophisticated, and open approach to science that is transparent about contingencies and open to real learning, there exist real possibilities for understanding difficult phenomena (including social-systems phenomena) (Batty 2012). Urban demands globally will require these gains if we are to succeed in providing for greater human flourishing (Burdett and Sudjic 2011).

Critical realism provides a clear rationale for experimental activity—a valuable feature for planners and planning researchers. The rational comprehensive method leveraged control, reductive analysis, and expert power to build freeways through downtowns, build public housing, and direct transportation investments with results that have often been troubling (Scott 1999). A new type of control-oriented planning practice is gaining ground through technical, data-driven approaches built on assumptions that big data will lead to the solutions we need. Big data systems and those that control them, however, are as likely to create new problems as they are to solve them (Borgman 2015; Derman 2011; O'Neil 2016; Postman 1993). Smart cities and big data are useful, but over-reliance on technical solutions may turn out to be the downtown freeways of our time if significant supporting research isn't well-matched with practices that support the common good (Friedmann 2000).

One of the tests of the efficacy of this research is the potential it has to support generative approaches to planning. The study of complex-systems dynamics has taught us that relatively simple or core "rules" that function effectively can lead to positive outcomes where more bureaucratic structures fail (Innes and Booher 2010; Ostrom 2005; Sanders 1998; Snowden and Boone 2007). The balance of control and permission may be most clearly seen in settings where informal development is common (Gouverneur 2014; Graham and McFarlane 2015) and where a more open and experimental tone is set for urban development—for example, tactical urbanism, guerrilla urbanism, flexibility on mother-in-law suites in suburbs, and so on. Designing processes that feed a changing context back into the decision-making and building cycle can lead to the right kinds of change at the right times.

Direct, problem-oriented experimentation can bridge practice and theory if the experimentation leads to improvements. Long-term success and the accumulation of knowledge require sophisticated thinking and more complex (not simply more complicated) forms of social organizing (Homer-Dixon 2001). Good ideas and sound thinking are no guarantee that new practices will follow. There is hope that an understanding of complex systems can be utilized in seeding the conditions for new strategies and practices that become more effective, not just more cumbersome, over time.

We know that the arrangement of social structures, institutions, and cultural patterns can have long-term effects on societies: "The planning of institutions of both types—for the realisation of planned change, and for subsequent control—is an important aspect of integrative planning. This means, for example, that planning for technological innovation ought to include planning for new social institutions" (Jantsch 1972, 137). If new institutions are not considered in a context of growing knowledge, we may fail to learn the lessons of history and constrain our urban growth possibilities through inadequately adaptive institutions (Schumpeter 2011), and inattention to the social dimensions of our collective challenges will continue: "The very rapid growth of the field of industrial relations as a professional specialty dramatizes the fact that our larger social systems, whether organizations or communities, are becoming more and more aware of their problems in the area of social progress in human relations and are turning more and more often to sources of outside professional help in solving them" (Lippitt, Watson, and Westley 1958, 275–76). This current project, set within a critical-realist philosophical framework and engaging in empirical work through complex systems, network science, and the interactions of social capital and spatial data endeavours to enlarge our understanding of the dynamics of both the social infrastructure that exists in our cities and that which is emerging amid the changes of our times.

Sources

Abarbanel, H., R. Brown, J. Sidorowich, and L. Tsimring. 1993. "The Analysis of Observed Chaotic Data in Physical Systems." *Reviews of Modern Physics* 65, no. 4:1331–92. https://doi.org/10.1103/RevModPhys.65.1331.

Abbott, R. 2009. "The Reductionist Blindspot." *Complexity* 14, no. 5:10–22. https://doi.org/10.1002/cplx.20274.

Acemoglu, D., S. Johnson, and J. Robinson. 2004. "Institutions as the Fundamental Cause of Long-Run Growth." 10481. National Bureau of Economic Research. Working Paper No. http://www.nber.org/papers/w10481.

Albert, R. Z., and L. Barabási. 2002. "Statistical Mechanics of Complex Networks." *Review of Modern Physics* 74:47–97. http://citeseer.ist.psu.edu/viewdoc/summary?doi=10.1.1.25.5619

Alexander, C. 2003a. "New Concepts in Complexity Theory Arising from Studies in the Field of Architecture: An Overview of Four Books of the Nature of Order with Emphasis on the Scientific Problems Which Are Raised." *Katarxis No. 3*. May. http://www.katarxis3.com/SCIENTIFIC%20INTRODUCTION.pdf.

———. 2003b. *The Nature of Order: An Essay on the Art of Building and the Nature of the Universe*. Vol. 2, *The Process of Creating Life*. Berkeley, CA: Center for Environmental Structure.

Allmendinger, P. 2009. *Planning Theory*. New York: Palgrave Macmillan.

Aristotle. 2012. *Aristotle's Nicomachean Ethics*. Translated by R. C. Bartlett and S. D. Collins. Chicago; London: University Of Chicago Press.

Assad, M. L. 1999. *Reading with Michel Serres*. Albany: State University of New York Press.

Australian Bureau of Statistics. 2004. "Measuring Social Capital: An Australian Framework and Indicators." Information Paper. http://www.ausstats.abs.gov.au/Ausstats/free.nsf/Lookup/13C0688F6B98DD45CA256E360077D526/$File/13780_2004.pdf.

Badash, L. 1972. "Completeness of Nineteenth-Century Science." *Isis* 63, no. 216:48–58. https://doi.org/10.1086/350840.

Batty, M. 2012. "Building a Science of Cities." *Cities* 29, Supplement 1:S9–S16. https://doi.org/10.1016/j.cities.2011.11.008.

Bechard, M., and I. Marchand. 2006. "General Social Survey Cycle 19: Time Use (2005)." Statistics Canada. Catalogue no. 12M0019GPE. http://data.library.utoronto.ca/datapub/codebooks/cstdli/gss/gss19/gssc19gidv2.pdf.

Bernard, H. R., P. Killworth, D. Kronenfeld, and L. Sailer. 1984. "The Problem of Informant Accuracy: The Validity of Retrospective Data." *Annual Review of Anthropology* 13:495–517.

Bethune, B. 2014. "The End of Neighbours." *Maclean's*. August 8. http://www.macleans.ca/society/the-end-of-neighbours/.

Bettencourt, L. M. A. 2013. “The Kind of Problem a City Is: New Perspectives on the Nature of Cities from Complex Systems Theory.” Working Paper, Santa Fe Institute, Santa Fe New Mexico. http://www.santafe.edu/media/workingpapers/13-03-008.pdf.

Bhaskar, R. 1978. “Possibility of Social Scientific Knowledge and Limits of Naturalism.” *Journal for the Theory of Social Behaviour* 8, no. 1:1–28. https://doi.org/10.1111/j.1468-5914.1978.tb00389.x.

Blais, P. 2010. *Perverse Cities: Hidden Subsidies, Wonky Policy, and Urban Sprawl.* Vancouver: University of British Columbia Press.

Boneham, M. A., and J. A. Sixsmith. 2006. “The Voices of Older Women in a Disadvantaged Community: Issues of Health and Social Capital.” *Social Science and Medicine* 62, no. 2:269–279. https://doi.org/10.1016/j.socscimed.2005.06.003.

Borgman, C. L. 2015. *Big Data, Little Data, No Data: Scholarship in the Networked World*. Cambridge, MA: MIT Press.

Bourdieu, P. 2008. “The Forms of Capital.” In *Readings in Economic Sociology*, edited by N. W. Biggart, 280–91. Oxford: Blackwell. http://onlinelibrary.wiley.com/doi/10.1002/9780470755679.ch15/summary.

Breiman, L. 2001. “Statistical Modeling: The Two Cultures (with Comments and a Rejoinder by the Author).” *Statistical Science* 16, no. 3:199–231. https://doi.org/10.1214/ss/1009213726.

Brody, B. A, ed. 1970. *Readings in the Philosophy of Science*. Englewood Cliffs, NJ: Prentice Hall.

Browning, C. R., S. L. Feinberg, and R. D. Dietz. 2004. “The Paradox of Social Organization: Networks, Collective Efficacy, and Violent Crime in Urban Neighborhoods.” *Social Forces* 83, no. 2:503–34. https://doi.org/10.1353/sof.2005.0006.

Buchanan, M. 2000. *Ubiquity: The Science of History . . . or Why the World Is Simpler Than We Think*. New York: Crown.

Buckley, W. 1968. Society as a Complex Adaptive System. In *Modern Systems Research for the Behavioral Scientist*, edited by W. Buckley, 490–513. Berlin: de Gruyter.

Burdett, R., and D. Sudjic, eds. 2011. *Living in the Endless City: The Urban Age Project by the London School of Economics and Deutsche Bank’s Alfred Herrhausen Society*. London: Phaidon.

Byrne, D. 1998. *Complexity Theory and the Social Sciences: An Introduction*. New York: Routledge.

Carnap, R. 1970. “Statistical and Inductive Probability.” In *Readings in the Philosophy of Science*. Englewood Cliffs, NJ: Prentice Hall.

Caro, D. H., A. Sandoval-Hernandez, and O. Luedtke. 2014. “Cultural, Social, and Economic Capital Constructs in International Assessments: An Evaluation Using Exploratory Structural Equation Modeling.” *School Effectiveness and School Improvement* 25, no. 3:433–50. https://doi.org/10.1080/09243453.2013.812568.

Carpiano, R. M., and L. M. Fitterer. 2014. “Questions of Trust in Health Research on Social Capital: What Aspects of Personal Network Social Capital Do They Measure?” *Social Science and Medicine* 116:225–234. https://doi.org/10.1016/j.socscimed.2014.03.017.

Chomsky, N. 1996. "Language and the Problems of Knowledge." In *The Philosophy of Language*, edited by A. P. Martinich, 558–57. 3rd ed. Oxford: Oxford University Press.

Chow, W. S., and L. S. Chan. 2008. "Social Network, Social Trust and Shared Goals in Organizational Knowledge Sharing." *Information and Management* 45, no. 7:458–65. http://www.sciencedirect.com/science/article/pii/S0378720608000888.

Christensen, C. 2011. *The Innovator's Dilemma: The Revolutionary Book That Will Change the Way You Do Business*. New York: Harper Business.

Christensen, C. M., H. Baumann, R. Ruggles, and T. M. Sadtler. 2006. "Disruptive Innovation for Social Change." *Harvard Business Review* 84, no. 12:94–101.

Christensen, C. M., and H. J. Eyring. 2011. *The Innovative University: Changing the DNA of Higher Education from the Inside Out*. 8th ed. San Francisco: Jossey-Bass.

Chung, S., H. Choi, and S. S. Lee. 2014. "Measuring Social Capital in the Republic of Korea with Mixed Methods: Application of Factor Analysis and Fuzzy-Set Ideal Type Approach." *Social Indicators Research* 117, no. 1:45–64. https://doi.org/10.1007/s11205-013-0341-8.

Cohen, N. 2011. "Cellphones Track Your Every Move, and You May Not Even Know." *New York Times*. March 26. http://www.nytimes.com/2011/03/26/business/media/26privacy.html.

Cohen, R., and S. Havlin. 2010. *Complex Networks: Structure, Robustness and Function*. Cambridge: Cambridge University Press.

Coleman, J. S. 1988. "Social Capital in the Creation of Human Capital." *American Journal of Sociology* 94:S95–S120.

Collins, R. 2000. *The Sociology of Philosophies: A Global Theory of Intellectual Change*. Rev. ed. Cambridge, MA: Belknap Press of Harvard University Press.

Crandall, D. J., L. Backstrom, D. Cosley, S. Suri, D. Huttenlocher, and J. Kleinberg. 2010. "Inferring Social Ties from Geographic Coincidences. *Proceedings of the National Academy of Sciences* 107, no. 52:22436–41. https://doi.org/10.1073/pnas.1006155107.

Cushing, J. T., and E. McMullin, eds. 1989. *Philosophical Consequences of Quantum Theory: Reflections on Bell's Theorem*. Notre Dame: University of Notre Dame Press.

Dandekar, H. C. 2005. "Qualitative Methods in Planning Research and Practice." *Journal of Architectural and Planning Research* 22, no. 2:129–37.

Derman, E. 2011. *Models. Behaving. Badly.* New York: Free Press.

Dubin, R. A. 1998. "Spatial Autocorrelation: A Primer." *Journal of Housing Economics* 7, no. 4:304–27. https://doi.org/10.1006/jhec.1998.0236.

Dugundji, E., D. M. Scott, J. A. Carrasco, and A. Paez. 2012. Urban Mobility and Social-Spatial Contact-Introduction." *Environment and Planning A* 44, no. 5:1011–15. https://doi.org/10.1068/a45183.

Dunkelman, M. J. 2014. *The Vanishing Neighbor: The Transformation of American Community*. New York: Norton.

Eagle, N. N. 2005. "Machine Perception and Learning of Complex Social Systems." PhD diss. Massachusetts Institute of Technology, Boston. http://reality.media.mit.edu/pdfs/thesis.pdf.

Fainstein, S. S., and S. Campbell, eds. 2011. *Readings in Planning Theory*. 3rd ed. Malden, MA: Wiley-Blackwell.

Fairfield, P. 2003. Review of *A House Divided: Comparing Analytic and Continental Philosophy*, by C. G. Prado, ed. *Symposium* 7, no. 2:251–53.

Feigenbaum, M. 1983. "Universal Behavior in Nonlinear Systems." *Physica D* 7, nos. 1–3:16–39. https://doi.org/10.1016/0167-2789(83)90112-4.

Feyerabend, P. K. 1970. "How to Be a Good Empiricist—A Plea for Tolerance in Matters Epistemological." In *Readings in the Philosophy of Science*, edited by B. A. Brody, 319–42. Englewood Cliffs, NJ: Prentice Hall.

Fischler, R. 2000. "Linking Planning Theory and History: The Case of Development Control. *Journal of Planning Education and Research* 19, no. 3:[233]–241.

Franke, S. 2005. *Measurement of Social Capital: Reference Document for Public Policy Research, Development, and Evaluation*. Interdepartmental Research Project Reference Tool. Ottawa: Policy Research Institute (now Policy Horizons Canada).

Friedmann, J. 2000. "The Good City: In Defense of Utopian Thinking." *International Journal of Urban and Regional Research* 24, no. 2:460–72. https://doi.org/10.1111/1468-2427.00258.

Friesen, M. J. 2013a. "Is Social Capital Measurement Still Relevant? A Roundtable Policy and Social Impact Assessment White Paper." Hamilton, ON: Cardus.

———. 2013b. "Social Infrastructure: Underpinning the Success of Cities." *Municipal World* 123, no. 12:11–14.

Gadamer, H.-G. 1960. *Truth and Method*. Translated by J. Weinsheimer and D. G. Marshall. 2nd ed. New York: Continuum.

Garcia, F. P., L. S. Martinez, and J. F. de G. Radoselovics. 2008. *Estimation of Social Capital in the World*. Working Papers Series. Bilboa, Spain: BBVA Foundacion.

Gesthuizen, M., T. van der Meer, and P. Scheepers. 2009. "Ethnic Diversity and Social Capital in Europe: Tests of Putnam's Thesis in European Countries." *Scandinavian Political Studies* 32, no. 2:121–42. https://doi.org/10.1111/j.1467-9477.2008.00217.x.

Gilson, E. 1988. *Linguistics and Philosophy*. Notre Dame: University of Notre Dame Press.

Goldspink, C. 1999. "Social Attractors: An Examination of the applicability of Complexity Theory to Social and Organisational Analysis. PhD diss. University of Western Sydney-Hawkesbury, Richmond, Australia.

Gouverneur, D. 2014. *Planning and Design for Future Informal Settlements: Shaping the Self-Constructed City*. Abingdon: Oxon; New York: Routledge.

Graham, S., and C. McFarlane. 2015. *Infrastructural Lives: Urban Infrastructure in Context*. New York: Routledge.

Gunderson, L. H., and C. S. Holling. 2002. *Panarchy: Understanding Transformations in Human and Natural Systems*. Washington, DC: Island Press.

Henkin, L. 1967. "Formal Systems and Models of Formal Systems." In *The Encyclopedia of Philosophy*, edited by P. Edwards, 8:61–74. New York: Macmillan and the Free Press.

Hintikka, J. 1998. "What Is Abduction? The Fundamental Problem of Contemporary Epistemology." *Transactions of the Charles S Peirce Society* 34, no. 3:503–33.

Homer-Dixon, T. 2001. *The Ingenuity Gap: Can We Solve the Problems of the Future?* Toronto: Vintage Canada.

Hu, C. 2014. "Life and Death in the Open System." *On Site Review* 32:12–14.

Humphreys, P. 2016. *Emergence*. Oxford: Oxford University Press.

Innes, J. E., and D. E. Booher. 2010. *Planning with Complexity: An Introduction to Collaborative Rationality for Public Policy*. New York: Routledge.

Irwin, E. G. 2010. "New Directions for Urban Economic Models of Land Use Change: Incorporating Spatial Dynamics and Heterogeneity." *Journal of Regional Science* 50, no. 1:65–91. http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1547412.

Jacobs, J. 1992. *The Death and Life of Great American Cities*. New York: Vintage.

Janssen, M. A., R. Holahan, A. Lee, and E. Ostrom. 2010. "Lab Experiments for the Study of Social-Ecological Systems." *Science* 328, no. 5978:613–17. https://doi.org/10.1126/science.1183532.

Jantsch, E. 1972. *Technological Planning and Social Futures*. New York: John Wiley & Sons.

Kawachi, I., B. P. Kennedy, K. Lochner, and D. Prothrow-Stith. 1997. "Social Capital, Income Inequality, and Mortality." *American Journal of Public Health* 87, no. 9:1491–98. https://doi.org/10.2105/AJPH.87.9.1491.

Kim, J. 1999. "Making Sense of Emergence." *Philosophical Studies* 95, nos. 1–2:3–36. https://doi.org/10.1023/A:1004563122154.

Kojima, K. 2014. "Crafting Space: Generative Processes of Architectural Configurations." *Architectural Design*, *Special Issue: Emphatic Space* 84, no. 5:38–45.

Kripke, S. 1996. "On Rules and Private Language." In *The Philosophy of Language*, edited by A. P. Martinich, 524–37. 3rd ed.. New York: Oxford University Press.

Kuhn, T. 1970. "The Function of Dogma in Scientific Research." In *Readings in the Philosophy of Science*, edited by B. A. Brody, 356–73. Englewood Cliffs, NJ: Prentice Hall.

———. 1996. *The Structure of Scientific Revolutions*. 3rd ed. Chicago: University of Chicago Press.

Kwan, M.-P. 2007. "Mobile Communications, Social Networks, and Urban Travel: Hypertext as a New Metaphor for Conceptualizing Spatial Interaction." *Professional Geographer* 59, no. 4:434–46. https://doi.

org/10.1111/j.1467-9272.2007.00633.x.

LeSage, J. P. 1997. “Regression Analysis of Spatial Data.” *Journal of Regional Analysis and Policy* 27, no. 2:83–94.

Lewin, R. 1999. *Complexity: Life at the Edge of Chaos*. Chicago: University of Chicago Press.

Lindblom, C. E. 1959. “The Science of ‘Muddling Through.’” *Public Administration Review* 19, no. 2:79–88. https://doi.org/10.2307/973677.

Lippitt, R., J. Watson, and B. Westley. 1958. *Planned Change: A Comparative Study of Principles and Techniques*. New York: Harcourt, Brace.

Little, D. 2002. “Transportation as a Large Historical Factor: A Case Study in New Philosophy of History.” Colloquium presented at the Humanitas Colloquium, University of Michigan-Dearborn. September. https://www.google.ca/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwjWi4mao8zSAhVC2IMKHf27DWQQFggcMAA&url=http%3A%2F%2Fwww-personal.umd.umich.edu%2F~delittle%2FTransport%2520as%2520a%2520causal%2520factor%2520in%2520history%2520short%2520version.htm&usg=AFQjCNFHLTaQ0fxei4nMhvnbVaAA0JZWPQ&sig2=OK2tJuBN8hnFTVDoS3NbCw.

Lochner, K., I. Kawachi, and B. P. Kennedy. 1999. “Social Capital: A Guide to Its Measurement.” *Health and Place* 5, no. 4:259–70. https://doi.org/10.1016/S1353-8292(99)00016-7.

Logan, J. R. 2012. “Making a Place for Space: Spatial Thinking in Social Science.” *Annual Review of Sociology* 38:507–24.

Logan, R. K. 2007. *The Extended Mind: The Emergence of Language, the Human Mind, and Culture*. Toronto: University of Toronto Press.

Lorenz, E. N. 1963. “Deterministic Nonperiodic Flow.” *Journal of the Atmospheric Sciences* 20, no. 2:130–41. https://doi.org/10.1175/1520-0469(1963)020<0130:DNF>2.0.CO;2.

Margolis, M. 2012. *Arduino Cookbook*. 2nd ed. Beijing: O’Reilly.

Martinich, A. P., ed. 1996. *The Philosophy of Language*. 3rd ed. New York: Oxford University Press.

May, R. 1976. “Simple Mathematical-Models with Very Complicated Dynamics.” *Nature* 261, no. 5560:459–67. https://doi.org/10.1038/261459a0.

McDoom, O. S. 2014. “Predicting Violence Within Genocide: A Model of Elite Competition and Ethnic Segregation from Rwanda. *Political Geography* 42:34–45. https://doi.org/10.1016/j.polgeo.2014.05.006.

McPherson, M., L. Smith-Lovin, and M. E. Brashears. 2006. “Social Isolation in America: Changes in Core Discussion Networks over Two Decades. *American Sociological Review* 71, no. 3:353–75.

Mir, R., and A. Watson. 2001. “Critical Realism and Constructivism in Strategy Research: Toward a Synthesis.” *Strategic Management Journal* 22, no. 12:1169–73.

Moray, N. 1963. *Cybernetics*. New York: Hawthorn.

Murphy, N. 1997. *Anglo-American Postmodernity*. Boulder, CO: Westview.

Newman, M. E. J. 2010. *Networks: An Introduction*. New York: Oxford University Press.

Omrani, H. 2015. "Predicting Travel Mode of Individuals by Machine Learning." *Transportation Research Procedia* 10:840–49. https://doi.org/10.1016/j.trpro.2015.09.037.

O'Neil, C. 2016. *Weapons of Math Destruction: How Big Data Increases Inequality and Threatens Democracy*. New York: Crown.

Ostrom, E. 1986. "An Agenda for the Study of Institutions." *Public Choice* 48, no. 1:3–25.

———. 2005. *Understanding Institutional Diversity*. Princeton: Princeton University Press.

Ostrom, E., and T. Ahn. 2003. *Foundations of Social Capital*. Cheltenham, UK; Northampton, MA: Edward Elgar.

Paldam, M. 2000. "Social Capital: One or Many? Definition and Measurement." *Journal of Economic Surveys* 14, no. 5:629–53. https://doi.org/10.1111/1467-6419.00127.

Papinski, D., and D. M. Scott. 2011. "A GIS-Based Toolkit for Route Choice Analysis." *Journal of Transport Geography* 19, no. 3:434–42. https://doi.org/10.1016/j.jtrangeo.2010.09.009.

Papinski, D., D. M. Scott, and S. T. Doherty. 2009. "Exploring the Route Choice Decision-Making Process: A Comparison of Planned and Observed Routes Obtained Using Person-Based GPS." *Transportation Research Part F—Traffic Psychology and Behaviour* 12, no. 4:347–58. https://doi.org/10.1016/j.trf.2009.04.001.

Pentland, A. 2014. *Social Physics: How Ideas Turn into Action.* New York: Penguin.

Pinker, S. 2014. *The Village Effect: How Face-to-Face Contact Can Make Us Healthier, Happier, and Smarter*. New York: Spiegel & Grau.

Portugali, J. 2011. *Complexity, Cognition and the City*. Berlin: Springer.

Postman, N. 1993. *Technopoly: The Surrender of Culture to Technology*. New York: Vintage.

Putnam, H. 1988. *Representation and Reality*. Cambridge, MA: MIT Press.

Reed, M., and D. Harvey. 1992. "The New Science and the Old: Complexity and Realism in the Social-Sciences." *Journal for the Theory of Social Behaviour* 22, no. 4:353–80. https://doi.org/10.1111/j.1468-5914.1992.tb00224.x.

Richardson, K. A., D. Snowden, and P. M. Allen. 2006. *Emergence: Complexity and Organization 2005 Annual*. Mansfield, MA: ISCE.

Richey, S. 2007. "Manufacturing Trust: Community Currencies and the Creation of Social Capital." *Political Behavior* 29, no. 1:69–88. https://doi.org/10.2307/4500234.

Rorty, R. 1979. *Philosophy and the Mirror of Nature*. Princeton: Princeton University Press.

———. 1998. *Truth and Progress*. Vol. 1. Cambridge, MA: Cambridge University Press.

Sanders, T. I. 1998. *Strategic Thinking and the New Science: Planning in the Midst of Chaos, Complexity, and Change*.

New York: Free Press.

Savitz, N. V., and S. W. Raudenbush. 2009. "Exploiting Spatial Dependence to Improve Measurement of Neighborhood Social Processes." *Sociological Methodology* 39:151–83.

Scheffer, M., J. Bascompte, T. K. Bjordam, S. R. Carpenter, L. B. Clarke, C. Folke, P. Marquet, N. Mazzeo, M. Meerhoff, O. Sala, and F. R. Westley. 2015. "Dual Thinking for Scientists." *Ecology and Society* 20, no. 2: https://doi.org/10.5751/ES-07434-200203

Schumpeter. 2011. "The Crescent and the Company." *The Economist*. January 29, 67.

Scott, J. C. 1999. *Seeing Like a State: How Certain Schemes to Improve the Human Condition Have Failed*. New ed. New Haven: Yale University Press.

Sekara, V., A. Stopczynski, and S. Lehmann. 2016. "Fundamental Structures of Dynamic Social Networks." *Proceedings of the National Academy of Sciences of the United States of America* 113, no. 36: 9977–82. https://doi.org/10.1073/pnas.1602803113.

Serres, M. 1995. *Conversations on Science, Culture, and Time: Michel Serres with Bruno LaTour*. Ann Arbor: University of Michigan Press.

Sieweke, J. 2014. "Preserving the Flow: Natural Disasters in Ignorance." In *Interventions/Adaptive Reuse* 5. Providence, RI: Rhode Island School of Design.

Simon, H. A. 1962. "The Architecture of Complexity." *Proceedings of the American Philosophical Society* 106, no. 6:467–82.

Snijders, T. A. B. 2011. "Statistical Models for Social Networks." *Annual Review of Sociology* 37:131–53.

Snowden, D., and M. E. Boone. 2007. "Leader's Framework for Decision Making." *Harvard Business Review*. November, 10.

Steinmetz, G. 1998. "Critical Realism and Historical Sociology: A Review Article." *Comparative Studies in Society and History* 40, no. 1:170–86.

Taleb, N. N. 2010. *The Black Swan: The Impact of the Highly Improbable*. 2nd ed. New York: Random House.

Taylor, C. 2004. *Modern Social Imaginaries*. Durham, NC: Duke University Press.

Thomas, G. 1997. What's the Use of Theory?" *Harvard Educational Review* 67, no. 1:75–104.

Tocqueville, A. de. 2001. *Democracy in America*. Edited by R. C. Heffner. New York: Signet Classics.

Tod, A. M., F. Kennedy, A.-J. Stocks, A. McDonnell, B. Ramaswamy, B. Wood, and M. Whitfield. 2016. "Good-Quality Social Care for People with Parkinson's Disease: A Qualitative Study." *BMJ Open* 6, no. 2:e006813. https://doi.org/10.1136/bmjopen-2014-006813.

Trofimova, I. 2000. "Principles, Concepts and Phenomena of Ensembles with Variable Structure." In *Nonlinear Dynamics in Life and Social Sciences*, edited by W. Sulis and I Trofimova, 217–31. Amsterdam: IOS Press.

van der Gaag, M. 2002. “The Resource Generator: Measurement of Individual Social Capital with Concrete Items.” Paper Presented at the 22nd Sunbelt International Social Networks Conference, New Orleans.

van Oorschot, W., and W. Arts. 2005. The Social Capital of European Welfare States: The Crowding Out Hypothesis Revisited.” *Journal of European Social Policy* 15, no. 1:5–26. https://doi.org/10.1177/0958928705049159.

Veenstra, G. 2002. “Explicating Social Capital: Trust and Participation in the Civil Space.” *Canadian Journal of Sociology / Cahiers Canadiens de Sociologie* 27, no. 4:547–72. https://doi.org/10.2307/3341590.

Waldrop, M. M. 1993. *Complexity: The Emerging Science at the Edge of Order and Chaos*. New York: Simon & Schuster.

Weinberger, D. 2012. *Too Big to Know: Rethinking Knowledge Now That the Facts Aren’t the Facts, Experts Are Everywhere, and the Smartest Person in the Room Is the Room*. New York: Basic Books.

Westley, F., B. Zimmerman, and M. Patton. 2006. *Getting to Maybe: How the World Is Changed*. Toronto: Random House Canada.

Wheatley, M. J. 2006. *Leadership and the New Science: Discovering Order in a Chaotic World*. 3rd ed. San Francisco: Berrett-Koehler.

Zhou, W.-X., D. Sornette, R. A. Hill, and R. I. M. Dunbar. 2005. “Discrete Hierarchical Organization of Social Group Sizes.” *Proceedings: Biological Sciences* 272, no. 1561:439–44.

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