CRITERIA FOR DEVELOPING MEDIATED URBAN NERVOUS SYSTEMS:

A COMPLEX ADAPTIVE SYSTEMS PERSPECTIVE

Mary Ann Allison, Ph.D.
Assistant Professor, Media Studies
Hofstra University, New York
USA

mary-ann.allison@hofstra.edu

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ABSTRACT

As communication technology becomes increasingly sophisticated and hierarchical power diminishes in Western Society, there is a concomitant increase in the complexity of public and private collective behavior and in the information and communication needed to support healthy cities. This paper uses complexity theory to set forth a framework for mediated urban nervous systems which facilitate shared understanding and collaboration at all system levels in urban areas.
Key words: city, complex adaptive systems, cybernetics, emergence, feedback, feedforward, ICT, urban communication

There is a growing body of scholarship that enhances the understanding of communication in urban environments (Burd, Drucker, and Gumpert, 2007; Castells, 1996; Horrigan, 2001; Jeffres, 2003; Sassen, 2002; Sassen et al., 2007). The Urban Communication Foundation (Gumpert and Drucker, 2007) calls attention to the challenges to cities as healthy entities because cities face serious challenges from a number of internal and external sources.

This theoretical paper brings together concepts and research from media ecology, complex systems theory, sociology, cybernetics, and human-computer interface design to propose an approach to monitoring and improving city health using feedback and feedforward mechanisms which simultaneously support management by government authorities, civil leaders, interventions by community groups, and the efforts of "bottoms-up" emergent peer groups.

Systems researchers (Allison, 2005; Bar-Yam, 1997; Kauffman, 1993; Luhmann, 1989; Mainzer, 1996) argue that human groups—including cities—are living complex adaptive social systems. Thus the literature on the complex adaptive systems (CAS) and evolution of emergent systems can be used as a framework to support urban communication systems which promote the health of a city as a whole as well as the residents and groups within and connected to it. It is both possible and desirable to consciously build elements of a city's mediated communication and information nervous system taking into account these characteristics, while simultaneously recognizing, connecting with, and amplifying elements which arise "unofficially." The primary aim of this paper is to put forward this framework and to illuminate some of the implications. To instantiate the possibilities, a review of a few examples of information and communication technologies (ICT) which facilitate intelligence in urban groups follows.

Context: Cities Change in Punctuated Equilibrium

As low-cost, easily portable ICT becomes simultaneously increasingly sophisticated, networked, and widely distributed, there are many important changes (Allison, 2005; Bar-Yam, n.d.a, b; boyd, 2006, 2008; Giddens, 2000; Laszlo, 1996, 2000; Levy, 1997, 1998, 2001) in the ways in which human groups—including cities—are organized.

In a multiple-cause and multiple-effect relationship characteristic of complex adaptive systems (CAS), there are, of course, other significant triggers of changes taking place in cities—as well as the larger social systems in which they are nested, such as nation states, and the smaller social systems nested inside them, such as neighborhoods. The development and diffusion of high-speed computing and graphic design, improvements in medicine, and developments in transportation contribute to the rapid increase in knowledge and ideas; communication, travel, and immigration; global commerce—all of which stress the traditional bureaucratic structure and formal processes of traditional city organization and governance.

Societies—and the groups within them—show increased complexity in a pattern of punctuated equilibrium—rapid bursts of change followed by periods of relative stability. Eldredge, Alcosser, and Gould (1991) first described this pattern which they found in the fossil records of biological species. Additional studies (Allison, 2005; Bar-Yam, n.d.a; Laszlo, 1996) show that punctuated equilibrium theory is a useful explanatory model for the pattern of changes in human social systems.

Humans are now in a major transition point in human social systems—comparable to the rise of bureaucracy, manufacturing, and cities in Western Society some 300 years ago. The challenges that cities face today, highlighted by the Urban Communication Foundation, are a part of this punctuation point. Affected by dramatically increased information and communication, higher structural complexity in an interconnected world, and increased flexibility and creativity at all systems levels, traditional city structures and process are reaching critical points of instability and will—along with the structures and processes within other levels of human social systems—move to the edge of chaos and then re-form in ways that will remain in comparative equilibrium until the next punctuation point.

One of the significant structural changes taking place now (Allison, 2005; Bar-Yam, n.d.a) is the reduction of authority and top-down hierarchical power. Alexander Dawoody (2011) describes the developing transformation of the traditional citizen or, in this case, urban resident, into a *global participant-observer*. Increasingly there is evidence of the power of global participant observers using widely-disseminated, networked ICT to force transparency and accountability. This change is taking place not only in Tunisia and Egypt (Smith, 2011) but also—with less violence but no less persistence—in North American cities. Chicago, Seattle, and San Francisco (Montalbano, 2010) are among the latest cities to open city data sets to the public.

In addition, Saskia Sassen draws attention to the fact that "the capabilities for global operation, coordination and control contained in the new information technologies…*need to be produced"* (italics added, Sassen, 2001:1). If cities cannot rely only on top-down authority to accomplish this production, how are they to proceed? As hierarchical power diminishes, there is a concomitant increase in the complexity of public and private collective behavior.

Those cities that are able to adapt rapidly to this change in structure and process internally (as a node in a global network) will be healthier and more successful. It is important, therefore, to understand the nature and criteria for physical and digital urban spaces which facilitate cooperation, productive emergence, and civic collaboration.

It is not only the internal organization of cities—with the new emphasis on the flocking mechanisms of cooperation, emergence, and civic collaboration—that is changing as a result of the current punctuation. The importance of city-to-city flows is increasing. Now, in addition to connecting generally with their peers, healthy communicative cities connect with specific partners, developing expertise and strength. Healthy cities recognize specialized relationships and build on family ties; flows of commercial, political and artistic information; travel and immigration patterns; and, of course, established commercial ties. The expertise arising from the deep structure of these

flows is significant. Returning to Sassen, "focusing on cities allows us to specify *a geography of strategic places at a global scale, places bound to each other*…" (italics added, Sassen, 2001:1).

Periods of Comparative Equilibrium in Recent Social Evolution: *Gemeinschaft, Gesellschaft, and Gecyberschaft*

In his seminal work, *Community and Society*—in the original German, *Gemeinschaft und Gesellschaft*—Ferdinand Tönnies (1996) created names for two distinctive periods in the punctuated equilibrium of Western society. Tönnies' gemeinschaft corresponds with the time when villages were the dominant form of social organization and agriculture was the primary form of production. Tönnies' gesellschaft is defined by the emergence of bureaucracies, cities, and manufacturing. To honor Tönnies, the currently emerging period of dynamic stability has been named *gecyberschaft*—ge-cyber-schaft, an American word modeled on the earlier German terms (Allison, 2005). The *gecyberschaft* period is characterized by flexible groups of purpose, information and service industries, and the primacy of relationships. Co-evolving with the increasing complexity of their environments, *gecyberschaft* cities will feature innovative forms of organization; increased structural complexity and flexibility; and—because they use information more effectively—will have greater autonomy than cities in earlier times.

Framework: The City as a Living, Complex Adaptive System

By categorizing cities as living complex adaptive systems (Luhmann, 1989), city leaders, urban planners, and residents gain access to the robust literature in complexity (Aldrich and Ruef, 2006; Bar-Yam, 2005; Goldstein, 2008; Goldstein et al., 2010, Glor, 2008; among many others).

Drawing on complexity theory and earlier work in social systems (Allison, 1997, 2005), the following framework was developed for use in understanding and enhancing cities and their communicative capabilities. There are thirteen characteristics of CAS which are particularly useful when examining human groups organized in cities. These characteristics are listed below in ascending order of system level and are followed by a brief description of the consequences for cities. Note that the characteristics which pertain to the lower levels of systems also characterize the higher levels, but the reverse is not the case.

At the level of *physical systems*, cities are

1. *open:* Because city boundaries are permeable, cities take in and give out matter, energy, residents and visitors, and, of special significance here, information and communication.
2. *dynamic and nonlinear*: The city, as an entity, as well as the systemic properties of the city as a whole, change over time. Forecasting accurately at this level of complexity is difficult; scenario planning is more likely to be effective.
3. *nested*: Cities are composed of smaller systems such as neighborhoods, church congregations, business organizations, and NGOs, each of which has unique identities and system properties. Cities are included in larger systems such as nation-states and federations. These larger systems also have unique characteristics.
4. *dissipating and emergent*: Cities use (dissipate) energy in order to maintain themselves as a city. This applies to both emergent and more consciously-directed elements.

Drawing on the complex adaptive system characteristics emergent with the rise of *biological systems* which apply to urban areas, cities are

5. *irreversible*: In cities, history matters. Past structures, processes, and events (real and imagined) are essential components of a city's present and future organization.
6. *cognitive*: Here the word cognition is used as Maturana and Varela (1980) and Capra (1996) define it. By perceiving certain changes in the environment and adjusting structurally, a "cognitive" plant grows toward sunlight. No *conscious* learning is required. In a process termed structural coupling, an organism's structure results in part from what it has perceived in the environment. Its structure is coupled to—but not determined by—the environment. Similarly, cities respond to changes in the environment whether or not directed to do so by the mayor or city council.
7. *autopoietic and self-referential*: Each city is a unique system, with a beginning and an end in time as well as in space. Cities are self-bounded (they do not necessarily respect legal boundaries), self-generated (although they may be governed; the government does not create the city), and self-perpetuating (cities maintain themselves unless there are catastrophic changes).

At the level of *human social systems*, cities are

8. *symbolic and languaged*: Human cities could not exist without human use of symbols and language.
9. *technological*: In addition to language, technologies—both processes and physical technology—are essential to cities.
10. *autonomous with regard to meaning/purpose:* People and groups generate meaning and purpose internally. Humans choose when and how to cohere. Authority does not insure cohesion. Even less can it mandate cooperation or emergent organization.

The pace of social evolution is not uniform. As cities move fully into the *gecyberschaft* age, urban residents are able to change consciously many of the city's systemic parameters. Particularly important in this context are the following three system characteristics. g*ecyberschaft* groups, including cities, can develop the capacity to exhibit traits which are

11. *far from the physical*: Healthy cities in the *gecyberschaft* era are less dependent on starting conditions, especially physical conditions. ICT flows rise in importance, subsuming flows of matter and energy, as do human flows of residents and visitors.
12. *continuously realigned*: Increased flexibility and higher levels of organization enable conscious coordination of meaning making and alignment of purposes at multiple, nested system levels. Groups of purpose (transient groups formed around a specific purpose) in, for example, neighborhoods, businesses, peer cities, and at nation-state level form shifting alliances as changing meanings and related purposes are negotiated. This might be pictured as multiple flocks shifting in tune with the environment and changing human purposes in a complex dance.
13. *capable of consciously-mediated reorganization*: For the first time, with education and intention, cities can become capable of conscious social evolution which includes both structural reorganization and coordination with emergent organization. There are early examples (Allison, 2006; Denning, 2006; Huston, 2006) where groups show the capacity to consciously select from social forms of organization characteristic of the current and earlier ages. For example, a group could choose *gesellschaft* bureaucratic structure and process to achieve certain objectives, such as financial control; *gemeinschaft* "village friends and family" norms for other objectives, such as developing trust and the close relationships which enrich lives; and *gecyberschaft groups of purpose* and *hastily formed networks* (HFNs) for still a third type of situation in which the environment is complex and rapidly changing, for example, when responding to earthquakes.

Vannevar Bush accurately predicted in "As we may think" (1945) that individual human capacities could be greatly extended by the "memory extender" (*memex* is the name he used for what is now a combination of personal computers and the Internet). Taking into account the characteristics of cities as living complex adaptive systems with the capacity for continuous realignment and consciously-mediated reorganization, it is posited that the capabilities of living cities can be significantly enhanced by the conscious development of mediated urban nervous systems, connecting and supporting all of their many parts.

Selected Considerations in Developing Urban Nervous Systems

The Basics: Cybernetics, Feedback, and Feedforward

In developing the field of cybernetics, Norbert Wiener was among the first to point out the importance of structure in understanding and predicting the performance of a system, writing that:

> "Cybernetics takes the view that the structure of the machine or of the organism is an index of the performance that may be expected from it" (Weiner, 1954: 57).

The importance of the structure of the system's means of perception is especially important. If an entity does not perceive something internally or in its environment, it cannot react or respond to it. Groups that have no structure in place to support balloting cannot function as democracies. In a time when there is no single central authority, cities that do not develop robust means of perception, feedback, and response which can be easily used by leaders, residents, and visitors who gather in bureaucracies but also in flocks, schools, and swarms will be handicapped.

In addition to drawing on the environment for the matter/energy used to maintain its existence as an entity, human communities interact with their environments—changing and being changed by them. Cyberneticists, information theorists, and systems thinkers (Bateson and Bateson, 2000; Bednarz, 1988; Shannon and Weaver, 1999; Von Bertalanffy, 1976; Wiener, 1954) have illuminated the importance of information and the ways in which systems receive, structure, and use their perceptions of the environment. As Wiener notes,

> "Information is a name for the content of what is exchanged with the outer world as we adjust to it, and make our adjustments felt upon it" (Weiner, 1954: 17).

Thus, when examining the interaction of cities and their environments, it is important to attend to a city's ability to:

- sense and model information from the environment (Bednarz, 1988; Shannon and Weaver, 1999; Richardson, 1984);
- respond to information about the system's environment (Beniger, 1986; Humphrey, 1992; Searle, 1984);
- get feedback on the results of its actions (Von Bertalanffy, 1976; Wiener, 1954); and
- evaluate alternative actions, learn, and generate meaning and purpose (Bednarz, 1988, 1990; Luhmann, 1989; Searle, 1984; Senge, 1990; Scharmer, 2007).

In addition to feedback mechanisms, *feedforward* procedures enable systems to respond to a specified change in the environment or in the system itself in a pre-determined way. This capacity assists groups to maintain stability or to respond quickly to anticipated but infrequent events. Both feedback and feedforward capabilities are important factors in group effectiveness.

More than the Basics: Supporting Cooperation and Group Intelligence

The Institute for the Future (IFF) (Saveri, Rheingold, and Vian, 2005; Saveri, Vian, Cascio, Kollock, Michalski, and Rheingold, 2007 a, b) has conducted several broad studies of the

characteristics which support the emergence of cooperation and participation in human groups. In addition to independently confirming that tracking feedback loops and instituting feedforward mechanisms which highlight important thresholds support system or group intelligence, IFF studies (Saveri et al., 2005: 28-29) suggest that a series of specific sensing abilities are critical to the formation of emergent group intelligence. These include the ability to identify key thresholds for achieving "phase" shifts in behavior when shifting goals, processes, or organizational structure is desirable; methods of supporting transparent identities for those seeking to participate in urban activities; and techniques for converting present knowledge into deep memory and universally accessible memory.

In short, it is important for cities to provide for residents and visitors a *mediated nervous system* which—through near real-time reporting of the status of incoming and outgoing flows, the activities of internal bureaucracies and more fluid groups of purpose, feedback concerning the effectiveness of the city's activities, and protective feedforward trigger points—facilitates fluid coevolution with the changing environment. The hypothesis is that this mediated nervous system will be a *sine qua non* for healthy, successful cities in *gecyberschaft.*

Salient Implications for Mediated Urban Nervous Systems

In this section, the thirteen characteristics of living complex adaptive social systems are revisited, this time extending the implications beyond cities as a generic classification to the implications for cities and urban areas with the goal of developing effective mediated nervous systems.

At the level of *physical systems*:

1. *open*: It will be difficult to block communication, whether or not desired At the city level, sensing and filtering information is important so that key messages are visible.
2. *dynamic and nonlinear*: The systematic sensing and reporting of key systemic characteristics is of fundamental importance.
3. *nested*: Systematic sensing and reporting of key characteristics at multiple levels with correlations (agreement and divergence) are important. Transparent and accessible identity and membership traits facilitate participation. Organization and individual identity should be "knowable," searchable, and visible (with some individual control).
4. *dissipating and emergent*: The resources required to support pattern sensing as well as act on the information received are key. Cities should establish common resources whenever possible.

At the level of *biological systems*:

5. *irreversible*: Individuals and groups must take negative, as well as positive, history into account. Building on positive history—information flows and human connections already in place and Sassen's (2008) deep knowledge, as examples—is likely to facilitate urban health. Cities should enable persistent memory in all systems.
6. *cognitive*: Cities are not able to divorce themselves from the environment and so must sense and work with their surroundings. City intelligence should sense and plan for strengths and weaknesses. Feedback and feedforward mechanisms are essential.
7. *autopoietic and self-referential*: Urban groups should understand any homeostatic processes already in place and add to them. Intelligence systems should be able to sense emerging boundaries. Groups must choose formal boundaries carefully.

At the level of *human social systems*:

8. *symbolic and languaged*: Urban groups should attend to symbols and languages in use and those needed. Education is a key resource. Monitoring systems should sense changes in use of symbols and language.
9. *technological*: Communicative cities will attend to both process and physical technology development, as well as physical and digital divides.
10. *autonomous* with regard to meaning/purpose: Individual and group identity and transparency is very important. Transparent methods of social accounting will facilitate cooperation and purpose sharing.

At the level of g*ecyberschaft* groups:

11. *far from the physical*: It is often easier to attend to the physical or to measure those elements such as financial data which lend themselves to reporting. Tracking and reporting on areas that are more difficult to measure but key to a balanced picture will provide a more complete urban nervous system. City leaders should consciously extend processes developed for the digital world to the physical world and vice versa.
12. continuously realigned: Healthy cities set up systems and platforms for easy participation, open economy, and distributed authority/decision-making. In addition, they enable coordination and cooperation at all levels. Communicative mediated intelligence systems sense and report on peer-to-peer production.
13. *capable of consciously-mediated reorganization*: The most effective urban intelligence systems sense and report on thresholds, phase shifts, and transition points (identifying and searching for trigger points is essential to success in this area).

The salient characteristics of living complex adaptive systems, along with the concomitant consequences for cities and selected implications for communicative cities, are summarized in Table 1 below.

Table 1: Characteristics of living complex adaptive cities with salient implications for healthy cities

Characteristic	Consequences for cities	Selected implications for healthy cities
Level 1. Physical Systems		
1. Open	City boundaries are permeable (open to matter/energy and information).	▪ Difficult to block communication, whether or not desired ▪ At city level, sensing and filtering important
2. Dynamic and nonlinear	The city and the systemic properties of the city both change over time.	▪ Systematic sensing and reporting of key characteristics important
3. Nested	Composed of smaller systems (e.g., neighborhoods) with unique properties; included in larger systems (e.g., nation-states) with unique properties.	▪ Systematic sensing and reporting of key characteristics at multiple levels with correlations (agreement and divergence) important ▪ Identity and membership facilitate participation: "knowable," searchable, visible (some individual control)
4. Dissipating and emergent	Emerging directed and undirected systemic patterns draw on internal or external matter/energy and information; cities require energy.	▪ Resources required to support pattern sensing as well as act on the information received ▪ Establish common resources whenever possible
Level 2. Biological Systems		
5. Irreversible	History matters; the past is an essential component of city present and future organization.	▪ Take negative history into account ▪ Build on positive history (flows already in place; Sassen's deep knowledge) ▪ Enable persistent memory
6. Cognitive	Cities respond to changes in the environment with and without conscious human intervention. Cities are structurally coupled with their environment.	▪ Cannot divorce the environment and so must sense and work with ▪ Sense and plan for strengths and weaknesses ▪ Feedback and feedforward essential

Characteristic	Consequences for cities	Selected implications for healthy cities
7. Autopoietic and self-referential	Cities are unique systems with a beginning and an end (in time). Cities are self-bounded, self-generated, and self perpetuating. Homeostatic processes helps to absorb change.	▪ Understand homeostatic processes already in place; add to them ▪ Observe emerging boundaries; choose formal boundaries carefully
Level 3. Human Social Systems		
8. Symbolic and languaged	Human use of symbols and language is essential to cities.	▪ Attend to symbols and languages in use and those needed ▪ Insure education ▪ Sense changes in others' use of symbols and language
9. Technological	Technologies—both process and physical—are essential to cities.	▪ Attend to both process and physical technology development ▪ Attend to physical and digital divides
10. Autonomous with regard to meaning/purpose	People and groups generate meaning and purpose internally. Humans choose when and how to cohere.	▪ Individual and group identity and transparency important ▪ Transparent methods of social accounting facilitate cooperation and purpose sharing
Level 4. *Gecyberschaft* Groups		
11. Far from the physical	Cities are less constrained by their initial starting conditions, especially physical circumstances, than they were in the past.	▪ Communication flows are critical to urban health ▪ Extend processes developed for the digital world to the physical world and vice versa
12. Continuously realigned	Conscious autonomy, meaning-making, and alignment of purposes resides at multiple, nested systems levels (e.g., individual, neighborhood, businesses, city, nation-state, global federations).	▪ Set up systems and platforms for easy participation, open economy, and distributed authority/decision-making ▪ Enable coordination and cooperation at all levels ▪ Sense and report on peer-to-peer production

Characteristic	Consequences for cities	Selected implications for healthy cities
13. Consciously-mediated reorganization	With education, cities are capable of conscious evolution including structural reorganization and adaption to changing purposes.	▪ Sensing and reporting on thresholds, phase shifts, and transition points (trigger points key)

Theory in Action

While it outside the scope of this paper to address the practical implementation of these models, as part of the conclusion it is important to review a few instances of urban ICT. There are many examples of government-directed or NGO-led top-down but generally inclusive ICT efforts, including as examples, those cities winning the Intelligent Community Forum's (n.d.) annual awards which rate 1) broadband infrastructure, 2) knowledge workforce, 3) innovation, 4) digital inclusion, and 5) marketing of the many cities using a balanced scorecard approach (Allison, 2008; Arveson, 2003; Kaplan and Norton, 1992) which takes into account multiple indicators of success.

ICT which facilitates urban collaboration, feedback, and feedforward is less well documented. Table 2 below lists a few examples to instantiate some of the possibilities.

Table 2: Examples of collaboration, feedback, and feedforward in ICT

Project Name and url	Overview	Characteristics
Big Box Evaluator http://www.bigboxevaluator.org/about-big-box.php	▪ Enables residents of an area to consider the implications of big box retail stores, especially their effect on the economy, environment, and character of the local communities	▪ Foundation sponsored ▪ Scenario planning ▪ Leading indicators ▪ Feedforward
DataSF http://www.datasf.org/	▪ Enables anyone to search the datasets available from the City and County of San Francisco	▪ Foundation sponsored ▪ Access to data ▪ Promotes innovative app development ▪ Feedback ▪ Potential for feedforward

Project Name and url	Overview	Characteristics
Gapminder—Urbanization http://www.gapminder.org/video/gap-cast/gapcast-2---urbanization.html Gapminder—World http://tools.google.com/gapminder/	▪ Easy to understand, compelling data visualization ▪ Clear pictures, some extrapolation of leading indicators ▪ Presents UNDP Millennium typical correlations: education, GDP, life expectancy	▪ Foundation sponsored ▪ Traditional information with excellent visual correlations ▪ Lagging indicators ▪ Feedback
Participatory Chinatown http://www.participatorychinatown.org/	▪ Social virtual world ▪ Single or multiple players ▪ Avatars complete a task in one of several choices of roles, then comment on community planning	▪ Foundation and university sponsored ▪ Feedback and feedforward
Interobang http://playinterrobang.com/	▪ Students (grades 6 -12) complete real-world missions to win prizes ▪ Game combining virtual and "real world" activities	▪ Foundation and big business sponsored ▪ Local and global ▪ Community and service focused ▪ Teaches collaboration and problem solving
Ten by Ten http://www.tenbyten.org/10x10.html	▪ Automated feedback based on weighted linguistic analysis of RSS feeds of top stories from *Reuters World News, BBC World Edition, New York Times International* ▪ Automated selection of the top 100 words with corresponding images	▪ Art, programming, and research center ▪ Lagging indicators, indicating attention ▪ Feedback ▪ Feedforward indicators could be added

Conclusion

This paper presents a framework for thinking about urban ICT based on the idea that cities are living complex adaptive systems. In addition, it is argued that it is important for cities to foster the development of mediated nervous systems. Such systems may provide government authorities, civil leaders, community groups, residents, and visitors with the results of traditional ICT as well as collaborative, feedback, and feedforward mechanisms, fostering an ability to adapt to highly complex, rapidly changing environments.

About the Author:

Mary Ann Allison, Ph.D., is an interdisciplinary scholar at Hofstra University who uses media theory, sociology, and complex systems theory to study the ways in which individuals, communities, and institutions are changing. In addition to teaching Media Studies, she conducts research for the Hofstra University National Center for Suburban Studies and the Urban Communication Foundation. Outside of academia, Allison's experience includes internal and external management, strategic planning, and product development and delivery. A Citibank Vice President for 16 years, Allison developed and implemented emerging technologies globally. Dr. Allison co-authored *The Complexity Advantage: How the Science of Complexity Can Help Your Business Achieve Peak Performance*.

Notes

1. *Groups of purpose* (Allison, 2005) are not related to kin-ties, geography, or bureaucracy. They often arise in electronically-mediated communication. *Hastily formed networks* (Denning, 2006; Huston, 2006) are multi-organization groups that come together to create coordinated action in unforeseen crises or opportunities.

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