Computational Social Science

biogeographic patterns. Their study, too, is centered on a large database, but in this case it is entirely of living organisms, the marine bivalves. Over 28,000 records of bivalve genera and subgenera from 322 locations around the world have now been compiled by these authors, giving a global record of some 854 genera and subgenera and 5132 species. No fossils are included in the database, but because bivalves have a good fossil record, it is possible to estimate accurately the age of origin of almost all extant genera. It is then possible to plot a backward survivorship curve (*8*) for each of the 27 global bivalve provinces (*9*).

On the basis of these curves, Krug *et al.* find that origination rates of marine bivalves increased significantly almost everywhere immediately after the K-Pg mass extinction event. The highest K-Pg origination rates all occurred in tropical and warm-temperate regions. A distinct pulse of bivalve diversification in the early Cenozoic was concentrated mainly in tropical and subtropical regions (see the figure).

The steepest part of the global backward survivorship curve for bivalves lies between 65 and 50 million years ago, pointing to a major biodiversification event in the Paleogene (65 to 23 million years ago) that is perhaps not yet captured in Alroy *et al.*'s database (*5*, *7*). The jury is still out on what may have caused this event. But we should not lose sight of the fact that the steep rise to prominence of many modern floral and faunal groups in the Cenozoic may bear no simple relationship to climate or any other type of environmental change (*10*, *11*).

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SOCIAL SCIENCE

Computational Social Science

A field is emerging that leverages the capacity to collect and analyze data at a scale that may reveal patterns of individual and group behaviors.

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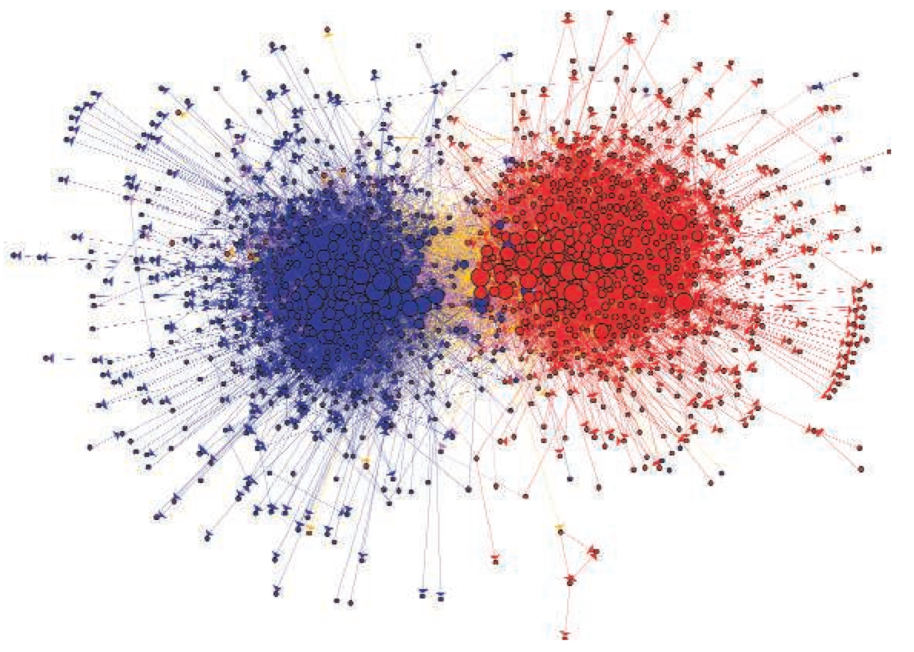
We live life in the network. We check our e-mails regularly, make mobile phone calls from almost any location, swipe transit cards to use public transportation, and make purchases with credit cards. Our movements in public places may be captured by video cameras, and our medical records stored as digital files. We may post blog entries accessible to anyone, or maintain friendships through online social networks. Each of these transactions leaves digital traces that can be compiled into comprehensive pictures of both individual and group behavior, with the potential to transform our understanding of our lives, organizations, and societies.

The capacity to collect and analyze massive amounts of data has transformed such fields as biology and physics. But the emergence of a data-driven "computational social science" has been much slower. Leading journals in economics, sociology, and political science show little evidence of this field. But computational social science is occurring—in Internet companies such as Google and Yahoo, and in government agencies such as the U.S. National Security Agency. Computational social science could become the exclusive domain of private companies and government agencies. Alternatively, there might emerge a privileged set of academic researchers presiding over private data from which they produce papers that cannot be critiqued or replicated. Neither scenario will serve the long-term public interest of accumulating, verifying, and disseminating knowledge.

What value might a computational social science—based in an open academic environment—offer society, by enhancing understanding of individuals and collectives? What are the



Data from the blogosphere. Shown is a link structure within a community of political blogs (from 2004), where red nodes indicate conservative blogs, and blue liberal. Orange links go from liberal to conservative, and purple ones from conservative to liberal. The size of each blog reflects the number of other blogs that link to it. [Reproduced from (*8*) with permission from the Association for Computing Machinery]

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obstacles that prevent the emergence of a computational social science?

To date, research on human interactions has relied mainly on one-time, self-reported data on relationships. New technologies, such as video surveillance (*1*), e-mail, and "smart" name badges, offer a moment-by-moment picture of interactions over extended periods of time, providing information about both the structure and content of relationships. For example, group interactions could be examined through e-mail data, and questions about the temporal dynamics of human communications could be addressed: Do work groups reach a stasis with little change, or do they dramatically change over time (*2*)? What interaction patterns predict highly productive groups and individuals? Can the diversity of news and content we receive predict our power or performance (*3*)? Face-to-face group interactions could be assessed over time with "sociometers." Such electronic devices could be worn to capture physical proximity, location, movement, and other facets of individual behavior and collective interactions. The data could raise interesting questions about, for example, patterns of proximity and communication within an organization, and flow patterns associated with high individual and group performance (*4*).

We can also learn what a "macro" social network of society looks like (*5*), and how it evolves over time. Phone companies have records of call patterns among their customers extending over multiple years, and e-Commerce portals such as Google and Yahoo collect instant messaging data on global communication. Do these data paint a comprehensive picture of societal-level communication patterns? In what ways do these interactions affect economic productivity or public health? It is also increasingly easy to track the movements of people (*6*). Mobile phones allow the large-scale tracing of people's movements and physical proximities over time (*7*). Such data may provide useful epidemiological insights: How might a pathogen, such as influenza, driven by physical proximity, spread through a population?

The Internet offers an entirely different channel for understanding what people are saying, and how they are connecting (*8*). Consider, for example, this past political season, tracing the spread of arguments, rumors, or positions about political and other issues in the blogosphere (*9*), as well as the behavior of individuals "surfing" the Internet (*10*), where the concerns of an electorate become visible in the searches they conduct. Virtual worlds, which by their nature capture a complete record of individual behavior, offer ample opportunities for research—experimentation that would otherwise be impossible or unacceptable (*11*). Similarly, social network Web sites offer a unique opportunity to understand the impact of a person's position in the network on everything from their tastes to their moods to their health (*12*), whereas Natural Language Processing offers increased capacity to organize and analyze the vast amounts of text from the Internet and other sources (*13*).

In short, a computational social science is emerging that leverages the capacity to collect and analyze data with an unprecedented breadth and depth and scale. Substantial barriers, however, might limit progress. Existing ways of conceiving human behavior were developed without access to terabytes of data describing minute-by-minute interactions and locations of entire populations of individuals. For example, what does existing sociological network theory, built mostly on a foundation of one-time "snapshot" data, typically with only dozens of people, tell us about massively longitudinal data sets of millions of people, including location, financial transactions, and communications? These vast, emerging data sets on how people interact surely offer qualitatively new perspectives on collective human behavior, but our current paradigms may not be receptive.

There are also enormous institutional obstacles to advancing a computational social science. In terms of approach, the subjects of inquiry in physics and biology present different challenges to observation and intervention. Quarks and cells neither mind when we discover their secrets nor protest if we alter their environments during the discovery process. As for infrastructure, the leap from social science to a computational social science is larger than from biology to a computational biology, largely due to the requirements of distributed monitoring, permission seeking, and encryption. There are fewer resources available in the social sciences, and even the physical (and administrative) distance between social science departments and engineering or computer science departments tends to be greater than for the other sciences.

Perhaps the thorniest challenges exist on the data side, with respect to access and privacy. Much of these data are proprietary (e.g., mobile phone and financial transactional information). The debacle following AOL's public release of "anonymized" search records of many of its customers highlights the potential risk to individuals and corporations in the sharing of personal data by private companies (*14*). Robust models of collaboration and data sharing between industry and academia are needed to facilitate research and safeguard consumer privacy and provide liability protection for corporations. More generally, properly managing privacy issues is essential. As the recent U.S. National Research Council's report on geographical information system data highlights, it is often possible to pull individual profiles out of even carefully anonymized data (*15*). Last year, the U.S. National Institutes of Health and the Wellcome Trust abruptly removed a number of genetic databases from online access (*16*). These databases were seemingly anonymized, simply reporting the aggregate frequency of particular genetic markers. However, research revealed the potential for de-anonymization, based on the statistical power of the sheer quantity of data collected from each individual in the database (*17*).

Because a single dramatic incident involving a breach of privacy could produce rules and statutes that stifle the nascent field of computational social science, a self-regulatory regime of procedures, technologies, and rules is needed that reduces this risk but preserves research potential. As a cornerstone of such a self-regulatory regime, U.S. Institutional Review Boards (IRBs) must increase their technical knowledge to understand the potential for intrusion and individual harm because new possibilities do not fit their current paradigms for harm. Many IRBs would be poorly equipped to evaluate the possibility that complex data could be de-anonymized. Further, it may be necessary for IRBs to oversee the creation of a secure, centralized data infrastructure. Currently, existing data sets are scattered among many groups, with uneven skills and understanding of data security and widely varying protocols. Researchers themselves must develop technologies that protect privacy while preserving data essential for research. These systems, in turn, may prove useful for industry in managing customer privacy and data security (*18*).

Finally, the emergence of a computational social science shares with other nascent interdisciplinary fields (e.g., sustainability science) the need to develop a paradigm for training new scholars. Tenure committees and editorial boards need to understand and reward the effort to publish across disciplines. Initially, computational social science needs to be the work of teams of social and computer scientists. In the long run, the question will be whether academia should nurture computational social scientists, or teams of computationally literate social scientists and socially literate computer scientists. The emergence of cognitive science offers a powerful model for the development of a computational social science. Cognitive science has involved fields ranging from neurobiology to philosophy to computer science. It has attracted the investment of substantial resources to create a common field, and created enormous progress for public good in the last generation. We would argue that a computational social science has a similar potential, and is worthy of similar investments.

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Supporting Online Material
www.sciencemag.org/cgi/content/full/323/5915/721/DC1

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CELL BIOLOGY

Moonlighting in Mitochondria

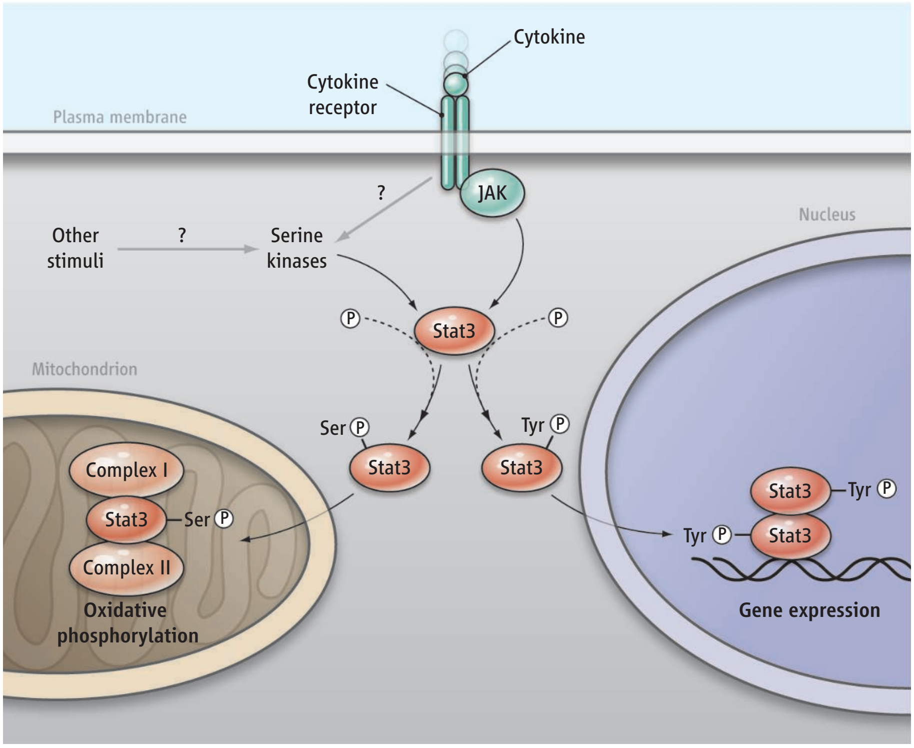
A cellular signaling pathway that responds to cytokines may coordinately control energy production by mitochondria.

Martin G. Myers Jr.

Molecules known as signal transducers and activators of transcription (STATs) regulate gene expression in the nucleus in response to cell surface receptors that are activated by cytokines. On page 793 of this issue, Wegrzyn *et al*. (*1*) reveal that the isoform Stat3 also functions in another organelle—the mitochondria—to control cell respiration and metabolism. This finding not only reveals a new role for Stat3, but implies its potential role in linking cellular signaling pathways to energy production.

Stat3 proteins represent the canonical mediators of signals elicited by type I cytokine receptors at the cell surface (*2*). For instance, the adipocytokine leptin activates Stat3 in hypothalamic neurons to promote the expression of the catabolic neuropeptide, propiomelanocortin, thereby regulating whole-body energy intake and metabolism (*3*). The binding of a cytokine to its receptor triggers an intracellular cascade of events, beginning with the activation of an enzyme, Jak kinase, which is associated with the receptor's cytoplasmic domain. The activated receptor-Jak complex then recruits and phosphorylates a tyrosine residue in cognate STAT proteins. This modification causes the STAT protein to relocate to the nucleus, where, as a dimer, it binds to specific DNA sequences and promotes gene expression (see the figure). Thus, the well-understood job of STAT proteins is to transmit a transcriptional signal from the cell surface to the nucleus. The phosphorylation of some STAT proteins on a specific serine residue may also contribute to their regulation (*2*).

Wegrzyn *et al*. have now identified another crucial role for Stat3, the isoform that responds to cytokines of the interleukin-6 and -10 families (including leptin). These cytokines act in the immune system and many other organ systems to regulate diverse cellular processes, including differentiation, proliferation, and apoptosis (*2*). Noting that GRIM-19, a mitochondrial protein, interacts with Stat3 and inhibits Stat3 transcriptional activity (*4*–*7*), the authors investigated the potential mitochondrial location of Stat3, revealing that a fraction of cellular Stat3 resides within the mitochondria of mouse myocytes and hepatocytes. Here, Stat3 associates with GRIM-19–containing



Dual deployment. The activation of a cytokine receptor at the cell surface promotes the tyrosine phosphorylation (Tyr-P) of Stat3, which dimerizes and moves to the nucleus to control gene expression. Serine phosphorylation (Ser-P) of Stat3 appears to be required for its action in mitochondria, where it promotes increased oxidative phosphorylation. Because many stimuli promote the serine phosphorylation of Stat3, many signaling pathways could regulate mitochondrial respiration via Stat3.

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Supporting Online Material for

Computational Social Science

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