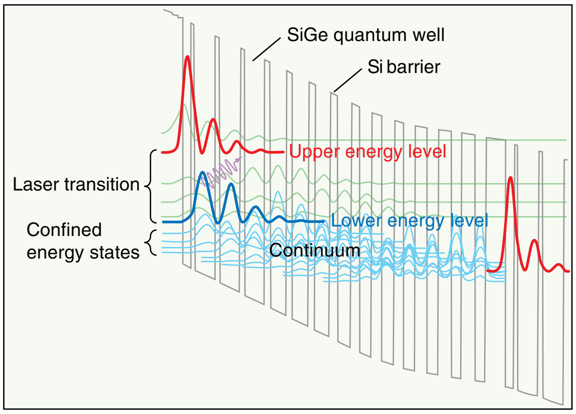

One period of a silicon/germanium quantum cascade laser. Traveling from left to right, the carriers enter the upper energy level, emit a photon upon falling to the lower level, and then move rapidly through the continuum to be reinjected into the upper level of the next period. A terahertz quantum cascade laser can have more than 100 such periods. Population inversion is achieved by designing the upper level to have a longer lifetime than the lower one, which is rapidly depopulated by the continuum.

optical phonon scattering. In III-V terahertz quantum cascade lasers, the upper state lifetime is substantially reduced above 40 K, but in silicon/germanium structures, time-resolved experiments have shown constant lifetimes up to ~150 K (*13*). Silicon also has a higher thermal conductivity than III-V materials. A silicon-based quantum cascade laser therefore promises to be a good candidate for a room-temperature terahertz source.

Because of material considerations, all silicon/germanium quantum cascade structures investigated to date have been based on transitions in the valence band. Unfortunately, the valence band is made up of many interacting subbands, and the carriers are holes (as opposed to electrons in the conduction band) with a very high effective mass. These and other factors make the design of successful silicon/germanium quantum cascade structures more challenging than is the case for III-V materials.

Lynch *et al.* demonstrated electroluminescence at 2.9 THz from transitions between energy levels in the same well (*14*). Bates *et al.* obtained similar results at 1.2 THz from transitions between energy levels in neighboring wells; such interwell transitions promise an increased upper state lifetime (*15*). Recently, Paul *et al.* have grown a cascade structure with a buried tungsten silicide layer (*16*). Such silicides may provide the means to grow cladding layers with good electrical conductivity but low optical absorption, vital for successful laser operation.

Optically pumped silicon impurity lasers in the terahertz range have been around for some years (*5*–*8*), but a compact, electrically pumped terahertz laser operating at room temperature remains elusive. The quantum cascade approach is arguably the most promising; here, silicon/germanium structures may offer key advantages over III-V materials for high-temperature operation. However, serious obstacles must be overcome before a working silicon quantum cascade laser can be produced.

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SOCIOLOGY

Network Theory—the Emergence of the Creative Enterprise

Albert-László Barabási

In the *Foundation Trilogy*, Isaac Asimov placed psychohistorian Harry Seldon so far into the future that Earth, the birthplace of the Galactic civilization, has been forgotten (*1*). Indeed, Star Trek's teleporting characters appear far more grounded in reality than Seldon's mathematical equations that accurately predict the multigalactic society's fate thousands of years into the future. Today, when reports about quantum teleportation fill the pages of the best physics journals, we wonder how long it will be until a real Harry Seldon produces an accurate mathematical theory of human behavior.

It may be hard to believe, but conditions for such a quantitative approach are increasingly in place. Indeed, records of human actions are already stored in numerous databases. E-mail and phone records document our social and professional interactions; travel records and GPS navigation systems capture our travel patterns and physical locations; credit-card companies maintain records of our shopping and entertainment habits. Although in the wrong hands, these data sets represent Orwellian tools of power, for scientists they offer incredible insights into human behavior. Combine this capability with the sophisticated tool of network theory (*2*–*7*), which analyzes relations between millions of individuals, and you get a glimpse of an unprecedented opportunity to quantify human dynamics. Although a mathematical theory of social complexity remains a pipe dream, it is not as farfetched as it may have appeared in 1942, when *Foundation* was first published. Proof of this can be found in the study by Guimerà *et al.* on page 697 of this issue (*8*). By taking advantage of publicly available data sets from both artistic and scientific fields, the authors offer powerful insights into the mechanisms governing collective human behavior.

Traditionally, the achievements of individuals such as Darwin and Einstein have dominated the public's image of science, yet today some of the most groundbreaking work is collaborative in nature (see the figure). But how do such creative teams come about? Are there discernible differences between collaborations that are sparklingly creative and those that are less inventive? Guimerà *et al.* use network theory to answer these questions. Their starting point is a collection of fascinating data sets: a century-long record of Broadway musicals and the publication records of several fields of science. These data sets allowed them to reconstruct the collaborative history of the individuals who contributed to a particular show or research publication. The investigators document a changing creative enterprise in which advances require an increasing number of contributors. The history of Broadway is particularly illuminating: The team size responsible for producing a show increased until the 1930s, after which it leveled off, fluctuating at around seven contributors for the past 70 years. In contrast, science continues to search for its optimal collaborative setup: The number of

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