JERRY BAUER

Figure 1 | Luquillo Experimental Forest. Wood and Silver[3] have studied the effect of drought on greenhouse gases emitted from soils in the Luquillo Experimental Forest, Puerto Rico.

change, none of which is able to capture the complex interplay of factors that can create substantial biogeochemical heterogeneity within and across tropical forests[7]. The authors' results are a prime example of the challenge facing scientists — many tropical regions have highly complex landscapes with varying nutrient availability, which in turn can regulate biological processes that influence greenhouse-gas production[8,9].

The possibility of positive feedback between climate change and greenhouse-gas emissions from soil has been recognized for decades. Wood and Silver's results suggest the opposite: declines in greenhouse-gas emissions following drought would reduce climate forcing. But as the authors highlight, the handful of studies in which rainfall has been excluded from tropical forests have shown positive, negative or no net effects of drought on soil greenhouse-gas emissions. Moreover, although it is crucial to consider the effects of drought alone, real-world emissions will hinge on the combined effects of changing precipitation and temperature, along with chronic shifts in atmospheric CO_2 levels and nutrient deposition — factors that were not manipulated in the authors' experiment. Finally, studies[10,11] have shown that the growth and carbon uptake of trees in the tropics are highly sensitive to climate, but the experimental plots used in Wood and Silver's study (1.54 square metres) were not large enough to simulate the potentially negative effects of drought on carbon uptake through tree growth. The overall effects of drought on the greenhouse-gas balance of the sites therefore remain unknown.

In recent decades, tropical forests have given us a discount on anthropogenic CO_2 emissions by absorbing more greenhouse gases than human activity produces. Wood and Silver's findings suggest that tropical soils may continue to offset greenhouse-gas emissions during drought. Perhaps more notably, their study highlights the need for additional large-scale experiments that can more completely resolve the potential effects of climate change on trace gas emissions in tropical forests. The authors' data are critical for improving and validating models that predict ecosystem and climate responses over large spatial and temporal scales. Considering the pivotal role of tropical ecosystems in basic human health and welfare, our understanding of fundamental ecosystem processes, and their potential response to climate change, remains woefully incomplete in complex and diverse tropical forests. ■

Cory C. Cleveland *and* **Benjamin W. Sullivan** *are in the Department of Ecosystem and Conservation Sciences, University of Montana, Missoula, Montana 59812, USA.*
e-mails: cory.cleveland@cfc.umt.edu; benjamin.sullivan@cfc.umt.edu

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SOCIAL SCIENCE

Poked to vote

A Facebook message sent out during the 2010 US congressional elections influenced the voting behaviour of millions of people. The experiment illustrates the power of digital social networks to spread behavioural change. SEE LETTER P.295

SINAN ARAL

Social networks are the pathways through which information, advice, resources and support flow between people. They are essential for many people's decision-making, cooperation and complex interdependence. Yet although humans have almost always lived in networks, advances in computing power and new social technologies have only recently facilitated the development of forms of networked communication that are automating and accelerating the social signals that pulse through the human network on a daily basis. The rapid dissemination of social signals in these digital networks — status updates, tweets, likes, posts, shares and so on — raises serious scientific questions: how, when and to what extent do these signals influence decision-making and the spread of behaviours in society? If social influence drives behaviour, then digital social signals could be used to promote widespread behaviour change and thus to transform commerce, politics and public health. On page 295 of this issue, Bond *et al.*[1] present some of the most convincing evidence to date that peer influence and digital social signals can affect political mobilization.

Political mobilization has been central to recent discourse about the transformative effects of social media — for example, the part that technologies such as Facebook or Twitter played in the protests collectively known as the Arab Spring, or may play in the forthcoming US presidential election. The question is: what role do peer influence and digital social signals have in mobilizing political expression? Do our friends' behaviours inspire us to be politically active, to protest or to vote?

These questions may seem relatively simple to answer, given the right data. But several statistical challenges make it difficult to quantitatively estimate peer influence in networks. For example, networks are homophilous — we tend to make friends with people like ourselves and thus have preferences that are highly correlated with those of our friends[2]. If two friends adopt a behaviour, one immediately after the

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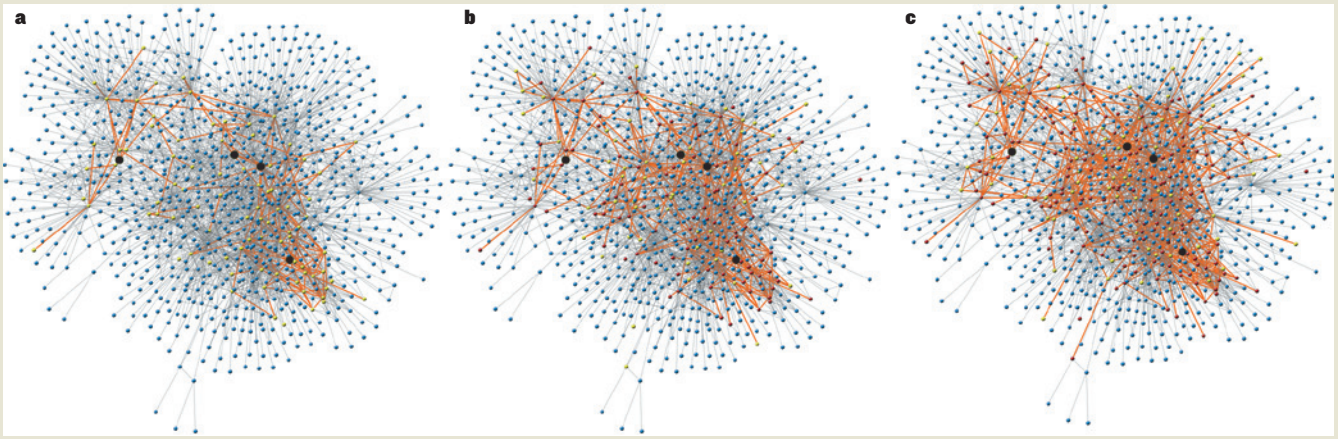
BOX 1

Networking behaviour



The images shown display the uptake of a personalized mobile-phone application across a network of Yahoo! customers communicating over the company's instant-messenger service[3]. Each panel displays a snapshot of one cluster of the network at 33 days (**a**), 41 days (**b**) and 62 days (**c**) after the application's launch. The four large black nodes represent customers who were initial adopters of the application; yellow nodes are new adopters in each period; red nodes are those who adopted in previous periods; and blue nodes are non-adopters. Orange lines highlight connections between previous adopters and new adopters that are activated as the product diffuses through the population.

A key question is how much the spread of behaviours such as product adoption is due to social influence — or homophily (correlated preferences among friends) — and/or other confounding factors. Such confounding factors mimic the influence that the spread of behaviours in social networks has on the resulting diffusion patterns. Separating that influence from homophily and other factors, and establishing estimates of the degree to which peer-induced action is responsible for the adoption of a behaviour, are essential for creating effective policies that promote positive behaviours in society and contain negative ones. **S.A.**

other, it is difficult to distinguish whether this is due to peer influence or homophily. Network peers are also likely to be exposed to similar environmental stimuli: we work together and thus receive the same employee incentives; we live together and so are exposed to the same neighbourhood events; and because we have the same preferences, we tend to browse the same websites and watch the same television shows, so we see the same advertisements. This correlated exposure to external stimuli could also contribute to correlations in peer behaviours over time.

Methods are now available that can separate peer influence from homophily and other confounding factors in observational data[3]. This is useful because most data on these questions are observational. But controlling for unobservable factors, such as latent homophily, remains difficult[4]. As an alternative to observational data, experimental network studies using random assignment can provide a more robust means of identifying causal peer effects in networks and distinguishing between influence and confounding factors. Such experiments have demonstrated a role for peer influence in product adoption[5–7] (Box 1), health behaviours[8] and altruism[9].

However, although it has been postulated that voting is also motivated by interactions with friends, neighbours and family members[10], most research and many 'get out the vote' mobilization campaigns have focused on the individual[11,12] (for an exception, see ref. 13 for experimental evidence of peer influence on voting behaviour in two-person households). By contrast, Bond and colleagues used a randomized experiment — involving 61 million people within the intricate social network of Facebook — to show that digital social signals directly influence political self-expression, information-seeking and real-world voting behaviour.

The experiment was conducted during the 2010 US congressional elections. The targeted Facebook users saw a statement at the top of their 'News Feed' that encouraged them to vote, provided a link to information on local polling places, contained a clickable 'I voted' button and showed a counter of Facebook users who had voted (see Fig. 1 of the paper[1]). This was the 'informational' message, received by a control group of users. Another group received a 'social' message, which additionally included six randomly selected profile pictures of Facebook friends of the user who had already clicked the 'I voted' button. The researchers categorized these friends into either ordinary friends or close friends on the basis of the degree of Facebook interaction.

The results show that users who received the social message were 2.08% more likely to report that they themselves voted, 0.26% more likely to seek information about a polling location, and 0.39% more likely to actually vote than users receiving the informational message (the authors estimated actual voting using data on 6.3 million users in their sample that could be matched to publicly available voting records). The authors also examined 'contagion' effects of the messages on users who themselves received neither the social nor the informational message, but who had a friend who received a message. Here, in the validated voting sample, individuals were 0.224% more likely to vote, for each close friend who received a message, than they would have been had their friend received no message.

Although these estimates may seem small, they translate into significant numbers of votes. A social message saying that a Facebook friend had voted generated 886,000 additional 'expressed' votes (clicks on the 'I voted' button), and messages involving a close friend generated an additional 559,000 expressed votes. In terms of real-world voting, the authors were able to validate 282,000 additional votes cast by people receiving a message that a close Facebook friend had voted.

This work has important implications for our understanding of how signals in social networks influence an individual's behaviour. But there is more work to be done. In particular, future work modelling the degree to which contamination or leakage in networked experiments[4] (also called interference[14]) affects

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inference, examination of how peer influence varies across behaviours[5], and evaluation of the social and structural conditions under which influence is more or less likely to propagate will all be essential to our understanding of the spread of behaviour change through human populations.

Advancing our understanding of peer influence in networks is the first step towards designing 'network interventions' that can promote positive behaviours in human populations, or contain negative ones[15]. It is perhaps obvious that this is relevant to, for example, targeted advertising and viral marketing. But such interventions also have the potential to promote positive social changes, such as increasing the rate of HIV testing, reducing violence, improving adherence to exercise, or increasing political mobilization and awareness. In this way, the science of social influence may have dramatic implications for products, politics and public health. ■

Sinan Aral *is at the Leonard N. Stern School of Business, New York University, New York, New York 10012, USA.*
e-mail: sinan@stern.nyu.edu

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ORGANIC SYNTHESIS

A biochemical messenger made easily

Biochemicals known as prostaglandins are challenging targets for synthetic organic chemistry. Yet by channelling the reactivity of a simple reactant, a powerful synthesis of one such compound has been achieved. SEE LETTER P.278

ERIK J. SORENSEN

Chemical messengers called prostaglandins are present in nearly all mammalian tissues. These elusive molecules mediate an extraordinary number of biological processes — including the regulation of body temperature, the contraction and relaxation of the human uterus, the aggregation of platelets in blood and cellular responses to inflammation. They have therefore been the targets of wide-ranging research[1] since the 1930s. In particular, their unique molecular architectures and great therapeutic potential have fired the creative imagination of synthetic organic chemists[2,3]. Writing on page 278 of this issue, Coulthard *et al.*[4] report one of the cleverest syntheses of one such molecule, prostaglandin $F_{2\alpha}$ ($PGF_{2\alpha}$), to date. The conciseness of their approach may open up new opportunities for drug discovery.

Prostaglandins contain two fat-soluble hydrocarbon chains on opposite sides of a ring of five carbon atoms (Fig. 1). Nature synthesizes $PGF_{2\alpha}$ and its analogues from arachidonic acid (a polyunsaturated fatty acid) and two molecules of oxygen, with a little help from some key enzymes. Although nearly every nucleated cell is capable of biosynthesizing prostaglandins, these compounds are short-lived and exceedingly difficult to isolate from biological samples. Since the late 1960s, chemists have therefore devised creative strategies for producing prostaglandins from simple chemicals in the laboratory. The development of dependable laboratory syntheses has contributed substantially to our knowledge of the compounds' remarkable range of pharmacological properties, as well as their relevance to human health.

Ideas about the preparation of $PGF_{2\alpha}$ have resulted in a diversity of pathways[5–9] — a diversity that demonstrates how well the principles of organic chemistry can be used to plan and execute synthetic routes to structurally complex molecules (Fig. 1). The approach now reported by Coulthard *et al.* will be praised for its remarkable brevity and for the bold strategy that guided it. The structural relationship between the simple starting material, succindialdehyde, and the coveted target is distant, and yet the authors perceived that a union of two molecules of succindialdehyde in a single laboratory operation might produce an intermediate hemiacetal compound that is tantalizingly close to the structure of $PGF_{2\alpha}$ (Fig. 2).

The risky aspect of the authors' strategy concerns the intrinsic reactivity of succindialdehyde and its potential to take part in undesired, polymer-forming reactions. Few chemists, even those of adventurous spirit, would have believed that a useful synthesis of the hemiacetal could be achieved as Coulthard *et al.* anticipated, through the direct pairing of two molecules of succindialdehyde in sequential carbon–carbon-bond-forming reactions known as aldol reactions. The great thing is that, not only did this direct approach work well, but it also achieved high stereoselectivity — it produced mostly one mirror-image isomer (enantiomer) of the product. This is crucial, because the biological activity of prostaglandins depends on their enantiomeric form.

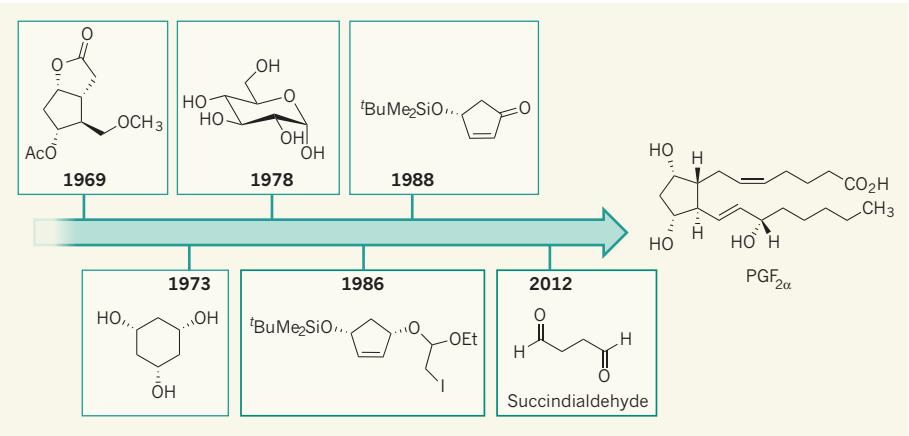

Figure 1 | Landmark syntheses of prostaglandin $F_{2\alpha}$ ($PGF_{2\alpha}$). The $PGF_{2\alpha}$ biochemical has long acted as a testing ground for organic synthesis. The dates of selected syntheses[5–9] are indicated, along with the molecule that acted as the starting point or key intermediate for each synthesis. Coulthard *et al.*[4] now report a concise synthesis of $PGF_{2\alpha}$ that starts from succindialdehyde. Ac is acetyl, $COCH_3$; Me is methyl, CH_3; Et is ethyl, C_2H_5; ^{t}Bu is tertiary butyl, $(CH_3)_3C$.

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