GROUP THEORY

What makes a successful team? **John Whitfield** looks at research that uses massive online databases and network analysis to come up with some rules of thumb for productive collaborations.

Flip through any recent issue of *Nature*, including this one, and the story is there in black and white: almost all original research papers have multiple authors. So far this year, in fact, *Nature* has published only six single-author papers, out of a total of some 700 reports. And the proportions would be much the same in any other leading research journal.

Of course, there is nothing new about this: the scholars who study the folkways of science have been tracking the decline of the single-author paper for decades now. And they have followed the parallel growth of 'invisible colleges' of researchers who are separated by geography yet united in interest. But what is new is how their studies have been turbocharged by the availability of online databases containing millions of papers, as well as analytical tools from network science — the discipline that maps the structure and dynamics of all kinds of interlinked systems, from food webs to websites.

The result is a clearer picture of science's increasingly collaborative nature, and of the factors that determine a team's success. Funding agencies are not using this work to decide where the money goes — yet. But the researchers behind the analyses are willing to give tentative tips on what their work reveals. They also think that their studies point to rules of thumb that apply very broadly, whether you're looking for a gene or putting on a show.

The first question a researcher might ask him- or herself is: should I collaborate at all?

Perhaps the rarity of single-author papers would translate into higher impact? To answer this question, sociologist Brian Uzzi of Northwestern University in Evanston, Illinois, and his colleagues analysed more than 2 million patents[1], along with nearly 20 million papers published since 1955. They found that in the early 1950s, the most cited paper in any year was more likely to have been written by a single author than a team, but this pattern reversed decades ago. And the citation gap continues to widen. "The image of the scientist alone at the workbench, plucking ideas out of the ether was true up to about the end of the Second World War," says Uzzi, "but not any more."

Uzzi doesn't know what drives this trend. It is not just a product of science's increasing technical complexity: the same pattern is seen in pencil-and-paper disciplines such as mathematics and the humanities. It is not just the Internet: author teams began to swell long before the online age, and the dawn of e-mail hardly affected that growth. And it is not just that large teams create many opportunities for future self-promotion: the pattern remains when self-citation is removed. Uzzi speculates that the increasing specialization of all fields plays a part, as may changing social

norms. Researchers have always swapped ideas and criticism, but when fields were small, authorship was not such an important mark of achievement. Reputation travelled by word of mouth, and everyone knew who had contributed the good ideas. Now, however, academia is too vast for that kind of informal credit assignment to work. So people need to get their ideas and their names into print, as well as on each other's lips.

So if lone wolves go hungry, who should researchers hunt with? Someone in their own discipline, or someone in another field? Should they build long-term relationships, or should they keep changing the people they work with?

Research is now revealing that these questions need to be answered with a careful weighing up of costs and benefits, rather than a list of absolute dos and don'ts: teams are most successful when they contain the right mix of specialism and diversity, and familiarity and freshness. And researchers are starting to find hints of how to strike this balance.

Uzzi and his team, for instance, looked at a sample of 4.2 million papers published between 1975 and 2005. Dividing universities into tiers based on the number of citations their researchers achieved, they found that teaming up with someone from another institution
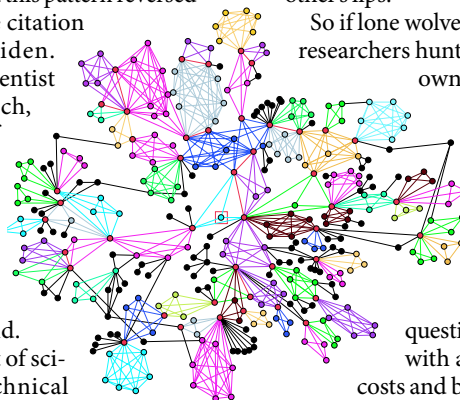
Brian Uzzi has tracked changes in how citation rates relate to the number of authors on a paper.

of the same or higher tier reliably produced more highly cited work than teaming up with someone down the corridor.

"There's something about between-school collaboration that's associated with the production of better science," Uzzi told participants at a meeting of network scientists in Norwich, UK, in June. At the same meeting Pietro Panzarasa, from Queen Mary University of London, presented an analysis of 9,325 papers written by 8,360 authors submitted to the 2001 UK Research Assessment Exercise in business and management studies. He too found that between-institution collaborations had a higher average impact than did those within institutions.

Middle ground

As well as looking at where people worked, Panzarasa looked at how specialized they were. First he assigned researchers to disciplines by analysing the keywords in their papers, and then he measured each author's breadth of experience by looking at the fields of their co-workers. Social scientists are divided over whether specialization is the best strategy, he says. "It is beneficial for productivity and earning, but there is also evidence from banking and academia that being a generalist pays off." Panzarasa's data show that the most highly cited papers were written either by authors who worked mostly with others in their own field or by those who worked with people in a wide range of other disciplines. But between these peaks lay a trough: papers that had authors from an intermediate number of disciplines were the most poorly cited.

"Being extremely specialized allows you to exploit the benefits of being embedded in your discipline, such as reputation, con-

sensus building and controlling the flow of knowledge," says Panzarasa. "When you go to the other extreme you can take advantage of all the information coming from different pools of knowledge. But if you're somewhere in the middle, you have less success — unless you feel you can manage very high levels of interdisciplinarity, it might be better to stay in your discipline."
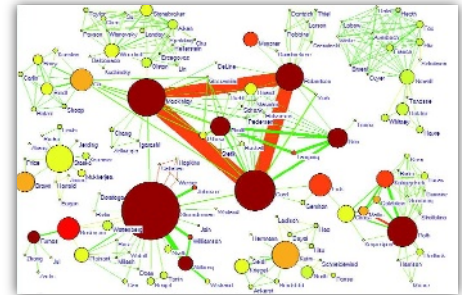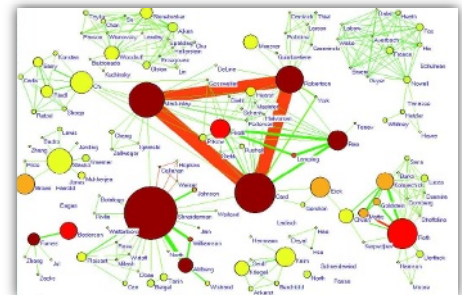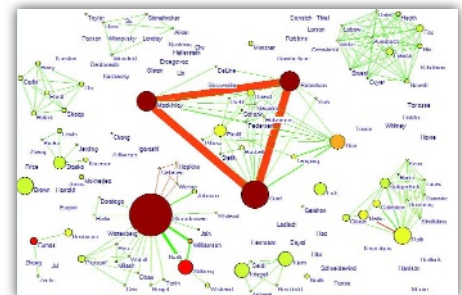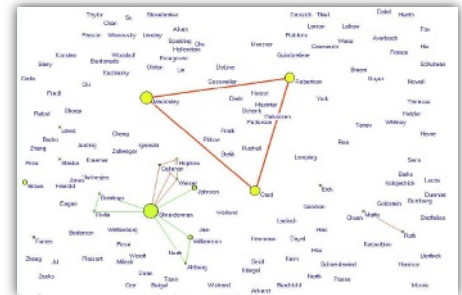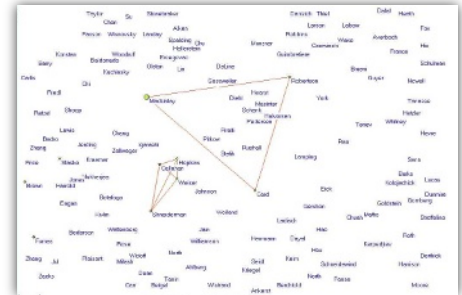
The most successful interdisciplinary authors, Panzarasa found, work with people who have independent authorship connections with each other, creating a tight social network. Panzarasa suspects that when these backup connections between colleagues are missing, the person in the middle can flounder as they try to process too many information streams. But his analysis also found that highly specialized workers who broaden their focus slightly produce more highly cited papers, as do those that exploit what social scientists call brokerage: bridging communication gaps between researchers who don't otherwise interact, and acting as a conduit for transferring knowledge from one field to another. Specialist brokers produced the most highly cited papers of any in his sample.

The lesson of these studies might seem to be that if you do decide to take the leap across disciplinary boundaries, then the more addresses and subjects you can cram onto an author list, the better. But not necessarily. All these surveys have looked for co-authorship patterns in the published literature, which means that they have a built-in bias: they look only at the collaborations that actually result in publication.

In fact, teams can also fail if they spread themselves too thinly. Jonathon Cummings, of Duke University's Fuqua School of Business in Durham, North Carolina, is monitoring more than 500 projects funded by the US National Science Foundation's information technology research programme, which creates cross-disciplinary teams of natural, social and computer scientists. He found that the most diverse teams were, on average, the least productive[2]. "Projects that had more universities involved were at a greater risk of not publishing," says Cummings, as were those that covered multiple disciplines.

This apparent discrepancy is resolved by thinking of interdisciplinary research as a high-risk, high-reward business, explains Sam Arbesman, a mathematician at Harvard Medical School in Cambridge, Massachusetts, who has studied authorship networks. "A more diverse team isn't always better — it might be that you get more really good or

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By mapping which authors collaborated with whom (lines) and when (colour of lines), Katy Börner and her colleagues show how networks extend with time and how the impact of both an author (thickness of nodes) and a partnership (thickness of lines) can grow.
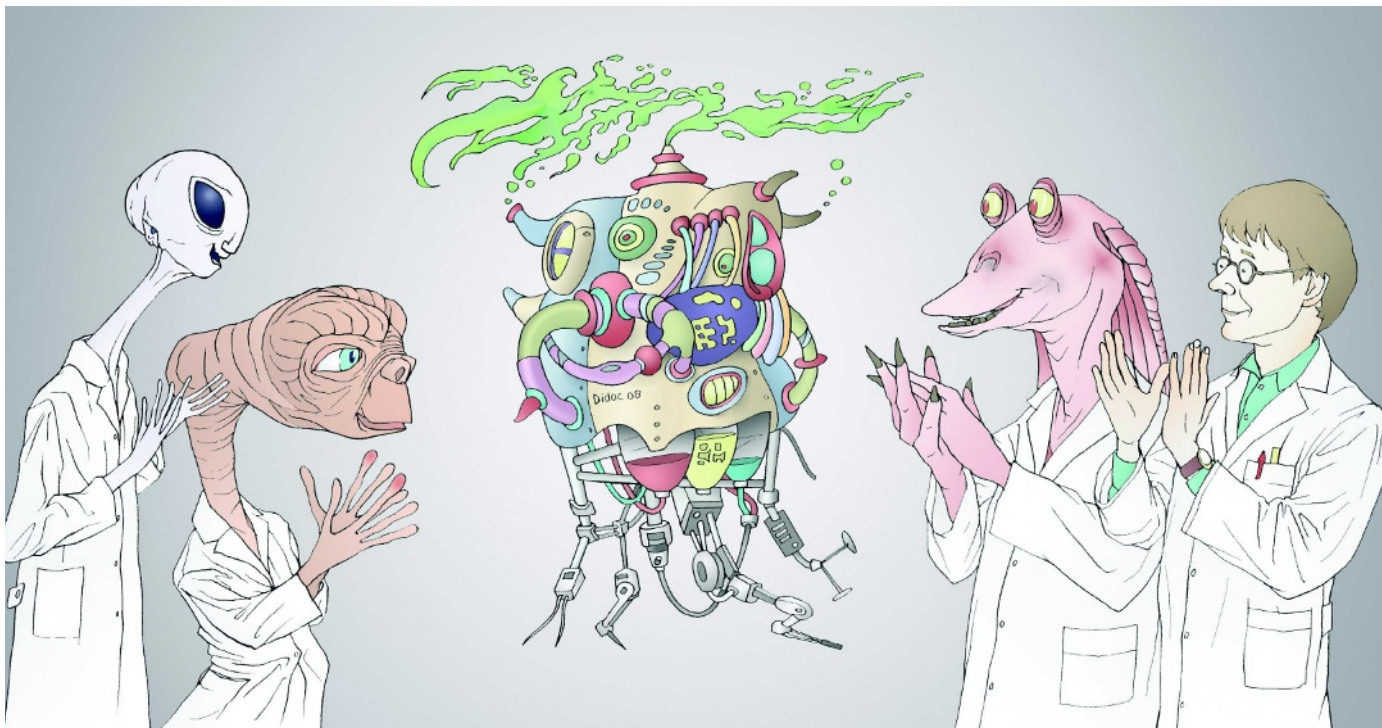
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really bad research," he says. Still, there are ways to reduce the risks that the work won't be publishable. Cummings found that if the principal investigators had a previous history of collaboration, their project was much more likely to be successful than if they had never written a paper together before. Such teams will have already paid the start-up costs of getting everyone familiar with one another's approaches and languages; new teams should invest in travel and seminars, he says. "Familiarity adds a lot of value."

Talent spotting

"We can spot projects that have been patched together at the last minute in response to the latest call for proposals," says Suzanne Iacono, who directs the information technology research programme. "Reviewers say, 'These people have never produced a paper before, and we're going to give them $15 million?'" The programme currently requires researchers to include plans for team-building in their proposals, but Iacono wants more than that. "I'd like to understand better the point at which bringing in more disciplines leads to a decline in knowledge production," she says.

But it is a fine line between a collaboration that has found its groove and one that has fallen into a rut. And it's not a line that people spot easily, because mature groups gravitate towards common ground and avoid areas of disagreement. Network scientists call this an echo chamber: a situation in which everyone tells everyone else what they want to hear, and a group that thinks it is performing well is really just mired in consensus.
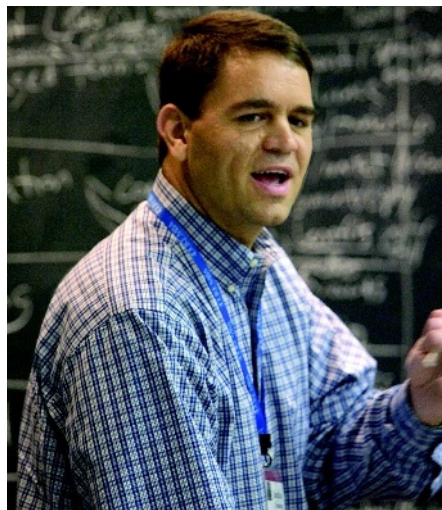
To avoid stagnating, scientists think that teams need a stream of fresh input. And the optimum rate of turnover seems to depend on the size of the team. In a paper published

in *Nature* last year[3], physicist Gergely Palla of the Hungarian Academy of Sciences in Budapest and his colleagues analysed networks of authorship on physics papers posted to the arXiv preprint server. They showed that teams with around 20 members had a better chance of surviving for a long period if they had a high rate of arrival and departure. For a team of three or four to persist, however, the opposite was true — they needed stability. Palla speculates that it's easy to find two people you like well enough to form a long-term working relationship; in a big team, fall-outs are inevitable, but the whole can persist if the comings and goings are constant and low-level. Endurance is not the same as quality of output, of course, but, as Pallas says: "It's hard to imagine that you would publish rubbish for a long time."

But even small groups benefit from some turnover. Looking at a data set of nearly 90,000

papers published between 1955 and 2004 by 115,000 authors in 32 journals spread across the fields of social psychology, economics, ecology and astronomy, Luis Amaral, a network scientist at Northwestern, and his colleagues measured the proportion of authors who had worked with each other before[4]. Papers in high-impact journals showed a strikingly lower proportion of these repeated interactions than did papers in low-impact journals. "The patterns with repeat collaboration are very different and dramatic," says Amaral. "In low-impact journals, people repeat collaborations almost all the time."

When people choose collaborators, says Uzzi, who also worked on this analysis, they look for two opposing things: high-status individuals with a proven record and good resources, and newcomers who have lots of time and energy to devote to a project. The trick is to find the balance. "If you had to give people a rule of

Jonathon Cummings (left) and Luis Amaral study how a team's composition affects its success.

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A. CAMPBELL

thumb, you might want 60–70% of a team to be incumbents, and 50–60% repeat relationships," Uzzi says. "That gets you into the bliss point across four very different scientific fields."

And this is not just in science — the same, they found, goes for Broadway musicals. It typically takes six specialists to create and put on a musical: one each to write the music, lyrics and dialogue, plus a choreographer, director and producer. The most critically and financially successful musicals have an intermediate level of turnover within the creative team[5]. Amaral thinks there may be group properties that influence outcomes across all kinds of collective effort — "but we'll need a lot of data to figure them out", he says.

Uzzi has been mobbed by organizations seeking to locate their bliss points. "The president of a university called me up to ask how he can tell what areas he should be investing in," he says. Corporations have been asking for tips on assembling work groups; venture capitalists want to know how to spot the next hot field; a delegation from the US National Institutes of Health (NIH) is interested in whether the work can help make funding decisions; and Uzzi has been invited to the offices of *Nature* and *Science*, as both journals strain after ways to detect the highest-impact papers.

First come, most cited?

Another issue is the opaque relationship between a paper's citations and its science. A known trend is that the more a paper is cited, the more citations it attracts, which stretches small gaps in quality into chasms in citation count. The process can also reward novelty above merit — in a preprint posted online this September, physicist Mark Newman of the University of Michigan in Ann Arbor models and measures the effects of 'first-mover advantage' on citations, showing that it has no relation to the quality of the research. Those who are the first to publish in a new field are likely to garner more citations than those who publish later[6]. "Were we wearing our cynical hat today," he writes, "we might say that the scientist who wants to become famous is better off writing a modest paper in next year's hottest field than an outstanding paper in this year's."

There are also other networks to consider: analysing every paper published in the *Proceedings of the National Academy of Sciences* between 1982 and 2001, Katy Börner, who studies networks and information visualization at Indi-

ana University in Bloomington, found that US authors are more likely to cite papers by workers at nearby institutions than from those on the other side of the country[7]. "People read widely," she says, "but when it comes to filling the slot at the end of the paper, they also consider who they have to face again in the hallway or at the next conference."

Such factors make some urge caution about using network analysis. At present, no one should be using such techniques to judge a collaboration's likely performance, says Deborah Duran, head of the systemic assessments branch of the Office of Portfolio Analysis and Strategic Initiatives at the NIH. "We can see a pattern, but we don't know what the pattern means," she says.

Louis Gross, a theoretical ecologist at the University of Tennessee in Knoxville, agrees. "It is very difficult

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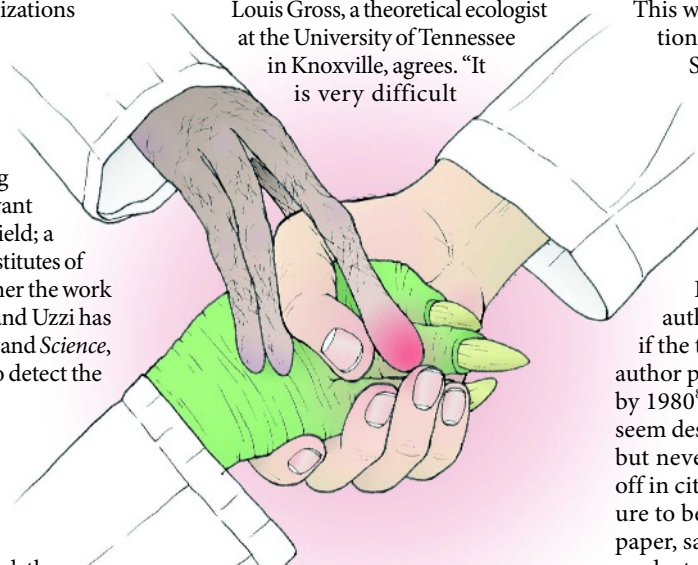
to account for the effects of social networking in evaluating metrics of citations. Network analysis definitely has potential, but an awful lot of social science needs to be integrated with these analyses to ensure that they are applied in an equitable way," he says. Gross has reviewed grant proposals for the European Commission; one risk in Europe, he says, is that if granting agencies place too much emphasis on encouraging international collaborations they will stunt development within institutions and nations.

But Duran does expect network studies to be an important part of what she calls "the emerging science of science management". The NIH already uses data-mining tools devised by the company Discovery Logic, based in Rockville, Maryland, to see how grants connect to papers, citations, patents and products. Duran suggests that in the future, network analysis could be used to track the spread of new ideas, work out the best ways to disseminate information or to

target particularly well-connected individuals to work on emerging issues. "I think, hope and believe that this will become useful," she says.

So, can a scientist looking to make the most of his or her talent really exploit these findings? Amaral says that network analysis might actually help young researchers to look beyond citation counts, which are dominated by a field's obvious stars, and find other groups with a healthy mix of rookies and veterans and a productive rate of turnover. At present, a do-it-yourself approach would be difficult: mapping the networks and measuring scientific success requires access to subscription databases such as ISI and computing resources that are beyond the reach of the average web-surfing graduate student. But this is about to change: Börner and her colleagues are soon to release an open-access tool for analysing scholarly networks. This will allow researchers to map connections using free sources such as Google Scholar, as well as Indiana University's database of 20 million publications, patents and grants and even its own bibliography files.

But however finely honed scientists' team-building strategies become, there will always be room for the solo effort. In 1963, Derek de Solla Price, the father of authorship-network studies, noted that if the trends of that time persisted, single-author papers in chemistry would be extinct by 1980[8]. In fact, many branches of science seem destined to get ever closer to that point but never reach it[9]. And whatever the payoff in citations might be, there's still a pleasure to be had in seeing just your name on a paper, says Matt Friedman, a palaeontology graduate student at the University of Chicago and a member of *Nature*'s sextet of singleton authors[10]. "With any piece of scientific work there are people who help you along the way," he says. "But knowing that you developed a project from start to finish largely under your own direction is gratifying. It's a nice validation of my ability to do science." ■

John Whitfield is a freelance journalist in London.

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