Some observations suggest that the fungal signal is produced only by hyphae that have undergone the branching response — that is, after perception of branching factor[11]. Akiyama and colleagues' results open up the possibility of inducing fungal responses in the absence of a host root, which might also help in identifying the fungal signal.

Despite the global importance of arbuscular mycorrhizal fungi and their potential in agriculture, research into their molecular genetics is still in its infancy. What deters geneticists who work with model systems, such as yeast, is that these fungi contain several nuclei within a single spore and the nuclei are probably genetically diverse[12]. Together with a complete absence of sex in all arbuscular mycorrhizal fungi that have been investigated, this hinders classical genetic approaches. A programme to sequence the entire 15-megabase genome of *G. intraradices* is under way — I hope the results will prompt more researchers to tackle the molecular biology of these fungi that are so essential to plant life on our planet. ■

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COMPUTATIONAL SCIENCE

Can get satisfaction

Carla P. Gomes and Bart Selman

The sheer complexity of some computational problems means they will probably never be solved, despite the ever-increasing resources available. But we can sometimes predict under what conditions solutions exist.

Computer scientists have been quite successful at developing fast algorithms: Google, for example, searches its index of more than eight billion web pages in a fraction of a second. The indexed-search problem is said to be 'tractable', or efficiently solvable; it is even possible to guarantee that, no matter what keywords you search on, you will get an answer quickly. Such a worst-case efficiency guarantee is the gold standard for algorithm design. But unfortunately, such a guarantee is not always possible: for many computational problems, we can either prove that no efficient algorithm exists, or we have good evidence that such an algorithm is unlikely to exist. Achlioptas *et al.*[1] (page 759 of this issue) provide a series of rigorous insights into a class of computational puzzles — known as constraint-satisfaction problems — that occur in areas as diverse as the scheduling of airline and train crews, data-mining, software design and computational biology.

Constraint-satisfaction problems are defined on the one hand by a set of variables (representing the unknowns of the problem), each of which can have a finite number of possible values, and on the other by a set of constraints. In constructing a schedule for a knockout sports tournament, for example, we can introduce a series of variables that can take one of two values: 1, 'true'; or 0, 'false'. The variable *X* might stand for 'team A plays team B in round 1'; if *X* is set to 1, this statement is true. If we introduce a second variable, *Y*, representing 'team A plays team C in round 1', we must then also introduce a constraint that says 'if *X* is 1, then *Y* should be 0'. This constraint is used to encode the fact that team A cannot play two different teams in the same round.

The encoding of real-world problems requires thousands of variables with tens of thousands of constraints. The challenge is to find an assignment of values to the variables such that all constraints are satisfied. With *N* binary (two-valued) variables, there are 2^N possible value assignments; so if *N* is 1,000, we have an enormous 'search-space' of $2^{1,000}$ — more than 10^{300} — different assignments, the vast majority of which violates one or more constraints. This exponentially scaling search-space is much too large to be examined explicitly. Computer scientists conjecture, however, that there is no algorithm that can do substantially better than can an exhaustive search — and an algorithm that works well for all possible sets of constraints is thus unlikely to exist[2]. But how difficult is it to find an assignment of values for a 'typical' set of constraints, such as might be found in a real-world application?

Certain sets of constraints are actually surprisingly easy to satisfy. In particular, if the problem has many variables with many possible values and only a few constraints, there will be many solutions that are relatively easy to find. On the other hand, if the problem contains few variables but a large number of constraints, often no assignment exists that satisfies all the constraints. The computationally interesting problems lie somewhere in the middle. For randomly generated constraint-satisfaction problems (Fig. 1), a sudden, sharp 'phase transition' occurs at a certain ratio of constraints to variables: at this value, we pass from a situation where almost all combinations of constraints can be satisfied, to one where very few combinations can be satisfied[3–8].

Achlioptas *et al.*[1] present a new approach to determining the lower bound on this phase transition in the so-called *k*-SAT problem. This is a constraint-satisfaction problem that has only binary variables and a special logical form of constraints that contain exactly *k* variables. It has been shown that any general constraint-satisfaction problem can be translated into a *k*-SAT problem, for any values of *k* larger than 2 (Fig. 2, overleaf). In fact, thousands of practical computational problems — from optical switching, supply-chain management and chip design, to protein folding — can be formulated as *k*-SAT problems.

Achlioptas and colleagues introduce a

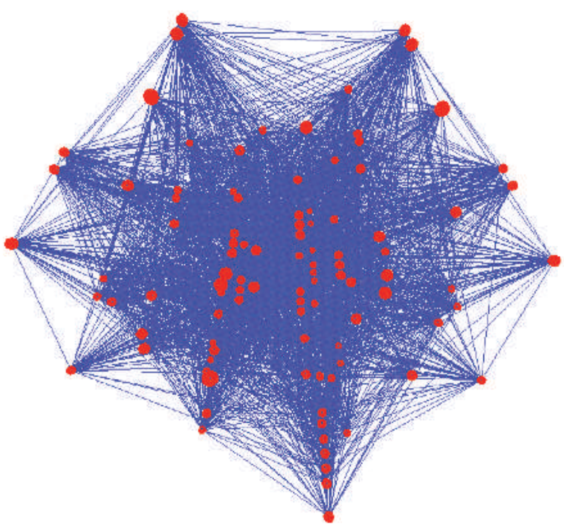

Figure 1 | Web of constraint. The dependency graph of a random constraint-satisfaction problem at a constraint-to-variable ratio of 7.9 (100 binary variables and 790 constraints). Each red dot represents a variable; a line connects two variables if they share a constraint. This graph arises from a problem in which each constraint connects exactly four variables (a 4-SAT problem). This problem is satisfiable — that is, there is an assignment to the variables such that all constraints are satisfied — as predicted by Achlioptas *et al.*[1]. (Figure devised by Anand Kapur.)

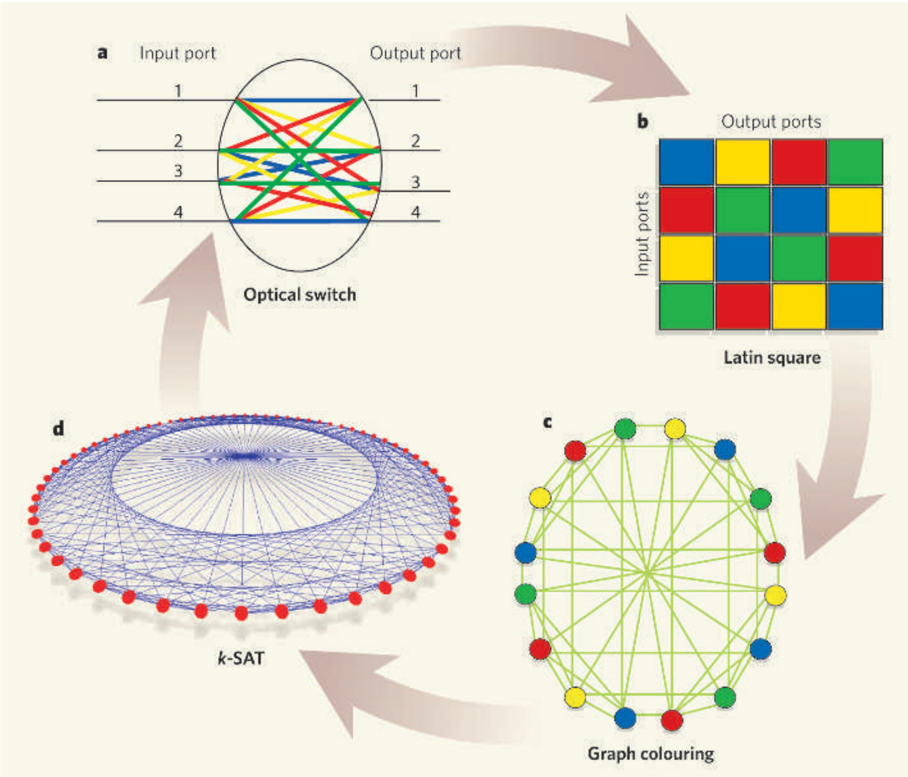

Figure 2 | Finding satisfaction. Constraint-satisfaction problems form a large class of practical computational problems, and encompass well-studied special cases such as the graph-colouring and *k*-SAT problems. **a**, An optical switch. The task is to assign a wavelength of light to each input–output path, such that a given wavelength is not assigned more than once to any input or output port. **b**, The optical-switch problem is equivalent to assigning different colours to the cells of a square matrix such that there is no repeated colour in any row or column (a 'Latin square'). This problem can be translated into **c**, a graph-colouring problem or **d**, a *k*-SAT problem. Achlioptas *et al.*[1] introduce a technique for determining whether random *k*-SAT problems will have a satisfying assignment — that is, an assignment to the variables such that all constraints are satisfied — and whether a random graph can be coloured with a given number of colours.

sophisticated probabilistic argument, the weighted-second-moment method, to show that values for variables that satisfy all the constraint clauses can be assigned with high probability up to a constraint-to-variable ratio of $2^k \ln 2 - k$. Their method cleverly considers the overall statistical properties of the exponential search-space, without actually identifying any specific satisfying assignment. The lower limits that they find for the position of the phase transition at different values of *k* are very close to the best-known upper limits, especially for larger values of *k*, thus limiting significantly the range of possible values where the phase transition can occur.

The authors also consider the graph-colouring problem, another widely studied constraint-satisfaction task (Fig. 2). In this problem, nodes of a graph are coloured such that no two connected nodes have the same colour. (Ensuring that, on a map, no two countries of the same colour border each other is an example of this problem.) Using the second-moment method, Achlioptas *et al.* can predict how many colours are needed to fill in random graphs — without actually showing a valid colouring.

Achlioptas and colleagues' approach was inspired in part by work that used advanced techniques from statistical physics to obtain insights into the *k*-SAT phase transition[9]. In turn, physicists have used the second-moment method to show rigorously that, as the phase-transition region is approached, the exponential search-space fractures dramatically, with many small solution clusters appearing relatively far apart from each other[10]. Traditional search procedures have trouble finding solutions in these search-spaces because they tend to get 'stuck' in between the solution clusters.

The quest for a deeper understanding of phase-transition phenomena in computational problems has been a catalyst to a productive interchange of ideas and concepts between statistical physics, mathematics and computer science. Step-by-step, this work is revealing the intricate structure of exponential search-spaces. These insights can lead to the design of new methods for searching such spaces[9], and thus to fundamentally new algorithms for computational problems. An open question is whether such techniques can be adapted to deal with constraint-satisfaction problems that have more inherent structure[11] than the *k*-SAT problem, and which occur in many real-world applications. ■

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CANCER

Inflammation by remote control

Alberto Mantovani

Smouldering beneath many latent tumours is a chronic inflammation that goads pre-malignant cells into becoming full-blown cancer. The spark that kindles these flames comes from an unexpected source.

Chronic inflammation makes individuals susceptible to many forms of cancer. The culprits that drive this process are inflammatory cells and signalling molecules of the 'innate' immune system — our in-born defence system, which recognizes potential threats without previous exposure to them. But in a surprising twist, de Visser *et al.*, writing in *Cancer Cell*[1], demonstrate that specialized cells from the 'adaptive' immune system orchestrate the innate inflammation that promotes tumour progression.

The link between inflammation and the promotion of cancer was first observed in the nineteenth century[2], but only in recent years has it become a generally accepted