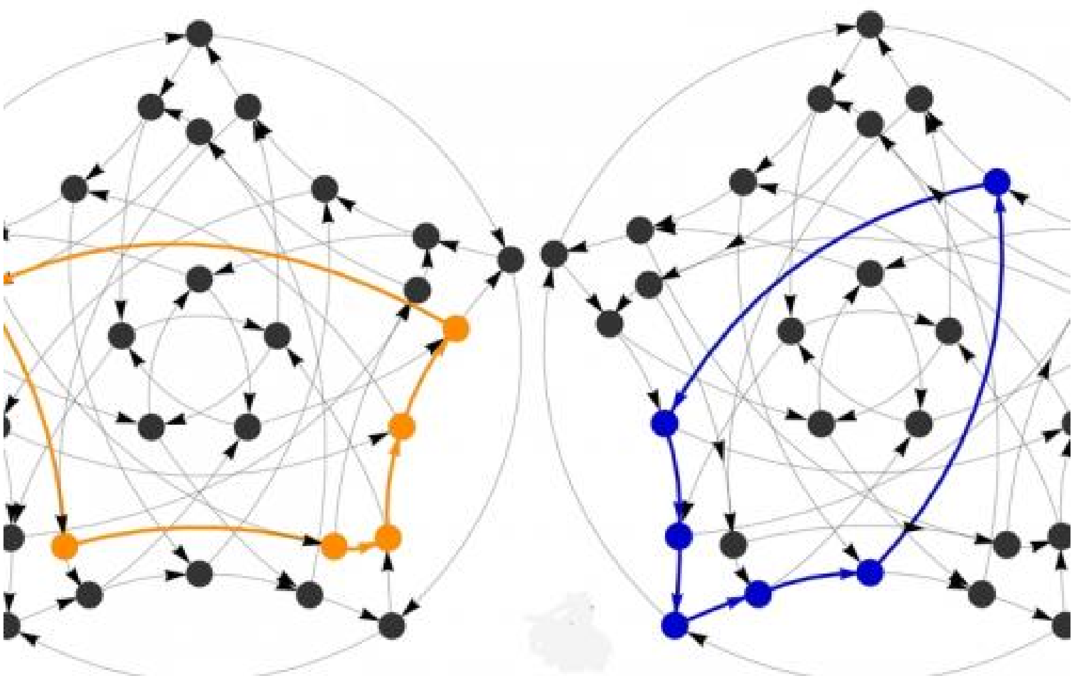
Computing in the net of possibilities

August 15 2012



In systems composed of coupled oscillating elements the saddle points form a network. The above networks belong to a system of five elements. The saddle points are depicted as points. Every saddle point is connected to four others: two of these connections lead to the particular saddle point, two others away from it. The figure shows two possible paths (orange and blue) the system may take. Each path corresponds to the result of a calculation. © MPI for Dynamics and Self-Organization

(Phys.org) -- Scientists at the Max Planck Institute for Dynamics and

Self-Organization in Göttingen have developed an entirely new principle for information processing. The complex network computer now stands as an alternative to the other possibilities in data processing - such as the conventional computer or the quantum computer. The fundamental requirement is a system, for instance a laser, with oscillating elements that can interact with one another. The researchers were able to demonstrate that the characteristic dynamics of such a system can be cleverly harnessed to perform the full range of logical operations. The complex network computer can even perform some tasks, such as the coarse sorting of numbers, considerably faster than conventional computers. Furthermore, the researchers have managed to take a first step in programming a robot according to the new principle.

A computer is much more than simply hardware. Foremost, it is a principle for the processing of data and information. The essence of the conventional computer for example, which has long had a decisive effect on our daily life, is not to be sought in transistors, chips and semiconductors. Rather, it is characterized by the ways and means of performing calculations with the help of two easily distinguishable states (conventionally known as 0 and 1). Scientists at the Max Planck Institute for Dynamics and Self-Organization in Göttingen have now developed a completely new principle for information processing. Their so-called complex network computer is equally capable of performing arbitrary calculations, but does this under completely different conditions.

"In contrast to classical data processing on a PC, our new approach is not based on a binary system of zeros and ones", explains Marc Timme, head of the Network Dynamics research group at Institute. What is more, a complex network computer could in principle be built from any oscillating system. "The simplest example is a pendulum", says Timme. However, particular electrical circuits whose components rhythmically exchange charge with each other, or lasers can also be said to oscillate. If several such units are linked - as with a number of pendulums connected to each other by a spring - they exhibit a special dynamic behaviour which lends itself to the processing of data.

Systems A choreography of oscillations correspond to a state of the whole system

The key to this behaviour are so-called saddle points: states of the whole system which are stable in some respects and unstable in others. "Imagine a ball sitting in the hollow of a real saddle”, explains Timme. If this ball is moved exactly parallel to the horse's back and then released, it will always roll back into the hollow. The initial state is stable with respect to this kind of disturbance. But if the ball is set in motion perpendicularly to the horse's back, it is a completely different matter: the ball will fall off; the state is unstable. In the case of connected pendulums, a special relation between the oscillations, in which particular pendulums move synchronously, corresponds to such a saddle point state.

In systems of connected oscillating elements, such saddle points form a kind of network: in response to an external disturbance that destabilizes a particular saddle point , the whole system shifts to another one. "In our example system each saddle point leads to two others, which in turn are connected with two further saddle points", explains Fabio Schittler Neves from the Institute. Which path the system actually takes in this net of possible states depends on the kind of disturbance.

"In our design, we regard each disturbance as an input signal that can be composed of several components", says Schittler Neves. Each component is coupled to one of the oscillating elements of the whole system. In the case of a group of coupled pendulums, for instance, a component signal corresponds to a slight impact on one of the pendulums. The relative strength of these component signals determines to which new saddle point state the system will tend.

All logical operations can be performed in one network

The input signal thus determines the path taken through the network of saddle points. The path taken corresponds to the result of the calculation. "The state then taken by the system allows inferences about the relative strengths of the individual signal components", explains Timme. "It's a kind of sorting by size."

In their latest publication, the researchers were now able to show that a complete system of logic can be built on this: all the logical operations – such as addition, multiplication or negation – can be represented. However, whereas a classical computer uses one component - a subsystem of the whole computer - to perform a particular logical operation like, for example, addition, the operation in a complex network computer takes place in the whole network simultaneously. "All logical operations can therefore be performed similarly in this network", explains Timme.

This means that even relatively small systems can perform an unbelievably large number of possible operations: whereas five oscillating elements provide only ten different system states and can therefore perform only ten different calculations, 100 elements provide 5×10^{20}. This number represents 10,000 times the number of letters in all the books in all the libraries in the world. In addition, the complex network computer performs some tasks, such as the coarse sorting of figures, much faster than its conventional equivalent.

The new principle of calculation enables a robot to navigate its way through an obstacle course

The new principle of calculation has also proved itself in its first practical application. It allowed the scientists to build a simple robot which finds its own way through an obstacle course. The input signals from its sensors correspond to the disturbances of the system. “In this case, electrical oscillators could serve as the hardware”, explains Schittler Neves. “This very first application shows how the robot’s brain functions when the basic principle of the complex network computer is imitated”, he adds. The scientists are currently working on a physical implementation in electronic hardware.

“We are still far away from a powerful computer in the true sense of the word”, says Timme. “But we were able to demonstrate that the idea basically works”, he adds. The current status is therefore comparable with that of the quantum computer. The theory of performing computations with the help of quantum algorithms is continually advancing. However, whether the hardware might be based on semiconductor structures, superconductors, arrangements of single atoms or completely different physical systems is still a subject for further research.

"In the case of complex network computers, it is probably not going to be coupled pendulums”, say Timme with a smile. Effective computation would require several thousand of such coupled pendulums. The system is more suitable for illustrative purposes. Systems of coupled lasers seem more promising to the researchers. Not only do they offer precisely controlled frequencies, which are a further requirement for complex network computers, they also operate in a particularly high range of up to several billion oscillations per second, enabling a computer to calculate particularly fast.

More information: Fabio Schittler Neves and Marc Timme, Computation by Switching in Complex Networks of States, *Physical Review Letters*, 2 July 2012.

dx.doi.org/10.1103/PhysRevLett.109.018701