Computing in a molecule

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(PhysOrg.com) -- Over the last 60 years, ever-smaller generations of transistors have driven exponential growth in computing power. Could molecules, each turned into miniscule computer components, trigger even greater growth in computing over the next 60?

Atomic-scale computing, in which computer processes are carried out in a single molecule or using a surface atomic-scale circuit, holds vast promise for the microelectronics industry. It allows computers to continue to increase in processing power through the development of components in the nano- and pico scale. In theory, atomic-scale computing could put computers more powerful than today's supercomputers in everyone's pocket.

"Atomic-scale computing researchers today are in much the same position as transistor inventors were before 1947. No one knows where this will lead," says Christian Joachim of the French National Scientific Research Centre's (CNRS) Centre for Material Elaboration & Structural Studies (CEMES) in Toulouse, France.

Joachim, the head of the CEMES Nanoscience and Picotechnology Group (GNS), is currently coordinating a team of researchers from 15 academic and industrial research institutes in Europe whose groundbreaking work on developing a molecular replacement for transistors has brought the vision of atomic-scale computing a step closer to reality. Their efforts, a continuation of work that began in the 1990s, are today being funded by the European Union in the Pico-Inside project.

In a conventional microprocessor – the "motor" of a modern computer – transistors are the essential building blocks of digital circuits, creating logic gates that process true or false signals. A few transistors are needed to create a single logic gate and modern microprocessors contain billions of them, each measuring around 100 nanometres.

Transistors have continued to shrink in size since Intel co-founder Gordon E. Moore famously predicted in 1965 that the number that can be placed on a processor would double roughly every two years. But there will inevitably come a time when the laws of quantum physics prevent any further shrinkage using conventional methods. That is where atomic-scale computing comes into play with a fundamentally different approach to the problem.

"Nanotechnology is about taking something and shrinking it to its smallest possible scale. It's a top-down approach," Joachim says. He and the Pico-Inside team are turning that upside down, starting from the atom, the molecule, and exploring if such a tiny bit of matter can be a logic gate, memory source, or more. "It is a bottom-up or, as we call it, 'bottom-bottom' approach because we do not want to reach the material scale," he explains.

Joachim's team has focused on taking one individual molecule and building up computer components, with the ultimate goal of hosting a logic gate in a single molecule.

How many atoms to build a computer?

"The question we have asked ourselves is how many atoms does it take to build a computer?" Joachim says. "That is something we cannot answer at present, but we are getting a better idea about it."

The team has managed to design a simple logic gate with 30 atoms that perform the same task as 14 transistors, while also exploring the architecture, technology and chemistry needed to achieve computing inside a single molecule and to interconnect molecules.

They are focusing on two architectures: one that mimics the classical design of a logic gate but in atomic form, including nodes, loops, meshes etc., and another, more complex, process that relies on changes to the molecule's conformation to carry out the logic gate inputs and quantum mechanics to perform the computation.

The logic gates are interconnected using scanning-tunnelling microscopes and atomic-force microscopes – devices that can measure and move individual atoms with resolutions down to 1/100 of a nanometre (that is one hundred millionth of a millimetre!). As a side project, partly for fun but partly to stimulate new lines of research, Joachim and his team have used the technique to build tiny nano-machines, such as wheels, gears, motors and nano-vehicles each consisting of a single molecule.

"Put logic gates on it and it could decide where to go," Joachim notes, pointing to what would be one of the world's first implementations of atomic-scale robotics.

The importance of the Pico-Inside team's work has been widely recognised in the scientific community, though Joachim cautions that it is still very much fundamental research. It will be some time before commercial applications emerge from it. However, emerge they all but certainly will.

"Microelectronics needs us if logic gates – and as a consequence microprocessors – are to continue to get smaller," Joachim says.

The Pico-Inside researchers, who received funding under the ICT strand of the EU's Sixth Framework Programme, are currently drafting a roadmap to ensure computing power continues to increase in the future.

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