Industry Developments:

Cooling Super and Quantum Computers

Supercomputers that can perform billions of calculations per second (gigaflops) also contend with the same issue that affects laptops and handheld devices – excessive heat. Cooling supercomputers has typically been achieved with facility-level air conditioning. Some systems also run cold water through heat exchangers to extract the heat from these machines.

Today, supercomputer OEMs and users are turning to other liquid cooling methods, including the full submersion of non-mechanical hardware in different liquids. The major drivers toward liquid cooling are cost and power. Maintaining a cold bath of inert liquid coolant can cost half as much as continually running a large scale air conditioning system. Some supercomputers require multi-million dollar electricity budgets, the bulk of which is the cost to keep their air conditioners online. [1]

Another supercomputer power issue concern is its availability. Japan has faced electricity shortages since the earthquake-caused meltdown of its Fukushima Daiichi power plant three years ago. When the Tokyo Institute of Technology needed more supercomputer performance, it installed the Tsubame KFC supercomputer, with a CarnotJet submersion cooling solution from Green Revolution Cooling. [2]

The Carnojet submersion cooling system meets the most basic requirement that the coolant be non-electrically conductive. Its coolant, GreenDEF, is a liquid fluoroplastic developed by Iceotope. In a

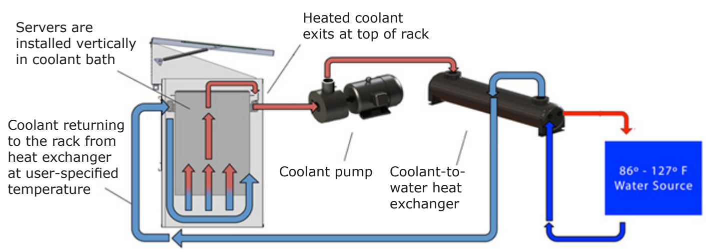

Figure 1. The CarnotJet Cooling System Features a Dielectric Coolant, GreenDEF, with 1,200 x the Heat Absorption Capacity of Air [3]

recent interview, company founder, Peter Hopton said "Most of the liquids people encounter on a daily basis don't mix well with electronics. Everyone's spilled coffee on their laptop or dropped their smartphone down the toilet, probably to disastrous effect. People can get nervous at the thought of mixing electronics and liquids but fortunately the substance we use doesn't conduct electricity so it's completely safe to do so. I've dunked my phone in the stuff countless times and it still works perfectly." [4]

Submersion cooling isn't the only liquid-based approach to cool supercomputers. IBM engineers took on the challenge to lower energy costs by pioneering hot-water cooling technology. IBM's hot-water cooling technology directly cools active components such as processors and memory modules with coolant temperatures that can reach as high as 113°F or 45°C. This technology was applied in the Leibniz Supercomputing Centre located near Munich. The Centre's SuperMUC supercomputer can provide a peak performance of up to three petaflops, more than that of 100,000 personal computers.

The IBM hot-water technology allowed the system to be built ten times more compact, while consuming 40% less energy than a comparable air-cooled system. According to IBM, SuperMUC combines its hot-water cooling capability, which removes heat 4,000 times more efficiently than air, with 18,000 energy-efficient Intel Xeon processors.

Figure 2. The Cooling System for the SuperMUC Computer Uses Hot-Water Technology to Cool 150,000 Cores [5]

The water that flows through the microchannels is conducted away from the machines, carrying heat with it to an exchange in which it is used in heating the human-occupied areas of the building. The integration of hot-water cooling and IBM application-oriented, dynamic systems management software, allows energy to be captured and reused to heat the buildings during the winter on the sprawling Leibniz Supercomputing Centre Campus, for savings of one million Euros ($1.25 million USD) per year. The water, having dropped some of its heat, is then pumped back to the processors, making direct contact with them and drawing heat away as it passes through on its next round. [5]

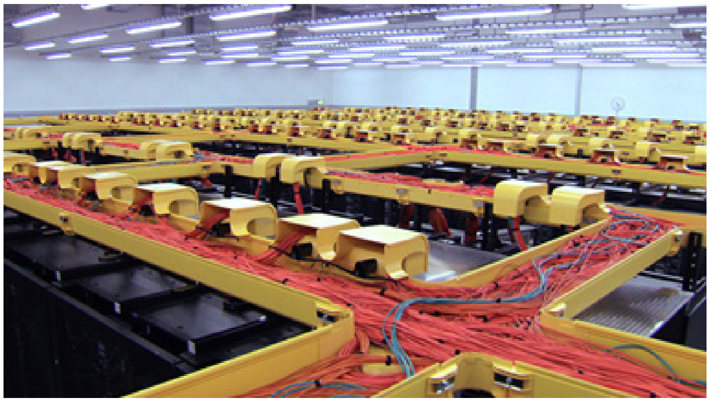

Figure 3. SuperMUC Cooling System Allows a Higher Inlet Water Temperature and Resulting Hot Outlet Water is Used to Heat Buildings [6]

Quantum Computing Turns to Supercooling

The Vancouver-based D-Wave company's D-Wave One system is built around a novel type of superconducting processor that uses quantum mechanics to massively accelerate computation. With traditional computers, the circuits are either on or off, and the binary code is represented by ones and zeros. Adding more processors increases the computer's power linearly. By contrast, a quantum computer uses quantum bits, or qubits, the quantum equivalent of a traditional bit. Its circuits exist in all possible states at the same time: a one, a zero and whatever is in between – and this superposition vastly increases the potential processing power.

According to the company, on a quantum computer, information processing is done on devices that obey the laws of quantum mechanics. These things have to be very small and very cold, and they can be built out of exotic materials.

The D-Wave quantum computer takes a ring of metal and cools it down close to absolute zero, at temperatures 250 times colder than interstellar space. Then other factors are eliminated to combat the decoherence that can destroy the quantum calculations. Light is removed by sitting the machine inside a black box. Radiation is shielded, sound is reduced as much as possible, and all the air is removed from the enclosure. The result is that when a current is applied to the ring, scientists can measure the superposition – 100 percent of the current is going clockwise at the same time that 100 percent of the current is going counterclockwise. That dual state is harnessed to solve problems.

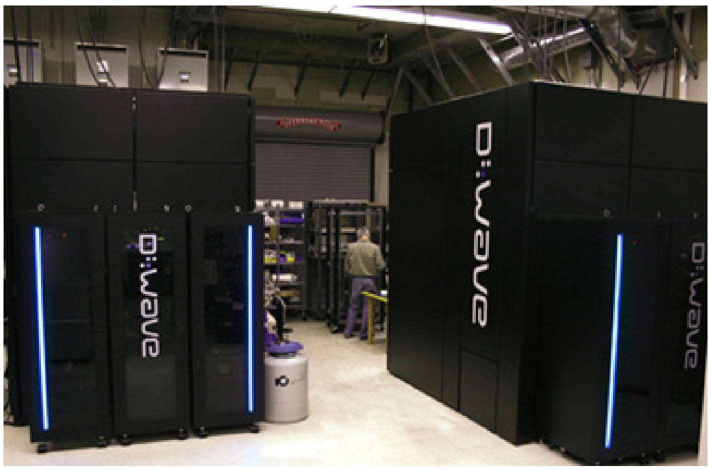

Figure 4. The D-Wave Quantum Computing System

The niobium chip at the heart of the D-Wave Two has 512 qubits and therefore could in theory perform 2^{512} operations simultaneously. That's more calculations than there are atoms in the universe, by many orders of magnitude.

But the nobium must be sufficiently cooled to become a superconductor. When ordinary metal conducts electricity, the electrons carrying the electric current collide with the imperfections in the metal and you get resistance. When cooling superconducting metal like niobium, the metal's electrons form Cooper pairs where the motion of one electron is matched by an equal and opposite motion of the paired electron, which stops the electrons hitting the imperfections and generating resistance, which means the electrons flow freely without you needing to pump in extra current. When the Cooper pairs enter the Josephson junctions in the chip – made up of two segments of superconducting niobium linked by a weak insulating barrier – they break up, creating electron-like quasi-particles that can tunnel through the insulator in the junction, effectively conducting the current through the junction [7].

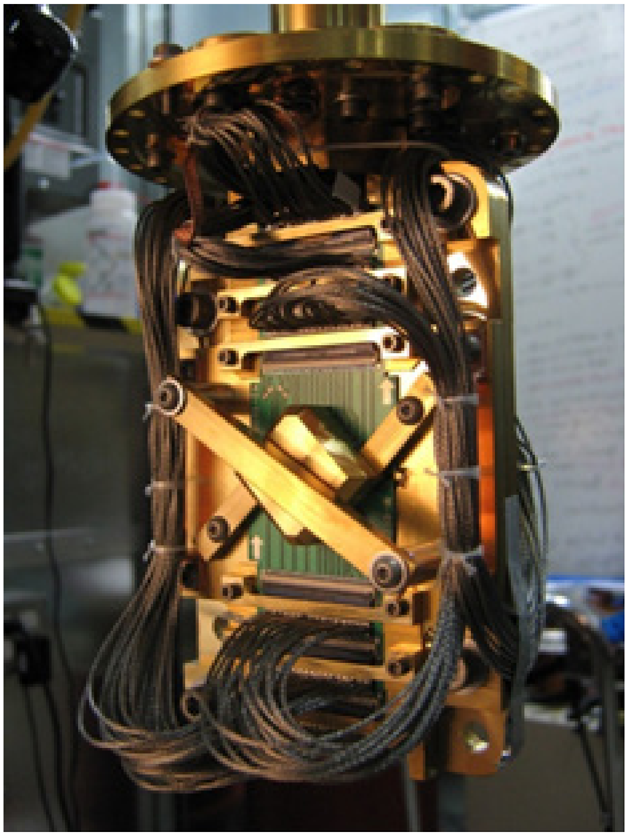

Figure 5. The Chip in D-Wave's Computers is Cooled Close to 0.02 K, Colder than Anything in the Known Universe [8]

The noteworthy point in all these sophisticated computing is the need for high capacity cooling- and the second main important point is that there is available cooling technology to manage even the quantum computing thermal management requirements. The challenge as always been on packaging the cooling technology in the platform of the final product that is cooling.

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