Limits on Fundamental Limits to Computation

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134 Citations on this paper

Very hardware and electrical engineering focused

Main point

Computer power is contingent on transistor density, energy consumption, and clock speed. To look at the future of the growth of computation power, the limitations of materials & manufacturing, engineering design, power & energy, time & space, and information & computational complexity are considered.

Materials & Manufacturing

- Precision of lasers, which is limited to $\lambda/2.8$ (Abbe diffraction limit). This limitation was broken with asymmetric illumination.

- Chip interconnects can either be fast or dense, but not both. New interconnect and structures help to break this limit.

- Traditional transistors are now manufactured on an atomic level, any smaller will soon become impossible. New transistor designs help in both size and reliability of transistors.

Engineering Design

- Optimization problems were still difficult to solve. Each new generation of hardware requires new software and optimization solutions. Design automation shifts focus from micro-architecture to algorithmic optimization.

Power & Energy

- Faster computation requires more energy which depends on physical scaling.

- Zero-energy computation is prohibited by Heisenberg uncertain principle.

- Applied superconductivity has found ways to achieve sub-thermodynamic computation, but is not scalable.

- Quantum architecture can also achieve sub-thermodynamic computation, but its also not scalable nor applicable for general use computation.

- Better energy consumption can be achieved by better scheduling algorithms for the processor, but is still limited by the hardware itself.

Time and Space

- Bits travel no faster than speed of light, quantum computing can resolve this, but does not allow traditional computing.

- Parallel tasks does not scale well with more parallelism (communication overhead, dependency, synchronization).

- Three dimensional circuits and quantum circuits are limited by their manufacturing yields and niche usage.

Informational & Computational Complexity

- $P \neq NP$ conjecture still prevents algorithms to solve critical optimization problems in satisfactory time. We still rely on fast run-time approximation solutions.

- Non-computable problems remain un-computable regardless of a human's ability to solve it.

Conclusion

Computing power will continue to scale, however the pace will soon be halted by computation limits. Technologies to circumvent can allow computation power to continue scaling, and understanding what the limitation challenges are allows research to better focus on circumventing it.

Discussion

Are there non hardware / software limitations?

To what extent do we benefit from more computation power?

To what extent does computation limitations affect our study and research in informatics?

How do we decide on which limitations to focus on? How do we determine which limitations will most impact our research?