Quantum Computation

The magic of wave dynamics

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The availability of different physical interactions makes it possible to design different types of computers.

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Wave algorithms can be useful in situations where

spatial resources are cheap and quantum algorithms are fragile.

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Large scale integration (say 10 or more components) is a technological challenge. Noone knows when that will arrive, or what a quantum computer will be used for.

It is inevitable

"Because the nature isn't classical, damn it . . ."

—R.P. Feynman

Laws of classical physics are convenient and useful,
and yet only approximations (that are not fully understood)
to the underlying laws of quantum physics.

Science: Observe and explain phenomena. Theorise!
Technology: Design and control phenomena. Optimise!

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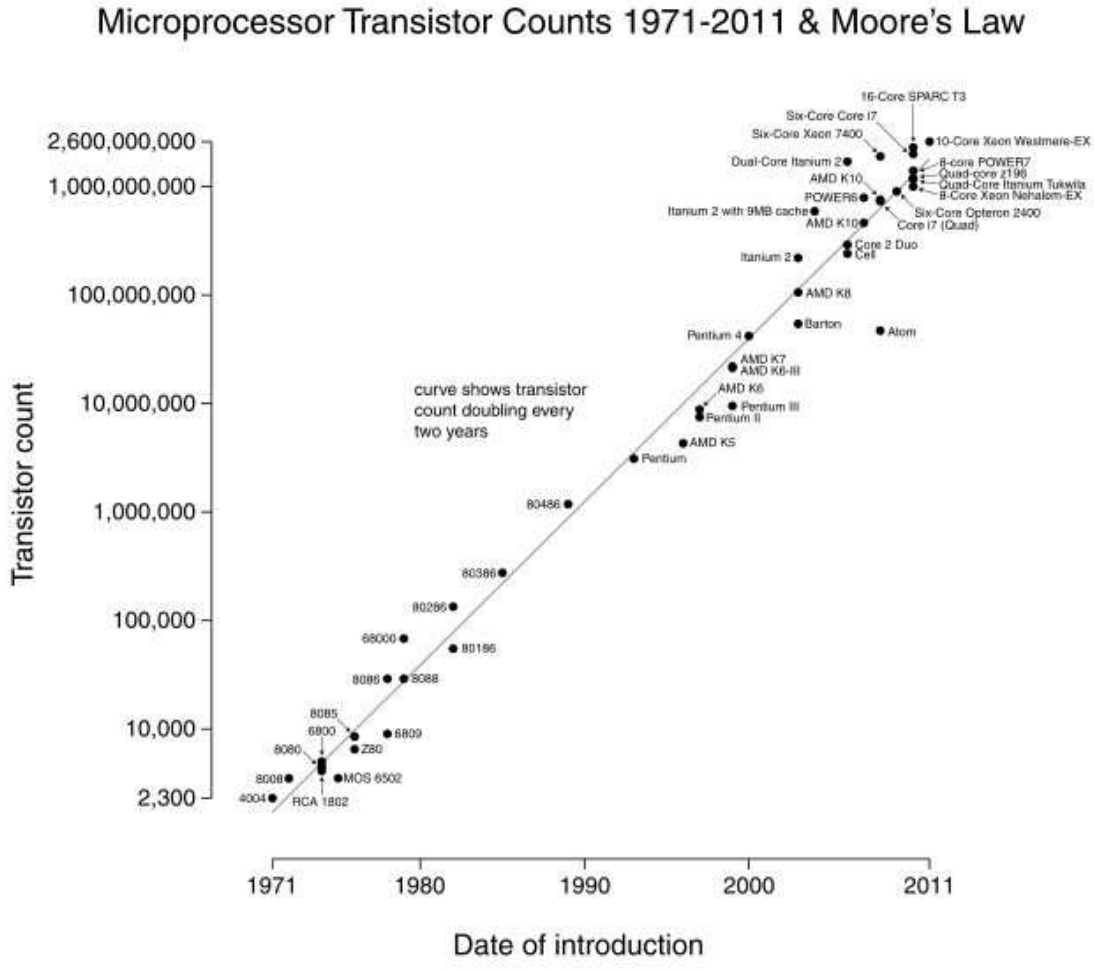
Optimisation

Minimise resources (space, time, energy, . . .):
Simple and quick operations with versatile composition.
Minimise errors (bounded error calculations):
Language with clearly distinguishable building blocks.

The minimal language for a given task plays an important role.

Shrinking computer circuits



Number of transistors on a chip doubles every two years.

1948: First transistor, size $\sim$ 1 cm. Today: VLSI circuits, size 22 nm.

Atomic size, 0.1 nm, is not very far!

(First nanotechnnology, and then decoherence, will have to be conquered along the way.)

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Superposition allows multiple signals at the same point at the same time. All of them can be simultaneously processed, and any one of them can be selectively observed (e.g. radio or cell-phone transmissions). This offers an SIMD parallel computing paradigm with no extra hardware. Which algorithms can exploit this?

Database Search

Classical:

Binary tree search is the optimal classical algorithm.
A sorted database of N items can be searched using $\log_2 N$ binary questions.
An unsorted database of N items can be searched using $N/2$ binary questions with memory, and using N binary questions without memory.

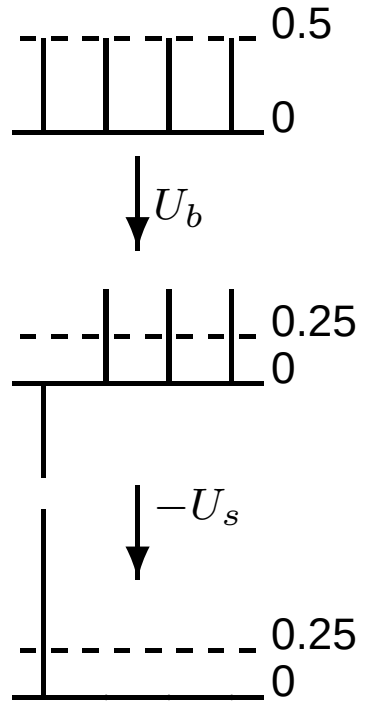
Quantum/Wave:

Wave mechanics works with amplitudes and not with probabilities. Superposition of amplitudes can yield constructive as well as destructive interference.
Optimal search solutions differ from the classical ones.

Grover's algorithm: An unsorted database of N items can be optimally searched using $(\pi/4)\sqrt{N}$ binary questions.

Grover's Database Search

The steps of the algorithm for the simplest case of 4 items in the database. Let the first item be desired by the oracle.



	Amplitudes	Algorithmic Steps	Physical Implementation
(1)		Uniform distribution	Equilibrium configuration
		Quantum oracle	Binary question
(2)		Amplitude of desired state flipped in sign	Sudden perturbation
		Reflection about average	Overrelaxation
(3)		Desired state reached	Opposite end of oscillation
(4)	Projection	Algorithm is stopped	Measurement

(Dashed line denotes the average amplitude.)

Wave Algorithms

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Video of amplitude amplification in coupled oscillators

Possible uses

Focusing of energy:

Concentration of total energy of a coupled oscillator system into a specific oscillator can have potential applications in processes that are highly sensitive to energy availability.

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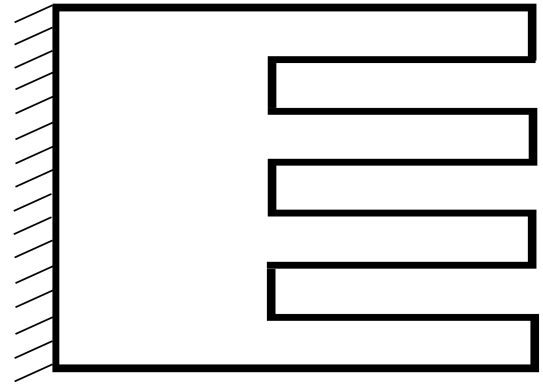
Nanomechanical devices: A coupled oscillator system can provide efficient focusing of energy at a specific location, when one cannot directly control the component concerned.

For example, a comb-shaped cantilever beam can be used as a selective switch or a sensor.



Catalysis: There exist many processes that need crossing of an energy threshold for completion. Their rates are typically governed by the Boltzmann factor for the energy barrier, $\exp(-E_{\text{barrier}}/kT)$. Energy amplification can speed up the rates of such processes dramatically.

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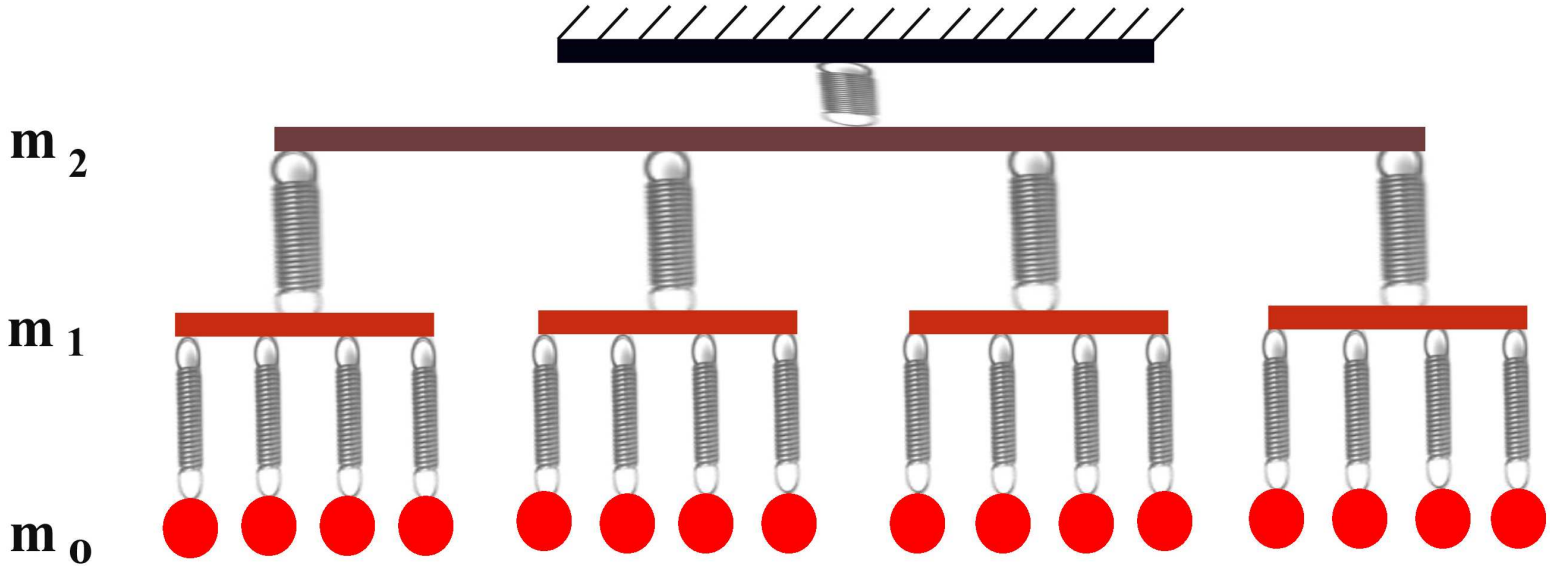
Shock absorbers and vibrational isolation: Instead of damping a single perturbed oscillator, it is much more efficient to disperse the energy into several oscillators while damping them together.

A hierarchical system of oscillators—four small ones coupled to a big one at every level with appropriate mass, spring and damping parameters—can provide a practical realisation of this idea.



(The initial impulse is taken to be a local disturbance, which subsequently spreads out.)

Language of the Genes

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   (Requires wave dynamics.)
3. Classically two nucleotide bases (one complementary pair) are sufficient to encode the genetic information. That would be a simpler system, and so it would have preceded (during evolution) the four nucleotide base system found in nature.
   Was the advantage provided by the wave algorithm the real incentive for nature to complicate the system?

Challenge

Construct a believable, and testable, atomic scale model implementing Grover's algorithm using nucleotide bases.

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References:

All my papers are available at http://arXiv.org/

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