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Theoretical Foundations of Computer Science 300

Lecture 10

Other Computing Models

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Outline

- Other Architectures
- Quantum Computing
- Biological Computing

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Assessment Criteria

- **None**. The material in this lecture is not assessable.

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Determinism

- The Decidability and Complexity discussed in this unit so far apply to deterministic Turing Machines only.
- Non-Deterministic Turing Machines are used as a way of testing for membership of NP.
- There are a number of computational models under development that aren't adequately modeled by the DTM or the NTM.

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Alternatives

- Quantum Computing – using Quantum uncertainty to generate something similar to non-determinism.
- DNA Computing – using the DNA in strands of viruses to encode and solve problems
- And there's many others, including photonic (light-based) computers and even living computers (made of leech parts!).

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And then there was…

- There are also some unusual implementations of the Turing Machine.
- One implementation, using cards and rules from the game Magic: the Gathering is described on a link in Blackboard.
- Another implementation is a working Turing Machine built entirely out of Lego!

The Lego TM

- Not only is it build out of Lego, it doesn't use electricity.
- The first 2 or so minutes explain what you already know. The rest talks about the machine.

  http://www.youtube.com/watch?v=KrNTmOSVW-U

- But now, on to something more serious … I carefully won't mention the computer circuits utilizing billiard balls!

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For more information, see http://rubens.ens-lyon.fr/

There are others – check YouTube

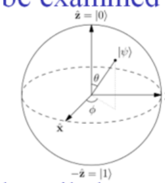
http://en.wikipedia.org/wiki/Billiard_ball_computer

QUANTUM COMPUTING

The Quantum Turing Machine
QTM = DTM ?

It's a little (qu)bit different

- Normal computers store information using bits
  - Bits take a value of either 0 or 1
  - Their value is always known and can always be examined



- A Quantum computer uses qubits:
  - A qbit also takes on a value of either 0 or 1
  - However the value of a qubit isn't determined until the qubit is collapsed – at that point either a 0 or a 1 is observed
  - The important fact is that *before* collapse, the qubit has a value of both 0 and 1 – this is called Quantum superposition
  - Because it has both values, we can effectively check both possibilities at once.

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Image from wikipedia. It's a Bloch sphere, which is a representation of a qubit.

PhD Movie

- This movie is a short introduction to quantum computing.
- From www.youtube.com/watch?v=T2DXrs0OpHU

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Applications

- Because quantum computers can try a large number of possibilities at once, they make a number of problems easier to solve.
- Any problem in NP can be solved in polynomial time by a NTM – but it is a little uncertain whether this holds for a QTM!
- However QTM have been shown to be very useful for specific applications:
  - Several types of optimization
  - RSA decryption

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Note that cracking RSA encryption has not actually shown to be NP-complete, although it is obviously in NP.

What problems CAN a QTM solve?

- There is a difference of opinion.
  - The general opinion, as presented in the PhD video clip, is that a QTM is similar in power to a NTM
  - A fairly strong body of research suggests that it is not true, but that QTMs instead have their own category of problems that they can solve in polynomial time – BQP
  - The extent of BQP is not known, but it is believed that it does **not** include any NP-complete problems

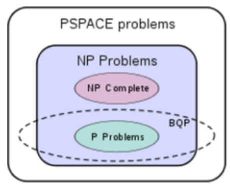

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Image from Wikipedia

QTM with post-selection

- A model of a QTM with post-selection has been proposed.
  - post-selection means putting conditions on probability
- This model has been shown to be equivalent in power to complexity class PP
  - PP is a probabilistic complexity class that includes problems such as SAT
  - In fact, PP includes all of NP, and thus all of NP-C!
  - The QTM with post-selection can thus solve all NP-complete problems in polynomial time. Theoretically.

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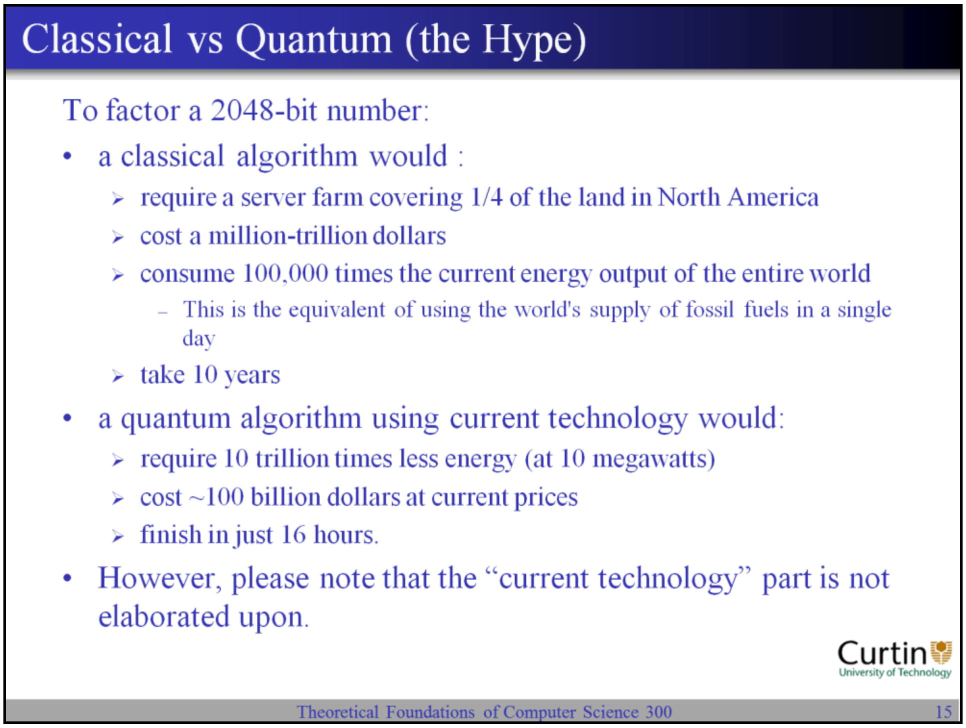

Quote from John Preskill - http://www.youtube.com/watch?v=8-IqQnGYB2M

So…?

- How powerful are quantum computers, really?

- The answer is going to depend on:
  - what sort of quantum computers we're talking about
  - whether not it's actually feasible to build practical quantum computers

- There are currently no quantum computers known to exist that are of a decent size (more than 10 qubits) and truly general.

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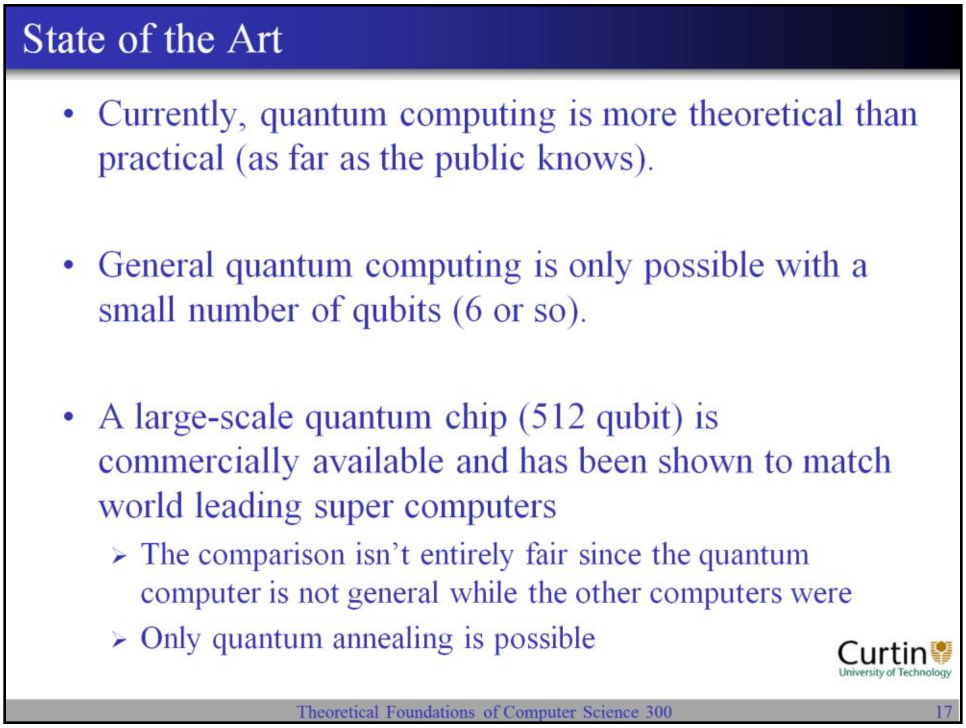

The company is called D-Wave (http://www.dwavesys.com/en/dw_homepage.html)

Google's Quantum Computer

http://www.youtube.com/watch?v=CMdHDHEuOUE#t=368

- This video is referred to in an article that discusses Google using the quantum computer to:
  - optimize Android
  - solve game trees faster than conventional computers
  - develop quantum machine learning applications for devices such as mobile phones
  - improve blink detection for Google Glass
  - "generate algorithms faster than the entire Google datacentre"!

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http://www.dailytech.com/Google+Uses+Quantum+Computers+to+Optimize+Android+Plots+World+Domination/article33536.htm

http://highscalability.com/blog/2013/10/30/strategy-use-your-quantum-computer-lab-to-tell-intentional-b.html

Other Work

- A recent (March 2013) breakthrough at Yale has possibly shown one more step to true quantum computing.
- The Yale scientists that they were able to isolate a qubit, but they cannot yet control the quantum collapse.
- The paper is here:

http://www.nature.com/nature/journal/v495/n7440/full/nature11902.html

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Other Work

- In Germany, work has been done on using electromagnetic fields to enclose qubits.
- Results have been presented demonstrating multi-qubit systems.
- A useful thesis can be found here:

http://edoc.ub.uni-muenchen.de/16099/1/Viehmann_Oliver.pdf

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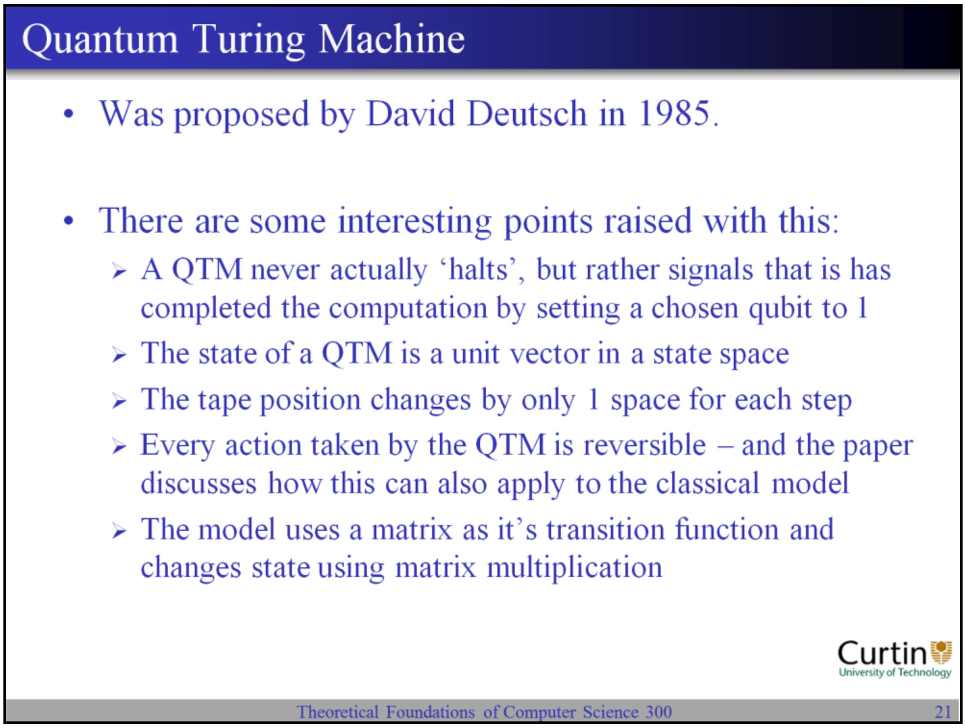
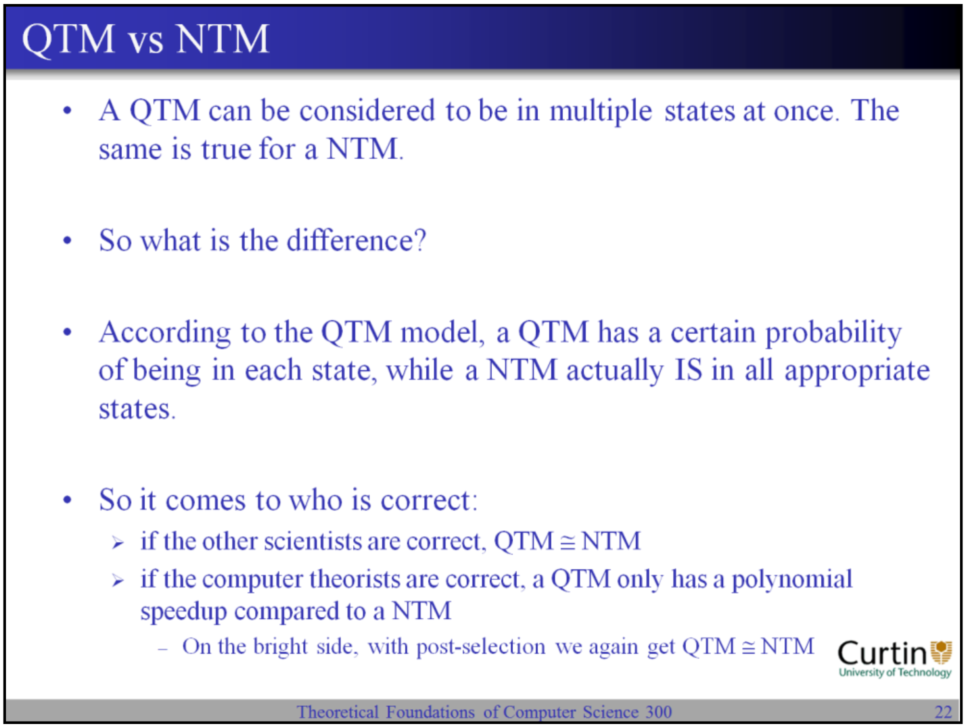


For quantum circuits, Wikipedia is once again your friend:
http://en.wikipedia.org/wiki/Quantum_circuit

Deutsch's paper is available online:
http://www.ceid.upatras.gr/tech_news/papers/quantum_theory.pdf



The last equivalence is fairly rough, but at the very least a quantum computer with postselection is expected to solve all problems in NP (and this includes NP-complete problems) in polynomial time.

DNA COMPUTING

Parallel Computing in a Test Tube

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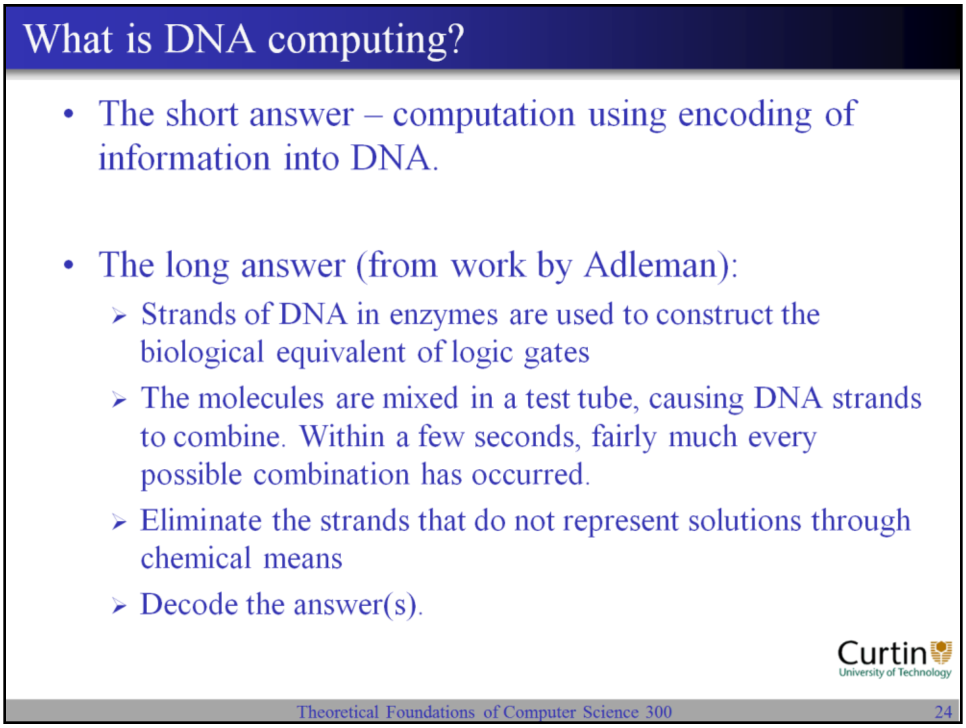

Adleman, L. M. (1994). "Molecular computation of solutions to combinatorial problems". *Science* **266** (5187): 1021–1024.

DNA Logic

- Logic gates built of DNA don't use electricity.
- Instead, they are sections of DNA that latch on to and combine other DNA in an appropriate manner.
- For example a DNA AND gate links two other DNA strands in sequence

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The Beginnings

- The Adleman method was designed as a proof of concept.
- The initial problem solved was finding a Hamiltonian Circuit through 7 cities.
- Solving the problem took seconds on the first try, but encoding and decoding took days.

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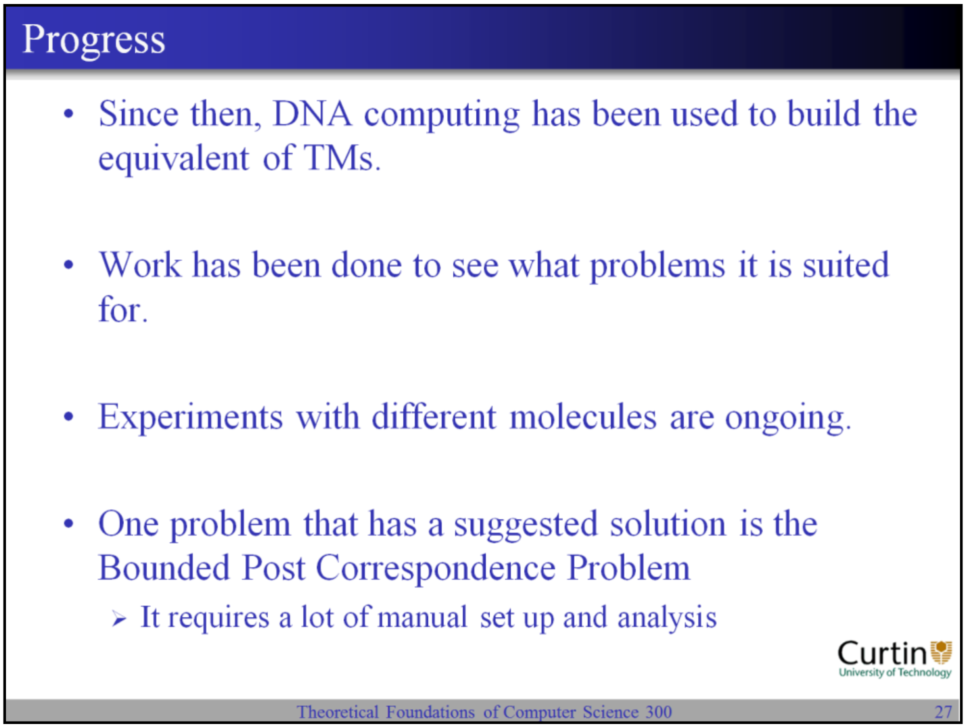

Lila Kari, Greg Gloor, Sheng Yu (January 2000). "Using DNA to solve the Bounded Post Correspondence Problem". *Theoretical Computer Science* **231** (2): 192–203

Available here:
http://www.csd.uwo.ca/~lila/pdfs/Using%20DNA%20to%20solve%20the%20Bounded%20Post%20Correspondence%20Problem.pdf

Progress

- Recently (March 2013) researchers stored all of the following in DNA:
  - Shakespeare's sonnets (text)
  - Scholarly paper (PDF)
  - A colour photograph (JPEG)
  - A part of Martin Luther King's speech (MP3)
- The files (total size around 750kB) were stored in the contents of a small test tube.
- The coding process includes an index and error correction.

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N. Goldman et al. Towards practical, high-capacity, low-maintenance information storage in synthesized DNA. Nature. doi:10.1038/nature11875.

DNA Storage Video

- http://www.youtube.com/watch?v=RmXJtKYdhT8
- Listen out for the estimate of the cost per MB.

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The Advantages of DNA Computing

- Huge memory space
  - 1L of water can contain enough DNA for around 10^{19} bytes.
  - That's about 9,094,947 TB!

- Massively parallel
  - It is possible to perform operations on all of this data in parallel
  - The potential speed of computation is around 10^{14} operations per second
  - By comparison, the current fastest computer (as of June 2013) is around $3.4x10^{16}$ flops.

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The Down Side

- At this stage, the DNA sequences must be set up using a rather slow process.
- Reading the results is also slow and can be expensive.
- So, while running the actual algorithm may be fast, this speed is lost due to the slow and work-intensive job before and after the calculation.

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ALTERNATIVE COMPUTING

The Rest

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Optical Computing

- The primary aim is to replace electronic components with photonic components
  - That means, components that use light (photons).
- The first optics device was produced in 2003, but there has not been much progress.
- There is also work using photoluminescence
  - That means chemical light

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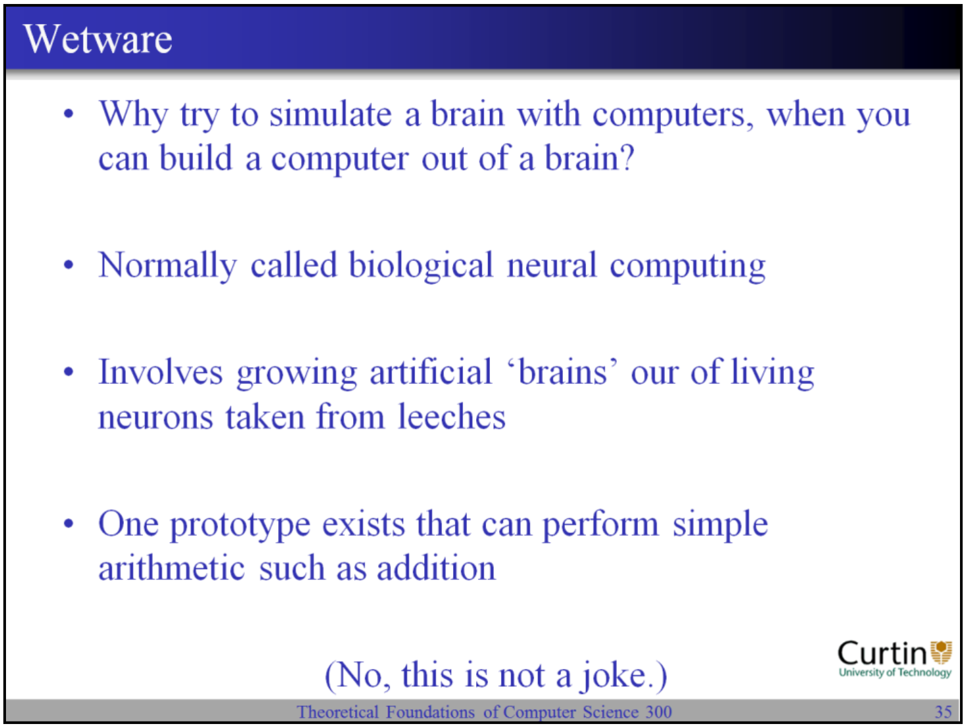
Chemical Computing

- The use of chemical reactions to change the state of substances.
- Has some of the advantages of DNA computing
  - Appears to be massively parallel
- Not to be confused with the simulation of chemical and molecular reactions using computers that is also referred to as chemical computing.



Borresen, Jon; Lynch, Stephen (1 December 2009). "Neuronal computers". *Nonlinear Analysis: Theory, Methods & Applications* **71** (12): 2372–2376

http://discovermagazine.com/2000/oct/feattech#.UnY4vflkPhc

Summary

- Other ways of computing are being developed.
- While they show promise, they are not yet ready to be fully deployed.
- It is important to keep abreast of developments in these fields in order to seize possible opportunities.
- Professional organizations are a good way to do this.

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