Quantum Processes and Computation: It's the final lecture

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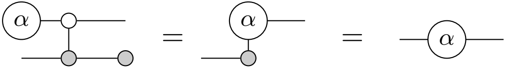
Now for some topics we haven't discussed

(a very brief overview)

Quantum Error Correction

- Manipulating qubits is hard and noisy.
- So we need to error-correct them.
- Problem 1: Can't clone information.
- Problem 2: Can't measure without destroying information.
- Still: Fault-tolerant quantum computing is possible...
- ... but current schemes need *a lot* of physical qubits.
- Factoring a 2048-bit number requires $\sim$4100 logical qubits, but tens of millions of physical qubits.

Magic State Distillation

- Most Fault-toleration computation schemes can only do Clifford computation.
- As we've seen: this is not enough.
- A common solution is to *inject magic states*.
- 

- Rawly produced magic states are too noisy to be useful.
- By using *magic state distillation* they become usable.
- In practical analysis of Shor's algorithm, $\sim$95% of resources are used for magic state distillation.

Understanding Quantum Theory

Why is the universe governed by quantum theory?

How do we study this?

- One way is to consider other possible physical laws and see how the universe would be.
- The main tool: Generalised Probabilistic Theories (GPT).
- Some results in this area: Any nonclassical GPT has entanglement, has incompatible measurements, allows Grover-like algorithms, ...

Related:

- Find intuitive principles from which to *derive* quantum theory.
- John's been working on this. You can ask him (or me) about it :)

Miscellanea

Some other topics

- Blind Quantum Computation: Client only prepares qubits, server does all the work, without knowing *what* it's doing.
- Resource theories: Can we quantify what is needed for efficient computation? Entanglement, superposition, nonlocality/contextuality, *mana*.
- Other graphical calculi:
  - ZW-calculus has *W-spiders* and can be used for modelling multipartite entanglement and interactions of *fermions*
  - ZH-calculus has *n*-legged *Hadamard spiders* and can be used to generalise MBQC from graph states to *hypergraph states*.
- Graphical reasoning in infinite-dimension: Non-standard analysis, infinitesimals, infinities and beyond.

And finally, some advertisements...

So you want to do more quantum stuff?

And you still have more courses to go?

MasterMath Quantum Computing by Ronald de Wolf:

- 8 EC course in Amsterdam
- Given in the spring of 2020
- Contains lots of different stuff!
- Quantum Fourier Transform, Quantum Walks, Quantum crypto, Quantum Error correction, fault-tolerant computing
- `https://homepages.cwi.nl/~rdewolf/qcnotes.pdf`

MasterMath Quantum Information Theory:

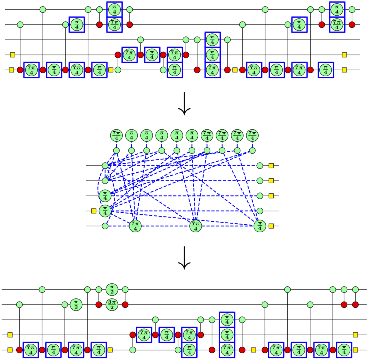
- By Michael Walter and Maris Ozols
- Quantum channels (a.k.a. ‘quantum maps’ from this course), entanglement theory, entropy, quantum optimisation problems
- Same day, just after other course

Thinking of doing an internship or PhD?

Come join me in Oxford!

Topics:

- **Quantum circuit optimisation**: can we use ZX calculus to make quantum programs run faster?



(SPOILER: Yes! But how much faster? We'll see...)

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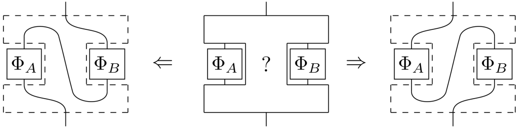
Topics:

- **Quantum causal structures**: mixing quantum theory with spacetime gives weird causal behaviours, e.g. superpositions of A-causes-B and B-causes-A.




```
(a0 -> a1) * (b0 -> b1) -> c0 -> c1
```

  Can we study these, and maybe even use them in a quantum computer?

- + lots more quantum theory, foundations, computation, linguistics using **diagrams**

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Some other options in Europe:

- Simon Perdrix (LORIA Nancy, France)

  - graphical calculus and completeness
  - measurement-based quantum computing

- Dominic Horsman (Grenoble, France)

  - graphical calculus + quantum error correction
  - working in a group that is building quantum computers! (semiconductor quantum dots)

- Ross Ducan (CQC, Cambridge, UK)

  - Cambridge Quantum Computing is a startup building **optimising quantum compilers**
  - Ross co-invented ZX-calculus
  - always looking for good people, especially if you can write code!

Thinking of doing an internship or PhD?

...a bit closer by:

- QuSoft in Amsterdam:
  - Focus on **quantum software**
  - Quantum algorithms, complexity theory, error correction, communication protocols
- QuTech in Delft:
  - Focus on **quantum hardware** (with a bit of software thrown in...)
  - They are really building quantum computers (superconducting, silicon, optics/NV-centres, you name it...)
  - Also theory groups: quantum information, networks, error-correction
- QT/e in Eindhoven
  - newest centre, focus on quantum material science
  - ...but also some people working on quantum crypto (and post-quantum crypto)

That's all![1]

[1] If you have more questions, e.g. about the exam, come to the question time tomorrow. Same Batt-place, some Batt-time.