QUANTUM COMPUTERS: FROM COUNTERCULTURE VISION TO CUTTING-EDGE TECHNOLOGY

A heartfelt plea in favor of "blue skies" theoretical research

Francesco Buscemi (Nagoya University)

7th RIKEN S&TDC Seminar with RIKEN Center for Quantum Computing 29 November 2023

THEORETICAL PHYSICS PHILOSOPHY OR ENGINEERING?

- For millennia, physics is considered part of philosophy, and inseparable from metaphysics
- Galileo (1564-1642) and Newton (1642-1727) still consider themselves philosophers
- The Industrial Revolution (~1760) understands the power of theoretical physics to provide ideas for engineering (e.g., **thermodynamics**, **electromagnetism**)
- Technological successes push theoretical physics toward engineering and away from philosophy
- At the beginning of the 20th century, classical physics is in a **deep crisis**: the new quantum theory is discovered by *new philosophers* (e.g., Einstein, Bohr, Heisenberg, Schrödinger)
- WWII and the Cold War push theoretical physics away from philosophy again: atomic energy, transistors, lasers, LED, MRI imaging... "*shut up and calculate!*"
- Theoretical physics falls behind engineering again in the 1970s
- But seeds of the "old philosophical mindset" remain, to bring about today's *second quantum revolution*



HERBERT'S "F.L.A.S.H. PROTOCOL"

1982

Foundations of Physics, Vol. 12. No. 12, 1982

FLASH¹—A Superluminal Communicator Based Upon a New Kind of Quantum Measurement

Nick Herbert²

Received January 15, 1982

The FLASH communicator consists of an apparatus which can distinguish between plane unpolarized (PUP) and circularly unpolarized (CUP) light plus a simple EPR arrangement. FLASH exploits the peculiar properties of "measurements of the Third Kind." One purpose of this article is to focus attention on the operation of idealized laser gain tubes at the one-photon limit.

¹ FLASH: acronym for First Laser-Amplified Superluminal Hookup.



THE "NO-CLONING" THEOREM

1982







SUPERPOSITION AND QUANTUM COMPUTERS

- 1985
- Another consequence of linearity, is that quantum systems can be prepared in a superposition state: $\Psi = c_1\phi_1 + c_2\phi_2$
- This paradoxical situation was well-known since Schrödinger's "cat paradox" argument (1935)
- David Deutsch discovers in 1985 a computational problem that can only be solved with a single operation **if the superposition of different inputs is possible**
- The problem Deutsch found is very artificial and completely useless, but it is the first proof of concept that **quantum computers are different from classical ones**
- In 1994, Peter Shor took this idea to a spectacular new level with his **factorization algorithm**, potentially breaking the RSA encryption protocol.

ENTANGLEMENT AND TELEPORTATION

- When the idea of superposition is applied to *pairs* of quantum systems, we have **quantum entanglement**
- When two systems are entangled, we *know exactly* the state of the **whole**, but we *completely ignore* the state of its **parts** (a paradox!)
- The paradox of quantum entanglement was first raised in 1935 by Einstein, Podolsky, and Rosen (EPR), as a **metaphysical problem** about the **ontological reality of quantum states**
- A breakthrough was obtained by John Bell in 1964, who made *metaphysics experimentally testable* (another paradox!)
- Born out of metaphysical concerns, quantum entanglement is now used as the building block for quantum repeaters (quantum teleportation, 1993) and a powerful form of quantum cryptography (Ekert's "E91" protocol)
- Nobel Prize in Physics 2022 (Aspect, Clauser, Zeilinger)

NOVEMBER 2023: WHERE DO WE STAND?

- Quantum information science is now a well-established field, with dedicated funding programs and journals (it wasn't like that until 10 years ago)
- Quantum cryptography is now a commercially viable technology
- Quantum computers are not (yet), but **the private sector has joined the race** with huge investments
- Again, the fundamental physics community is drifting toward engineering...

IS THIS A GOOD THING?

- In the short term, **YES!** More people, more opportunities, more funds, more visibility...
- But, as the past teaches us, there is a danger of standardizing the field and dismiss new revolutionary ideas, thus marginalizing independent thinkers, seen as "misfits"
- When that happens, the flow of ideas dries up and a field dies

All science, but *especially theoretical physics*, should always have a healthy amount of **blue skies research**

