Quantum Teleportation

Teleportation is the name given by science fiction writers to the feat of making an object or person disintegrate in one place while a perfect replica appears somewhere else. How this is accomplished is usually not explained in detail, but the general idea seems to be that the original object is scanned in such a way as to extract all the information from it, then this information is transmitted to the receiving location and used to construct the replica, not necessarily from the actual material of the original, but perhaps from atoms of the same kinds, arranged in exactly the same pattern as the original. A teleportation machine would be like a fax machine, except that it would work on 3-dimensional objects as well as documents, it would produce an exact copy rather than an approximate facsimile, and it would destroy the original in the process of scanning it. A few science fiction writers consider teleporters that preserve the original, and the plot gets complicated when the original and teleported versions of the same person meet; but the more common kind of teleporter destroys the original, functioning as a super transportation device, not as a perfect replicator of souls and bodies.

In 1993 an international group of six scientists, including IBM Fellow Charles H. Bennett, confirmed the intuitions of the majority of science fiction writers by showing that perfect teleportation is indeed possible in principle, but only if the original is destroyed. In subsequent years, other scientists have demonstrated teleportation experimentally in a variety of systems, including single photons, coherent light fields, nuclear spins, and trapped ions. Teleportation promises to be quite useful as an information processing primitive, facilitating long range quantum communication (perhaps unltimately leading to a "quantum internet"), and making it much easier to build a working quantum computer.   But science fiction fans

(top, left) Richard Jozsa, William K. Wootters, Charles H. Bennett. (bottom, left) Gilles Brassard, Claude Crépeau, Asher Peres. Photo: André Berthiaume.

will be disappointed to learn that no one expects to be able to teleport people or other macroscopic objects in the foreseeable future, for a variety of engineering reasons, even though it would not violate any fundamental law to do so.

In the past, the idea of teleportation was not taken very seriously by scientists, because it was thought to violate the uncertainty principle of quantum mechanics, which forbids any measuring or scanning process from extracting all the information in an atom or other object. According to the uncertainty principle, the more accurately an object is scanned, the more it is disturbed by the scanning process, until one reaches a point where the object's original state has been completely disrupted, still without having extracted enough information to make a perfect replica. This sounds like a solid argument against teleportation: if one cannot extract enough information from an object to make a perfect copy, it would seem that a perfect copy cannot be made. But the six scientists found a way to make an end run around this logic, using a celebrated and paradoxical feature of quantum mechanics known as the Einstein-Podolsky-Rosen effect. In brief, they found a way to scan out part of the information from an object **A**, which one wishes to teleport, while causing the remaining, unscanned, part of the information to pass, via the Einstein-Podolsky-Rosen effect, into another object **C** which has never been in contact with **A**. Later, by applying to **C** a treatment depending on the scanned-out information, it is possible to maneuver **C** into exactly

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Teleported Replica of Object A
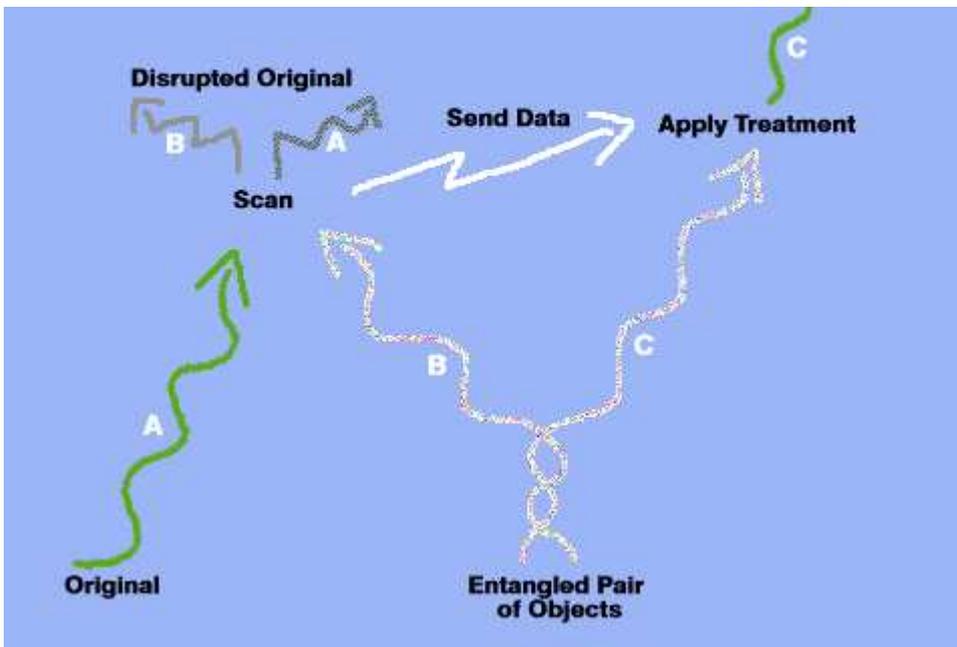
the same state as **A** was in before it was scanned. **A** itself is no longer in that state, having been thoroughly disrupted by the scanning, so what has been achieved is teleportation, not replication.

As the figure to the left suggests, the unscanned part of the information is conveyed from **A** to **C** by an intermediary object **B**, which interacts first with **C** and then with **A**. What? Can it really be correct to say "first with **C** and then with **A**"? Surely, in order to convey something from **A** to **C**, the delivery vehicle must visit **A** before **C**, not the other way around. But there is a subtle, unscannable kind of information that, unlike any material cargo, and even unlike ordinary information, can indeed be delivered in such a backward fashion. This subtle kind of information, also called "Einstein-Podolsky-Rosen (EPR) correlation" or "entanglement", has been at least partly understood since the 1930s when it was discussed in a famous paper by Albert Einstein, Boris Podolsky, and Nathan Rosen. In the 1960s John Bell showed that a pair of entangled particles, which were once in contact but later move too far apart to interact directly, can exhibit individually random behavior that is too strongly correlated to be explained by classical statistics. Experiments on photons and other particles have repeatedly confirmed these correlations, thereby providing strong evidence for the validity of quantum mechanics, which neatly explains them. Another well-known fact about EPR correlations is that they cannot by themselves deliver a meaningful and controllable message. It was thought that their only usefulness was in proving the validity of quantum mechanics. But now it is known that, through the phenomenon of quantum teleportation, they can deliver exactly that part of the information in an object which is too delicate to be scanned out and delivered by conventional methods.
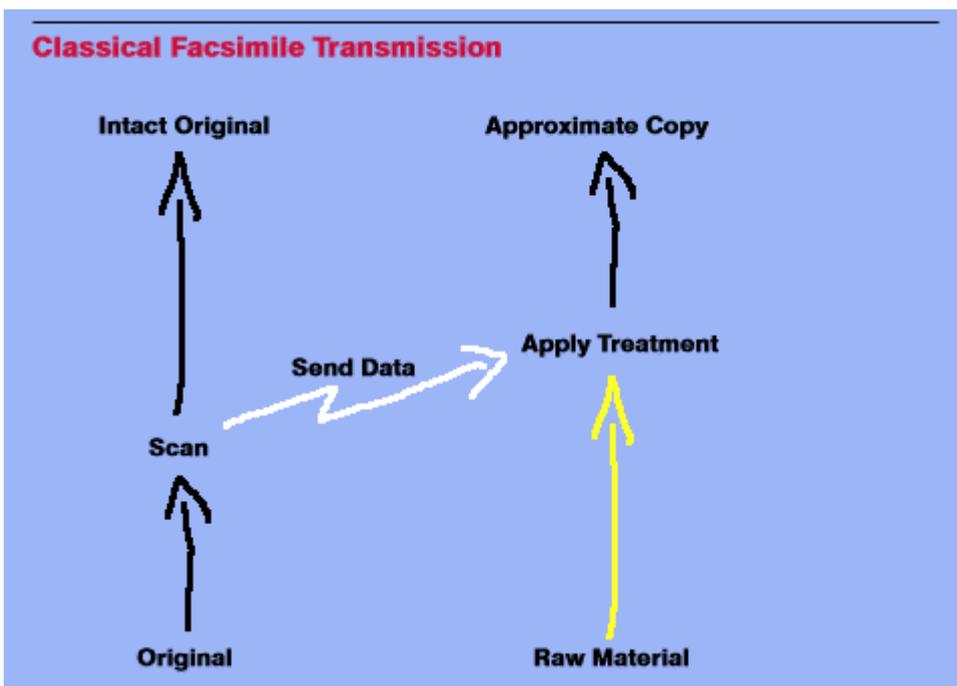
This figure compares conventional facsimile transmission with quantum teleportation (see above). In conventional facsimile transmission the original is scanned, extracting partial information about it, but remains more or less intact after the scanning process. The scanned information is sent to the receiving station, where it is imprinted on some raw material (eg paper) to produce an approximate copy of the original. By contrast, in quantum teleportation, two objects **B** and **C** are first brought into contact and then separated. Object **B** is taken to the sending station, while object **C** is taken to the receiving station. At the sending station object **B** is scanned together with the original object **A**

which one wishes to teleport, yielding some information and totally disrupting the state of **A** and **B**. The scanned information is sent to the receiving station, where it is used to select one of several treatments to be applied to object **C**, thereby putting **C** into an exact replica of the former state of **A**.

To learn more about quantum teleportation, see the following articles and links:

- C.H. Bennett, G. Brassard, C. Crepeau, R. Jozsa, A. Peres, and W. Wootters, "Teleporting an Unknown Quantum State via Dual Classical and EPR Channels", *Phys. Rev. Lett.* vol. **70**, pp 1895-1899 (1993)
  (the original 6-author research article).
- Tony Sudbury, "Instant Teleportation", *Nature* .**362**, 586-587 (1993) (a semipopular account).
- Ivars Peterson, *Science News*, April 10, 1993, p. 229. (another semipopular account).
- Samuel Braunstein, A fun talk on teleportation
- Q&A on Teleportation by BBC News Online science editor David Whitehouse
- Wikipedia article
- Experimental Articles
  - D. Bouwmeester et al. *Nature* **390**, 575-9 (1997) (photons)
  - D. Boschi et al. *Phys. Rev. Lett.* **80**, 1121-1125 (1998) (photons)
  - A. Furusawa et al. *Science* **282**, 706-709 (1998) (coherent light field)
  - M.A. Nielsen et al. *Nature* **396**, 52-55 (1998) (nuclear magnetic resonance)
  - I. Marcikic et al. *Nature* **421**, 509-513 (2003) (photons, long distance)
  - M. Riebe et al. *Nature* **429**, 734-737 (2004) (trapped calcium ions)
  - M.D. Barret et al. *Nature* **429**, 737-739 (2004) (trapped beryllium ions)
  - R. Ursin et al. *Nature* **430**, 849 (2004) (photons, long distance)
- Theoretical Articles
  - G. Brassard *Physica D* **120** 43-47 (1998) Teleportation as a quantum computation
  - Gottesman and I Chuang *Nature* 402 390-393 (1999), teleportation as a computational primitive
  - X. Zhou, D. Leung, I. Chuang Quantum gate constructions from teleportation-like primiitve
  - L. Vaidman quant-ph/0111124 Using teleportation to measure nonlocal variables
- For recent experimental and theoretical articles, do a title search on "teleportation" in the ArXiv E-print Archive

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