A Primer on Quantum Computing

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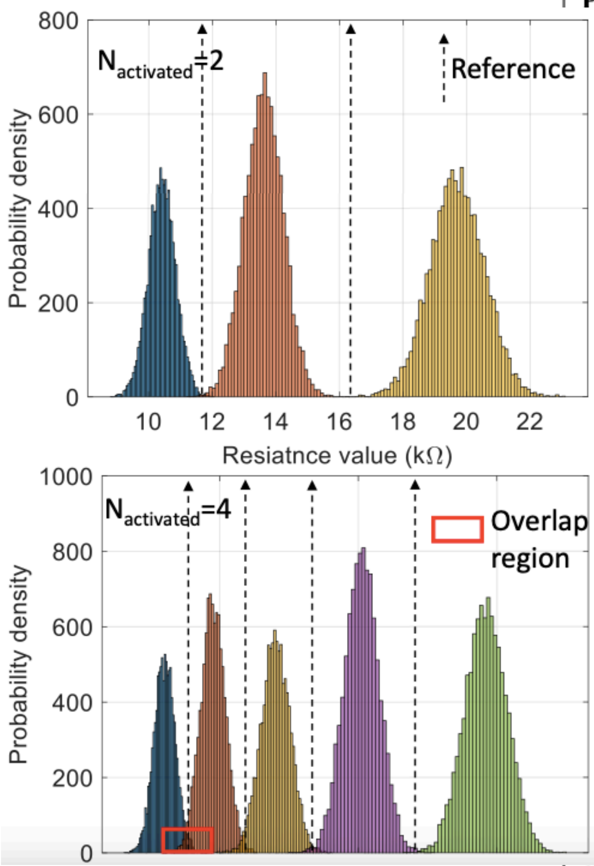
Recap: Key reliability metrics

- Retention time: Ability to store data without corruption
- Endurance: Number of read/write cycles before failure
- Error rate: Frequency of error during read/write operation
- Power cycling: Stability under repeated on/off cycles
- Temperature stability: Resilience under varying thermal condition

Recap: CIM reliability



Reliability issue/*description*	Effect on logic gates	Statistical behavior	Implementation in proposed framework
Program variability (cycle-to-cycle C2C) and device-to-device (D2D)) 20,21]: *t each programming (even with ame applied voltage/time), the esultant resistance state will be lightly) different*	Variations in device resistance lead to voltage variations in resistive voltage divider	The read-out resistance state after programming follows a statistical distribution, where the programming sets the distribution mean. Mean is statistically distributed, following either a C2C distribution (1 device): or a D2D distribution (multiple devices)	In MC-runs: draw devices parameters (filament length etc.) out of statistical distributions. Evaluate device resistance after switching with JART-model, fit to distribution and end resistance states.
Vrite Failures [23,24]: *t any fixed programming conditions, ot all devices will switch (both for ET and RESET)*	Switching of memristive devices is not guaranteed for a certain (V,t) pulse. Devices have no fixed switching threshold.	Switching follows a stochastic process.	Obtain mean fitted switching probability function using MC-analysis with varied device parameters.
Read Noise [25] (also known as RTN or program instability): *hort-time current fluctuations umps) during device read-out over me, caused by resistance changes. luctuations increase with resistance.*	Variations in device resistance lead to voltage variations in resistive voltage divider (similar as Program variability)	At each device read, actual resistance values are varying over a statistical distribution. Mean is determined by programming. Distribution width increases with resistance.	Modeled as random walk with changes in oxygen vacancy concentration (only applied for Scouting)
Retention/State Drift [26] *ong-time changes of device esistance , effect is typically emperature accelerated*	Device resistance drifts over time and may lead to increased number of failures	Effect can be deterministically described on level of distributions as shift and tilt of read resistance distribution	-
Endurance *Device resistance window typically ecreases with increasing number of rogram cycles, at the end devices no onger switch (stuck at 0 or 1)*	Change of device resistance may cause voltage divider and output stage errors, while stuck-at devices may cause write failures	Effect is also deterministic on distribution level: drift of C2C distributions and eventually occurrence of write failures	-
Sudden bit flips *Radiation-caused perturbation of CMOS based logic gates.*	Logic error	Potentially Erratic	Not present in ReRAM devices (but may affect transistors)

Recap: Techniques to improve reliability

- Error correction codes (ECC)
  - Single error correction, double error detection codes (SECDED)
- Redundancy
  - Triple modular redundancy (TMR) or higher
- Wear levelling
  - A standard techniques to prevent premature wear in NVMs/Flash
- Circuit level techniques
  - Write verification for Flash and RRAM
  - Adaptive compression etc.

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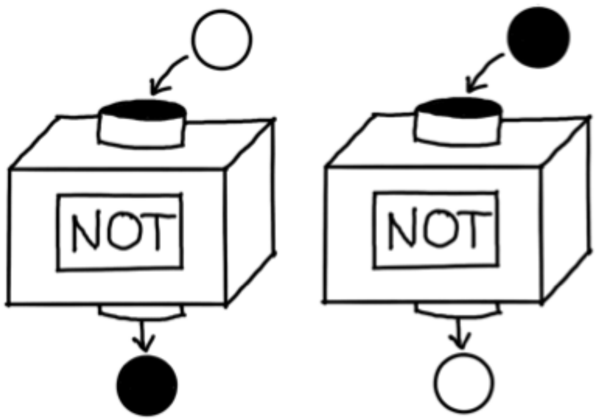
> "No, you're not going to be able to understand it.... You see, my physics students don't understand it either. That is because I don't understand it. Nobody does. ... The theory of quantum electrodynamics describes Nature as absurd from the point of view of common sense. And it agrees fully with an experiment. So I hope that you can accept Nature as She is – absurd"
>
> -- Richard Feynman

Quantum Computing



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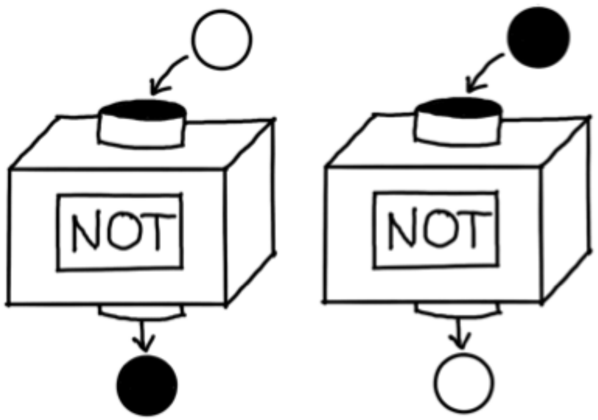

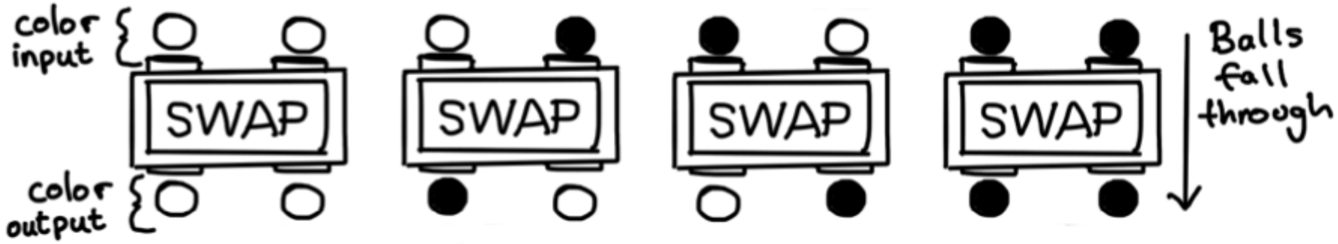

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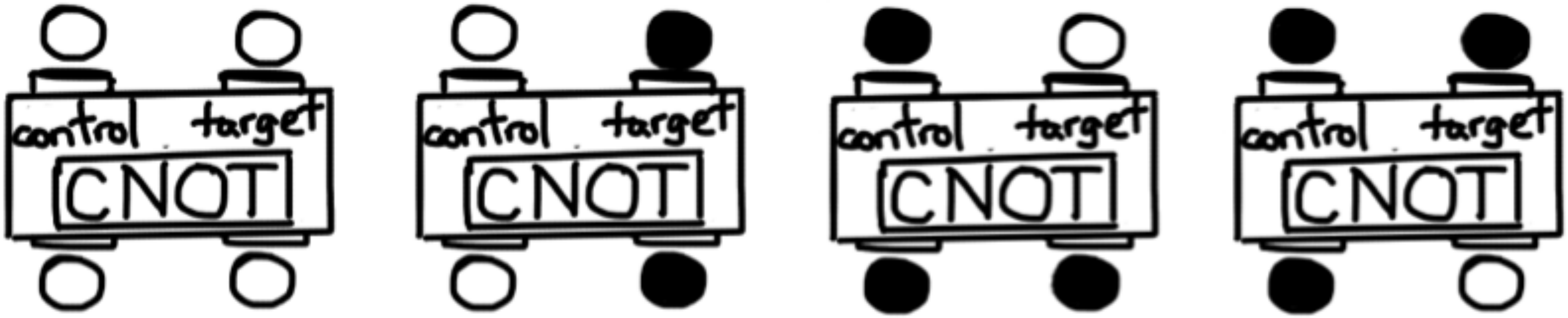

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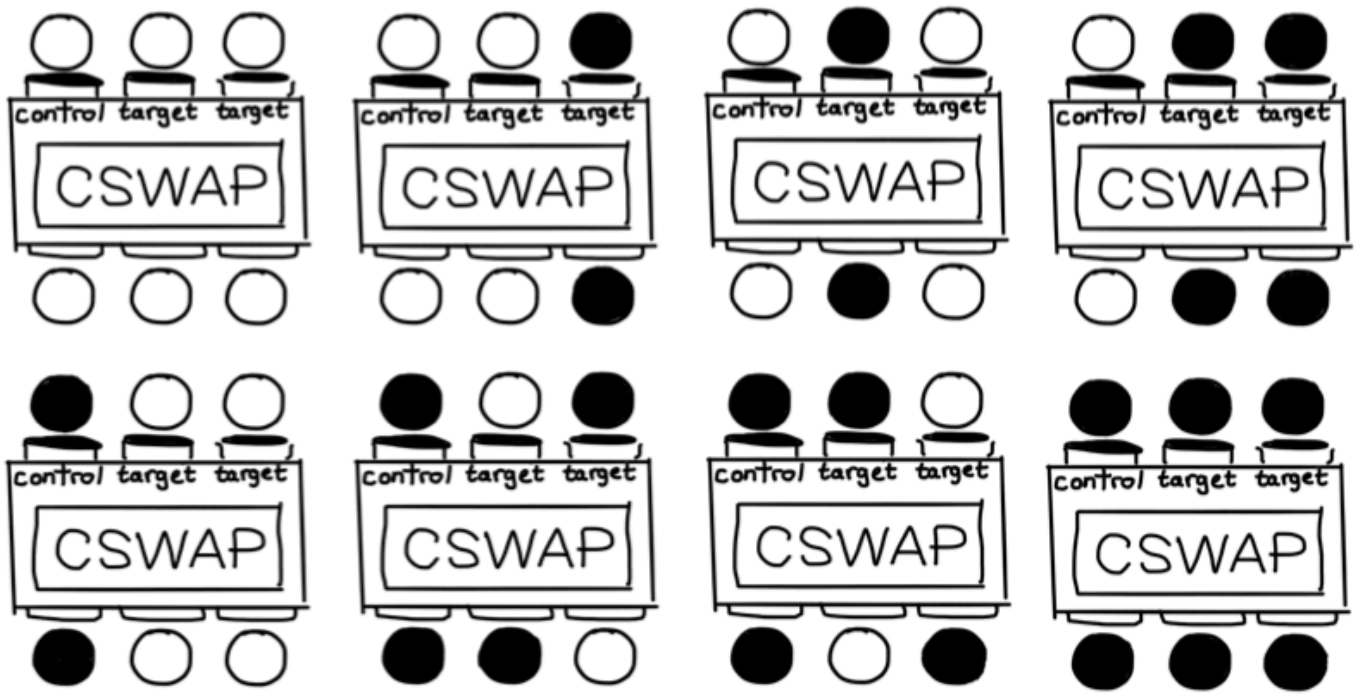

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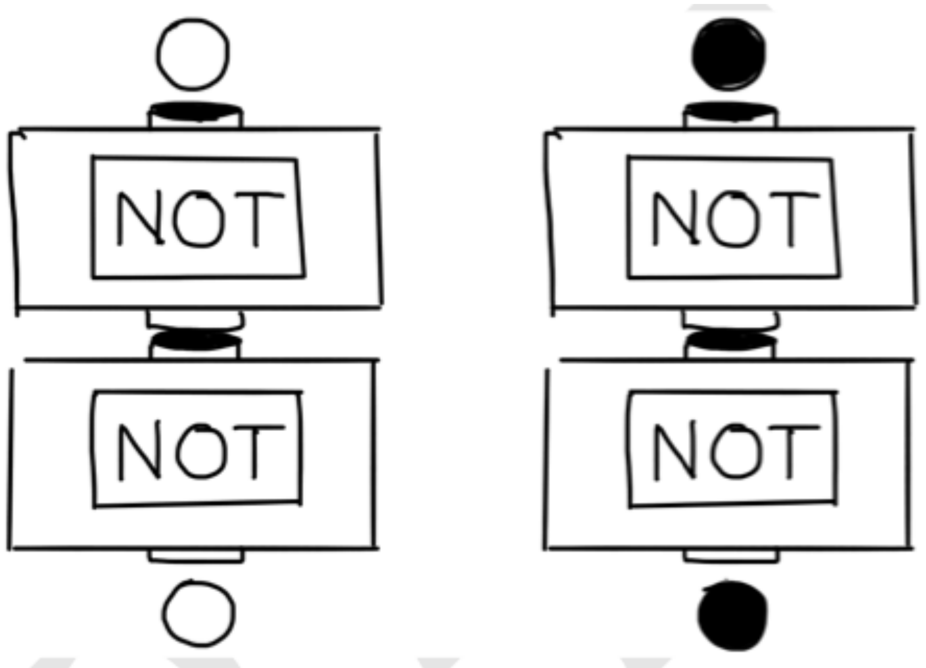

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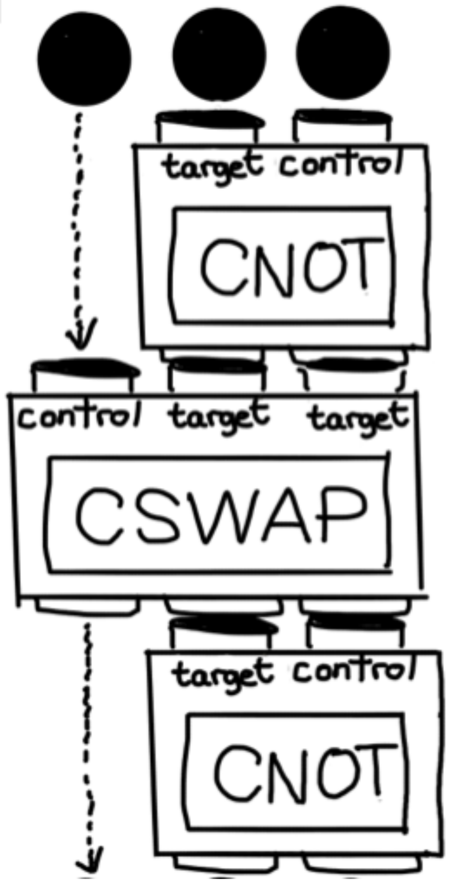

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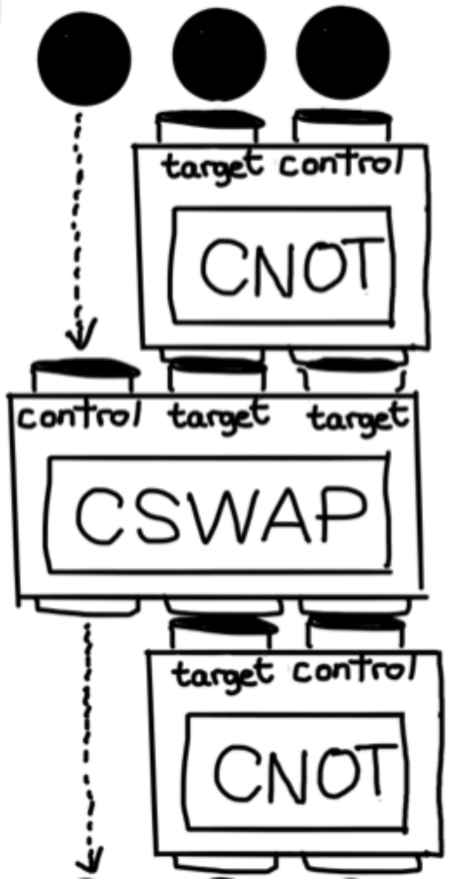

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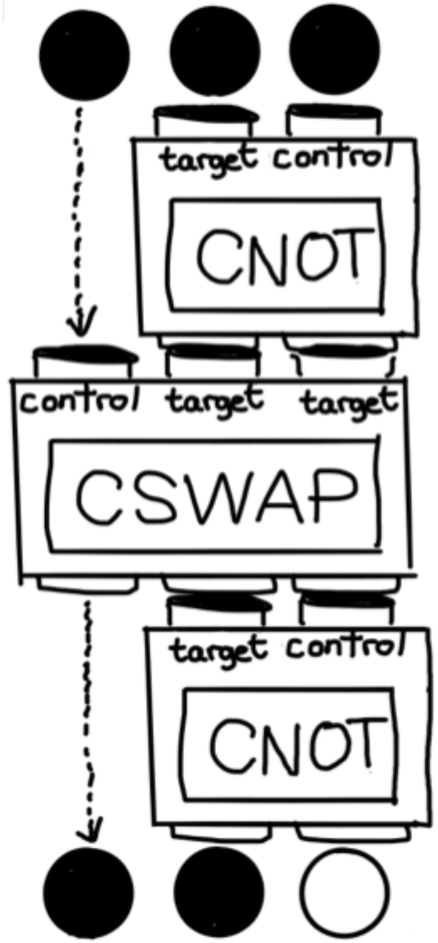

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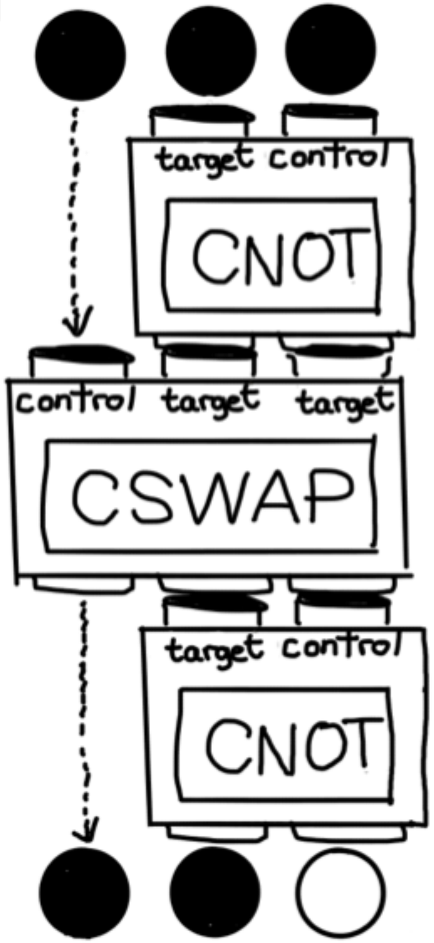
- This is referred to as a control-control-Not (CCNOT) gate



Terry Rudolph, Q is for Quantum, 2017

Quantum Computing

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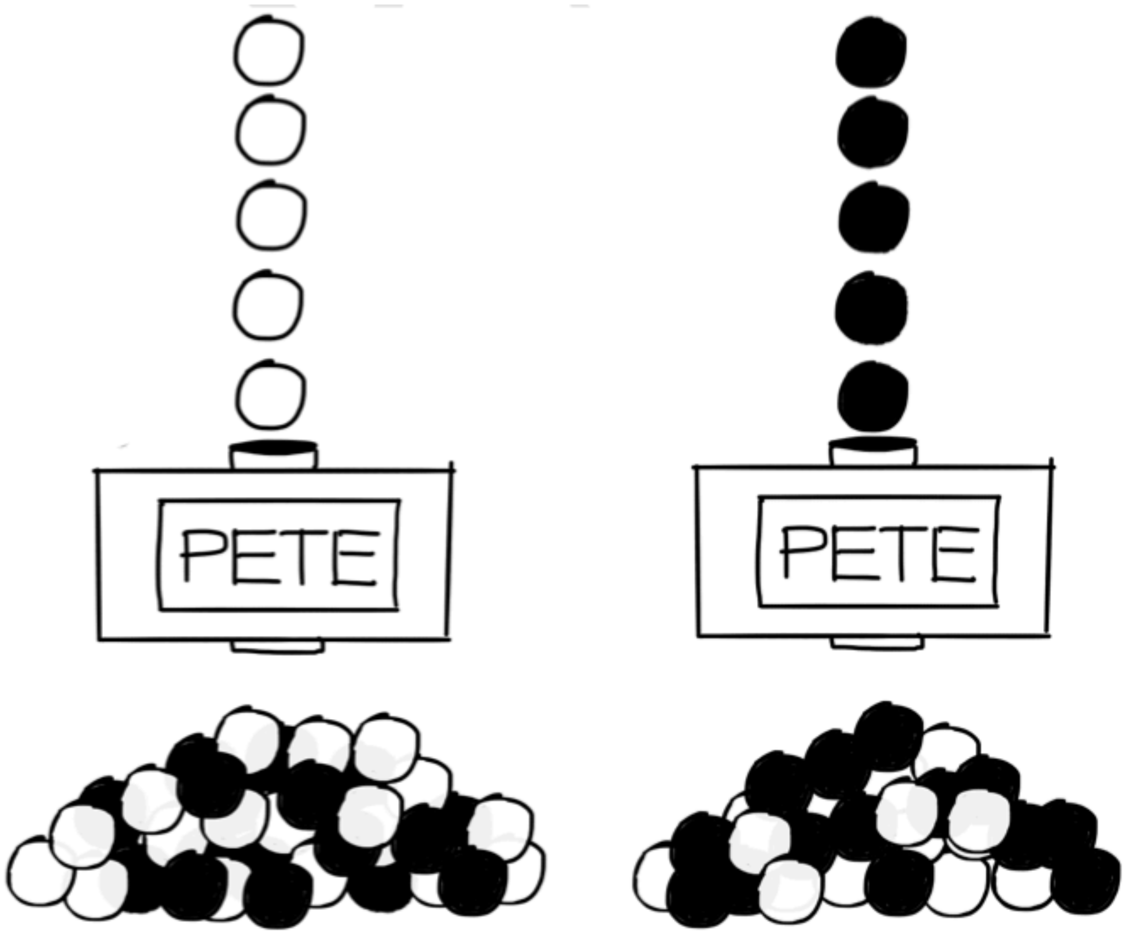
- Lets look at something more interesting now



Quantum Computing

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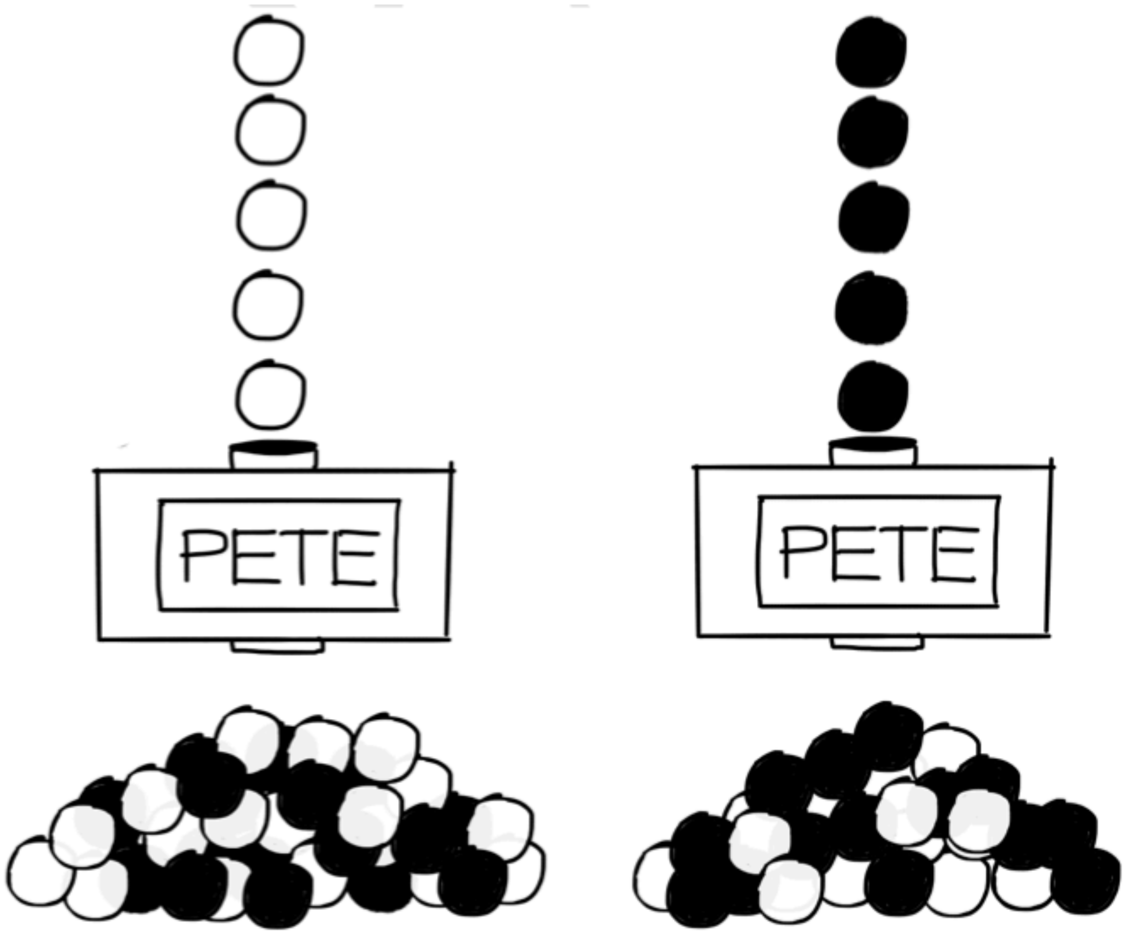
- How is the PETE box different than the boxes we have seen so far?



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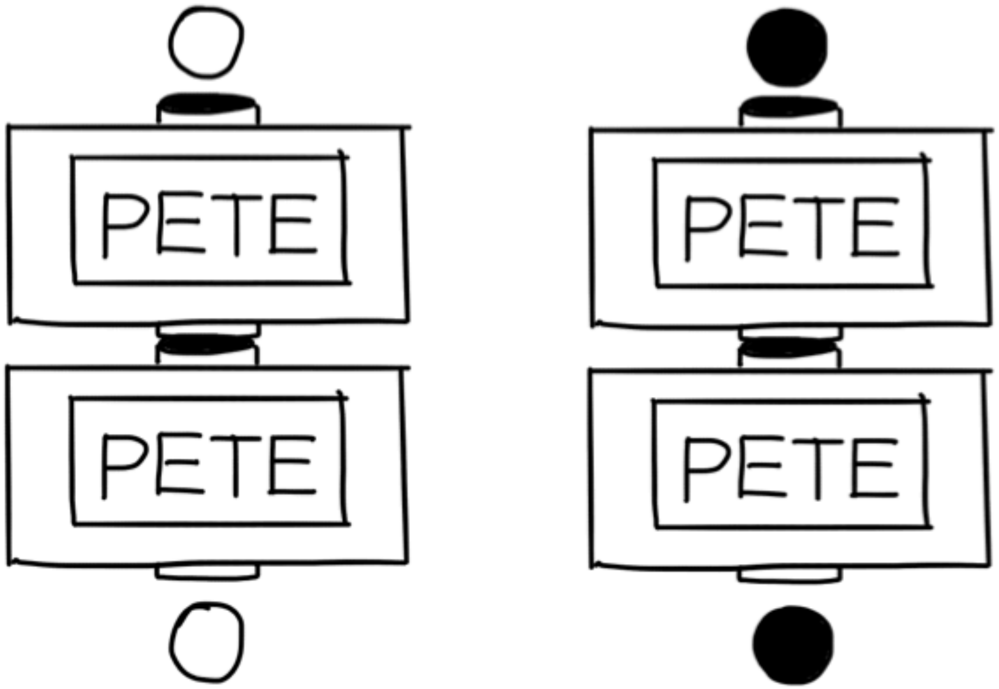
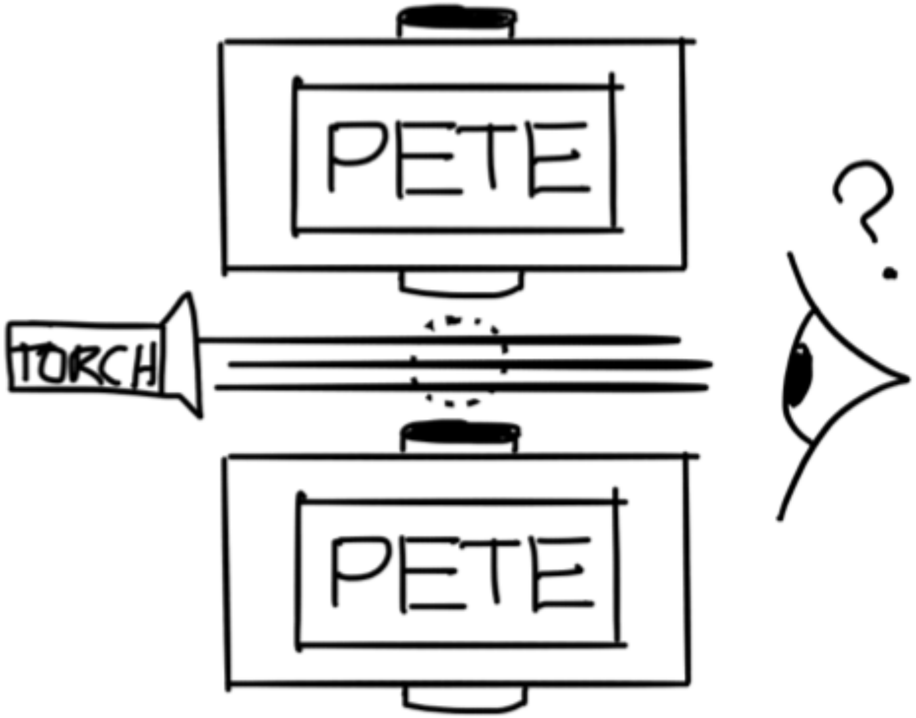


Quantum Measurment



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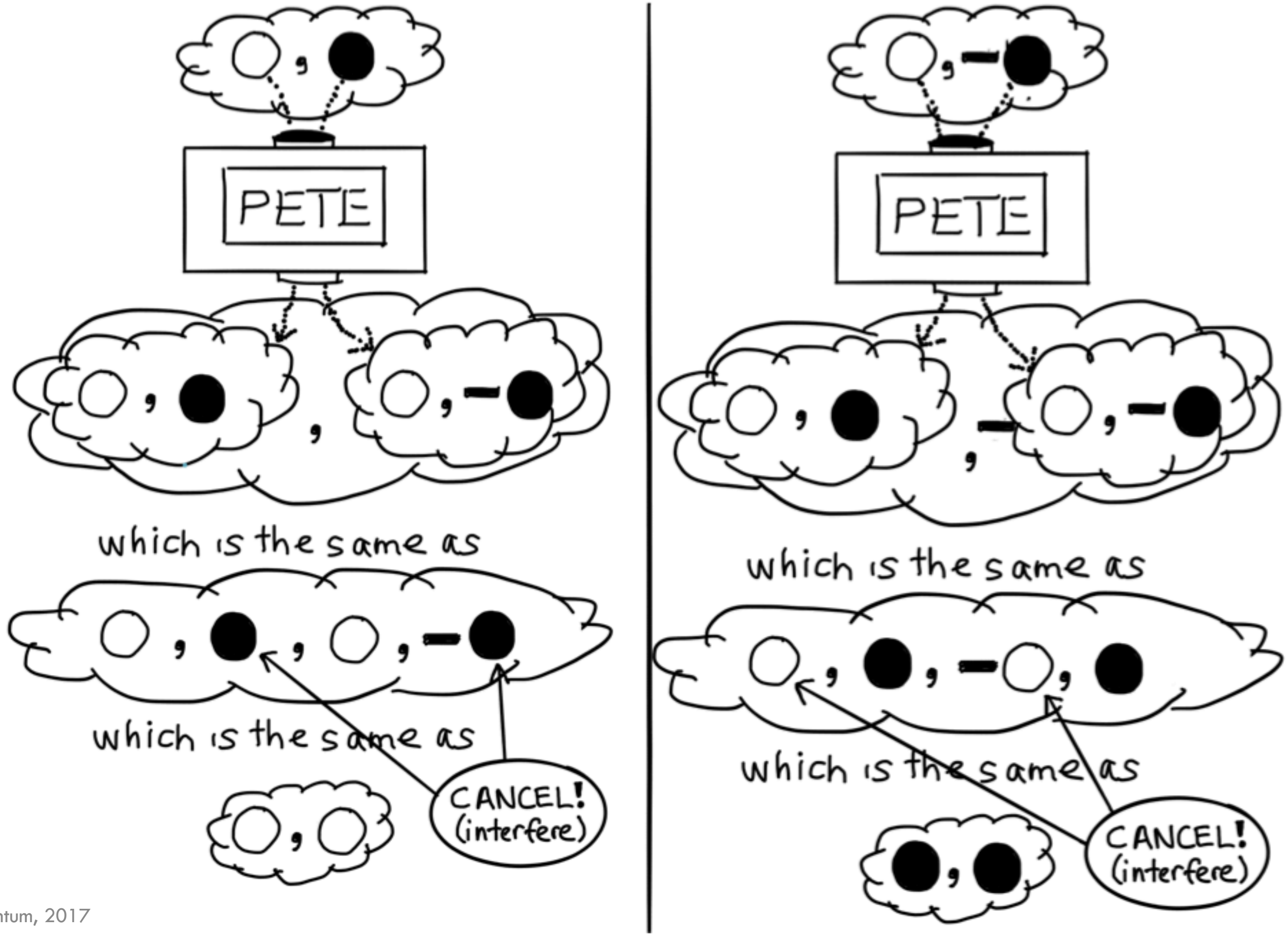
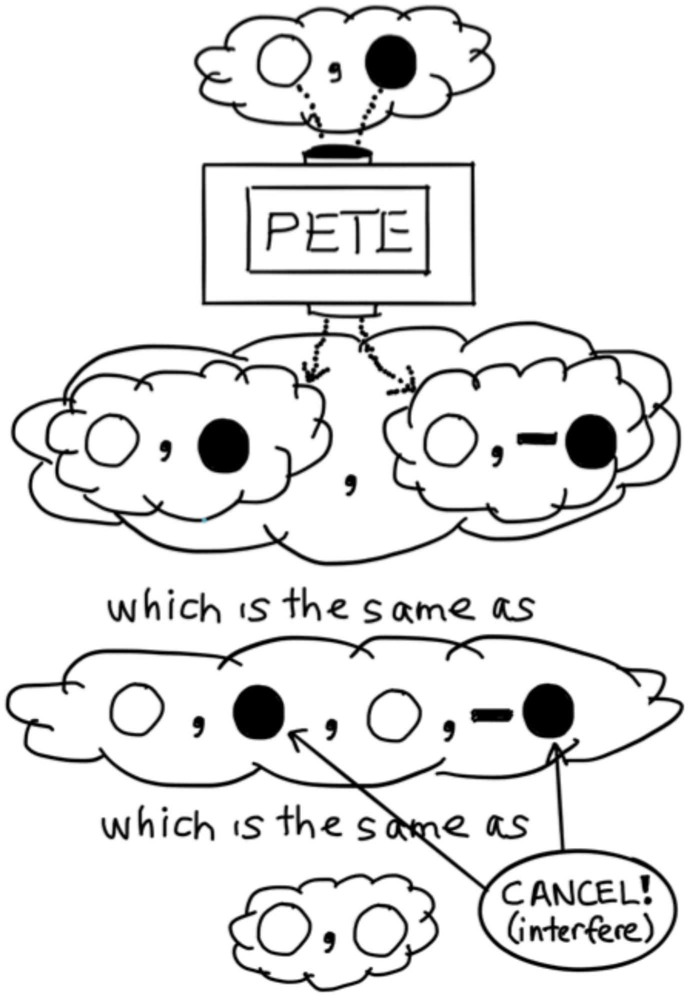
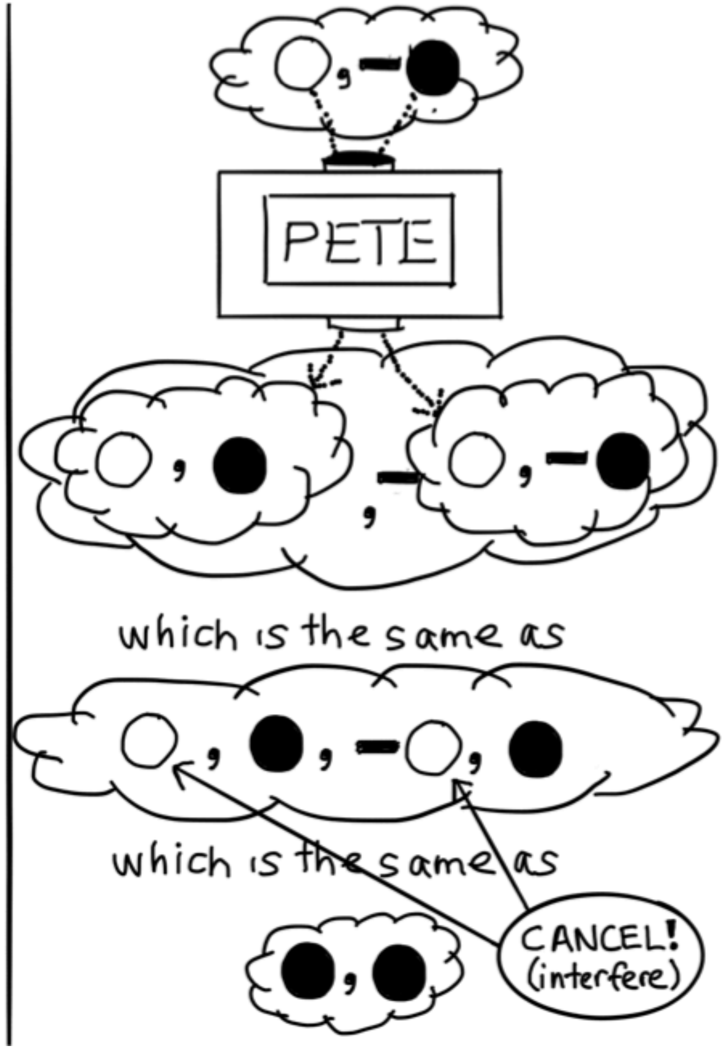


Superposition





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- Two different physical properties (black, white) of a system can be manipulated with extremely simple physics rules (NOT, CNOT, SWAP etc)

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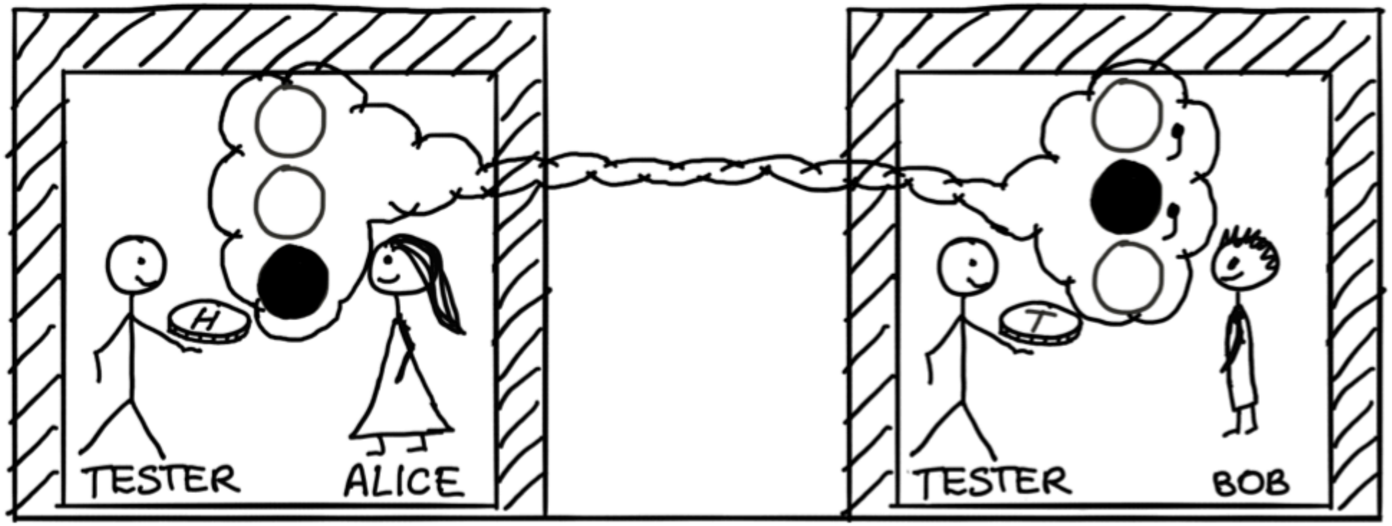
Summary so far..

- Two different physical properties (black, white) of a system can be manipulated with extremely simple physics rules (NOT, CNOT, SWAP etc)
- There exists some experiments that exhibit fundamental randomness (PETE)
- The different physical states can sometimes be in superposition (the cloud state)
- The cloud state grows rapidly as we add more systems into it
- These fundamentally new concepts open up vast new territories of previously unthinkable problems to take on.

Entaglement



Thank you!

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