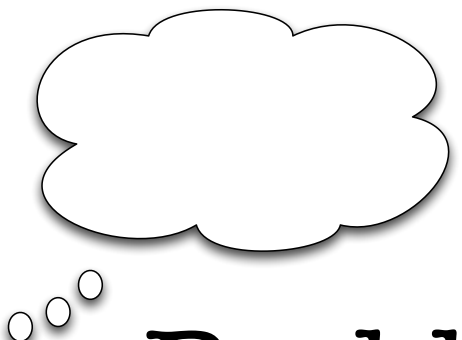
EE5340

INTRODUCTION TO QUANTUM COMPUTING AND PHYSICAL BASICS OF COMPUTING

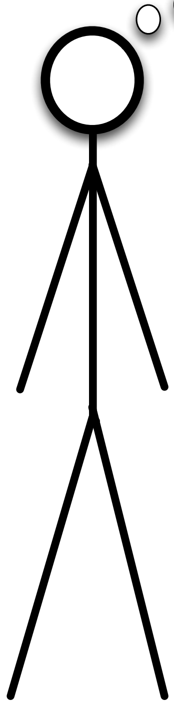
Overview

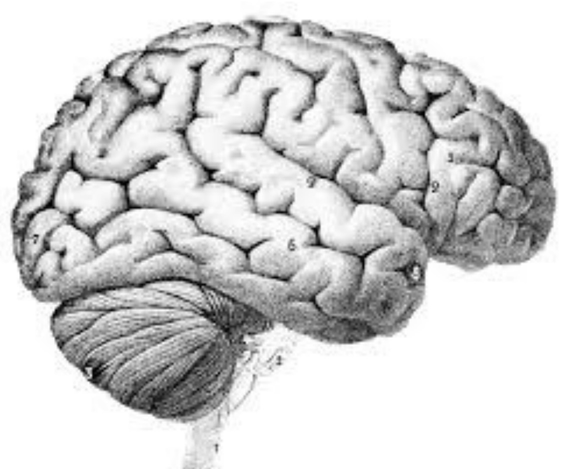
Ulya Karpuzcu

Solving A Problem Using a Computer …

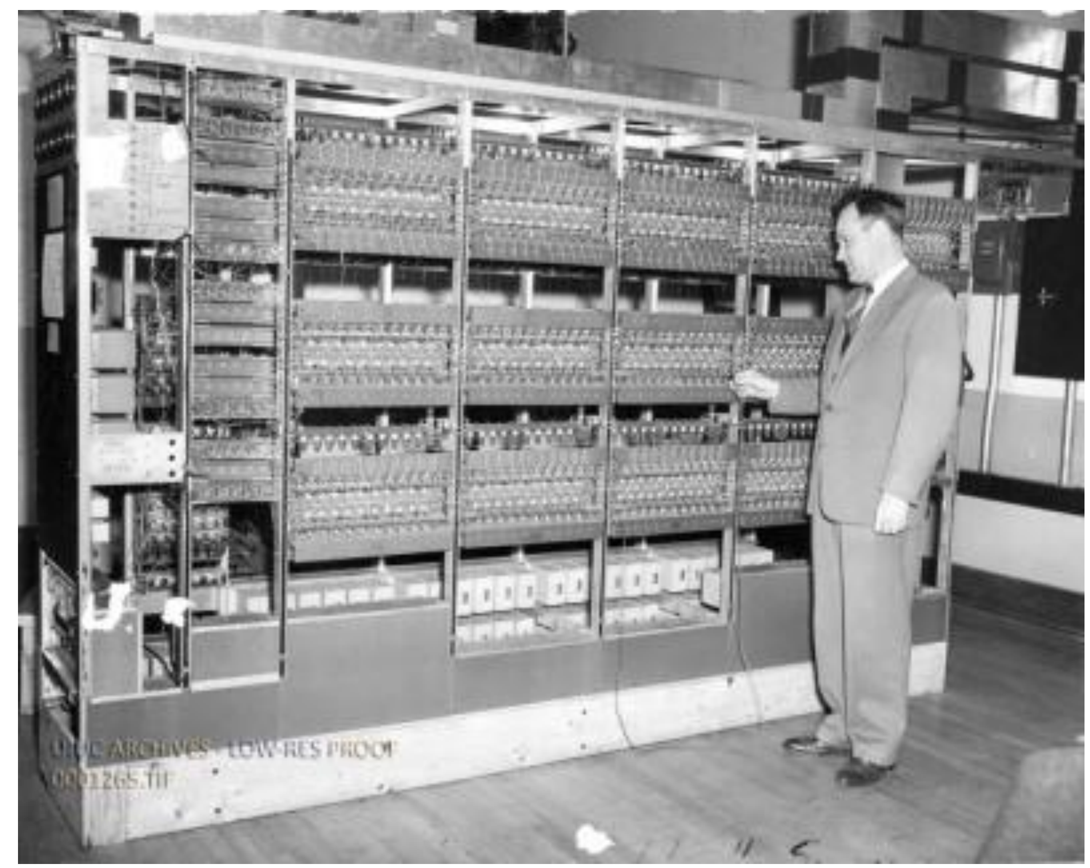


Problem





vs.



http://archives.library.illinois.edu

Quantum vs. Classical Computing

- Fundamentally different computing paradigm
- Can potentially solve classically “intractable” problems
  - Complements classical computing
  - Examples
    - Molecular dynamics simulation
    - …
    - Encryption (factoring large numbers)

What is Quantum Computing?

- Study of information processing tasks performed using quantum mechanical systems
- Quantum Mechanics (QM):
  - Mathematical set of rules for the construction of physical theories

- Classical computers cannot efficiently simulate QM
- Build computers based on QM principles? [Feynman, 1982]
- What other problems can QCs solve faster than classical computers?
  - Unknown
  - Q-algorithm design is challenging
    - QM is “unintuitive”
    - The algorithm should be “better” than any classical counterpart

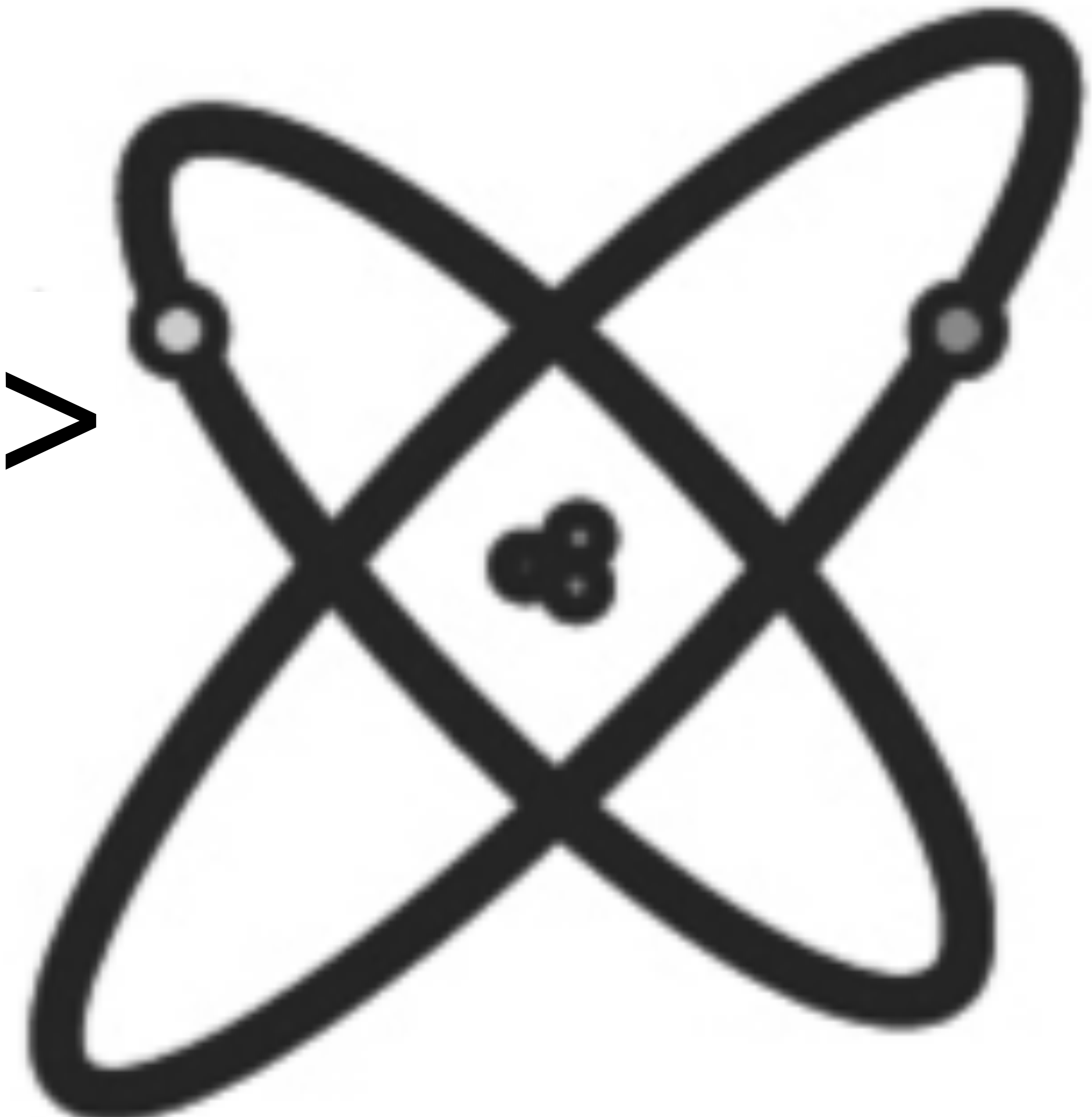
Quantum Bits: qbits

- Mathematical "objects"
- Have "state":
  - Two observable basis states: |0> and |1>
    - Forming "basis" states
    - |>: Dirac notation, standard notation for states in QM
  - vs. 2-state (0 or 1) classical bits
    - qbits can be in any state form by linear combinations (superpositions) of basis states

$$|\psi >= a|0 > +b|1 >= a \begin{bmatrix} 1 \\ 0 \end{bmatrix} + b \begin{bmatrix} 0 \\ 1 \end{bmatrix} = \begin{bmatrix} a \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ b \end{bmatrix} = \begin{bmatrix} a \\ b \end{bmatrix}$$

- State of a single qubit: |Ψ> = a|0> + b|1>
  - $|a|^2$ Probability that the qbit will be observed in the state |0>
  - $|b|^2$ Probability that the qbit will be observed in the state |1>
- Without direct observation, the state of a single qbit spans $[a,b]^T$

Physical Realization Example

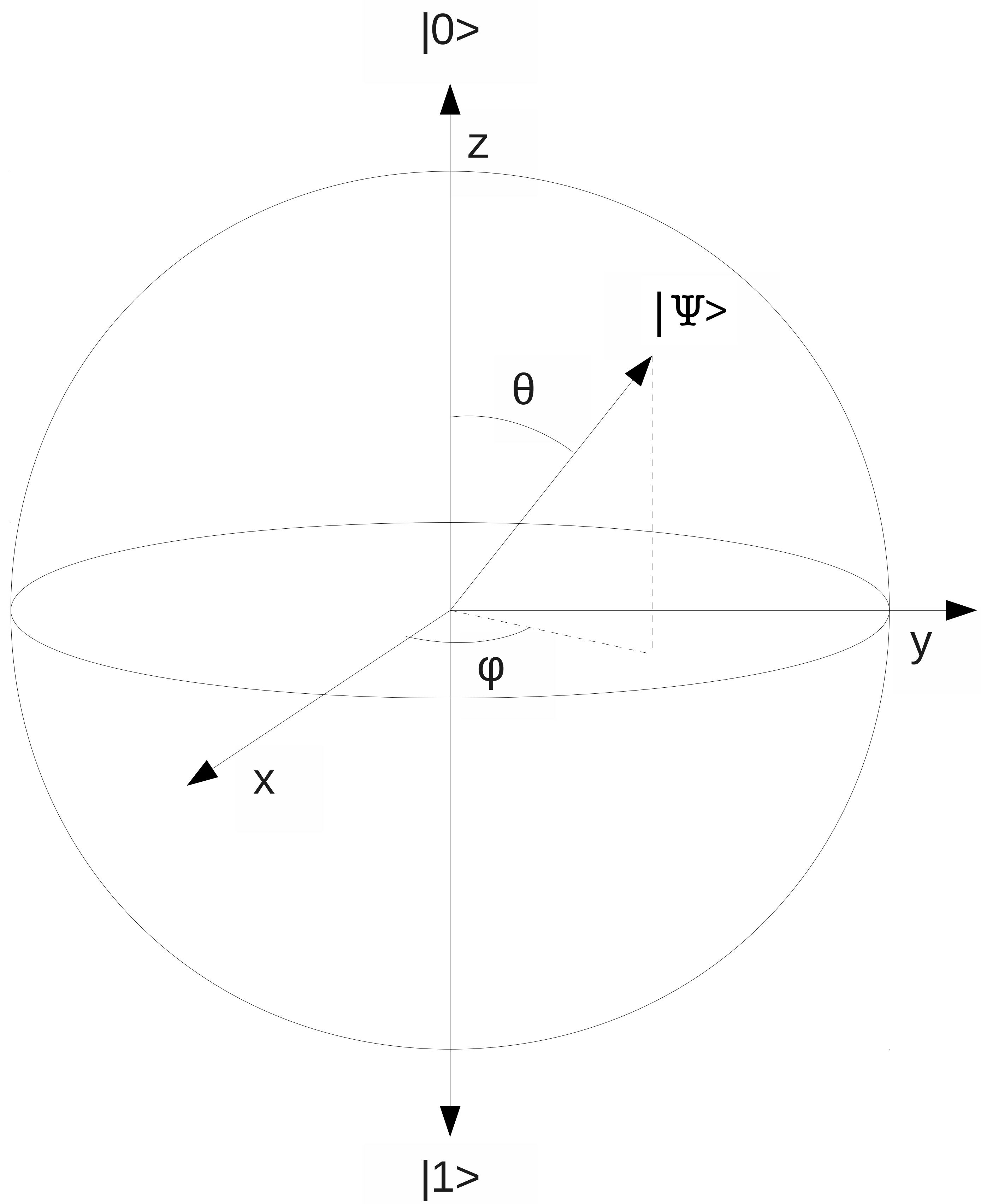


|0>

|1>

$$|+> = \frac{1}{\sqrt{2}}|0> + \frac{1}{\sqrt{2}}|1>$$

Bloch Sphere Representation



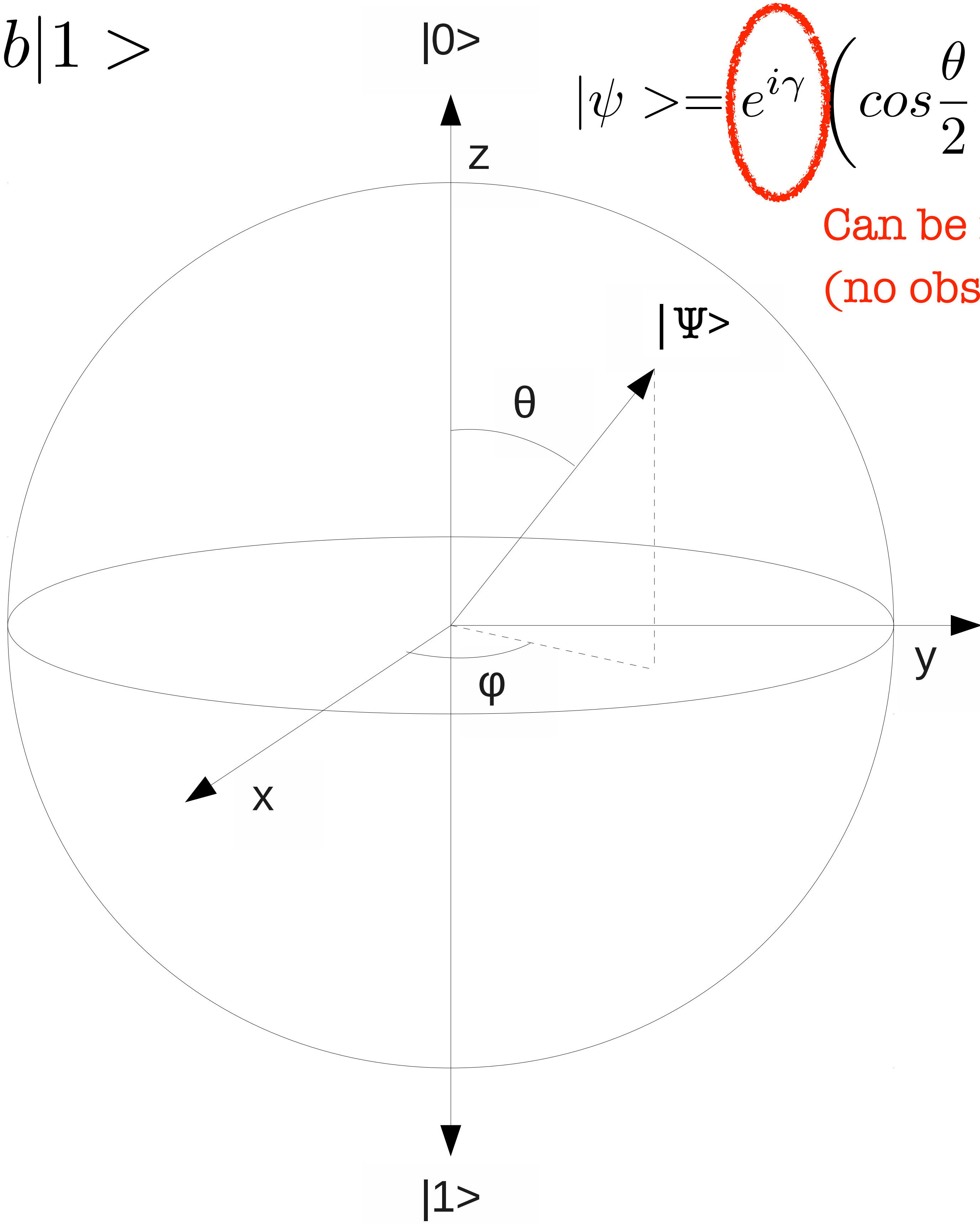
Bloch Sphere Representation

$$|\psi>= a|0> + b|1>$$

$$|a|^2 + |b|^2 = 1$$

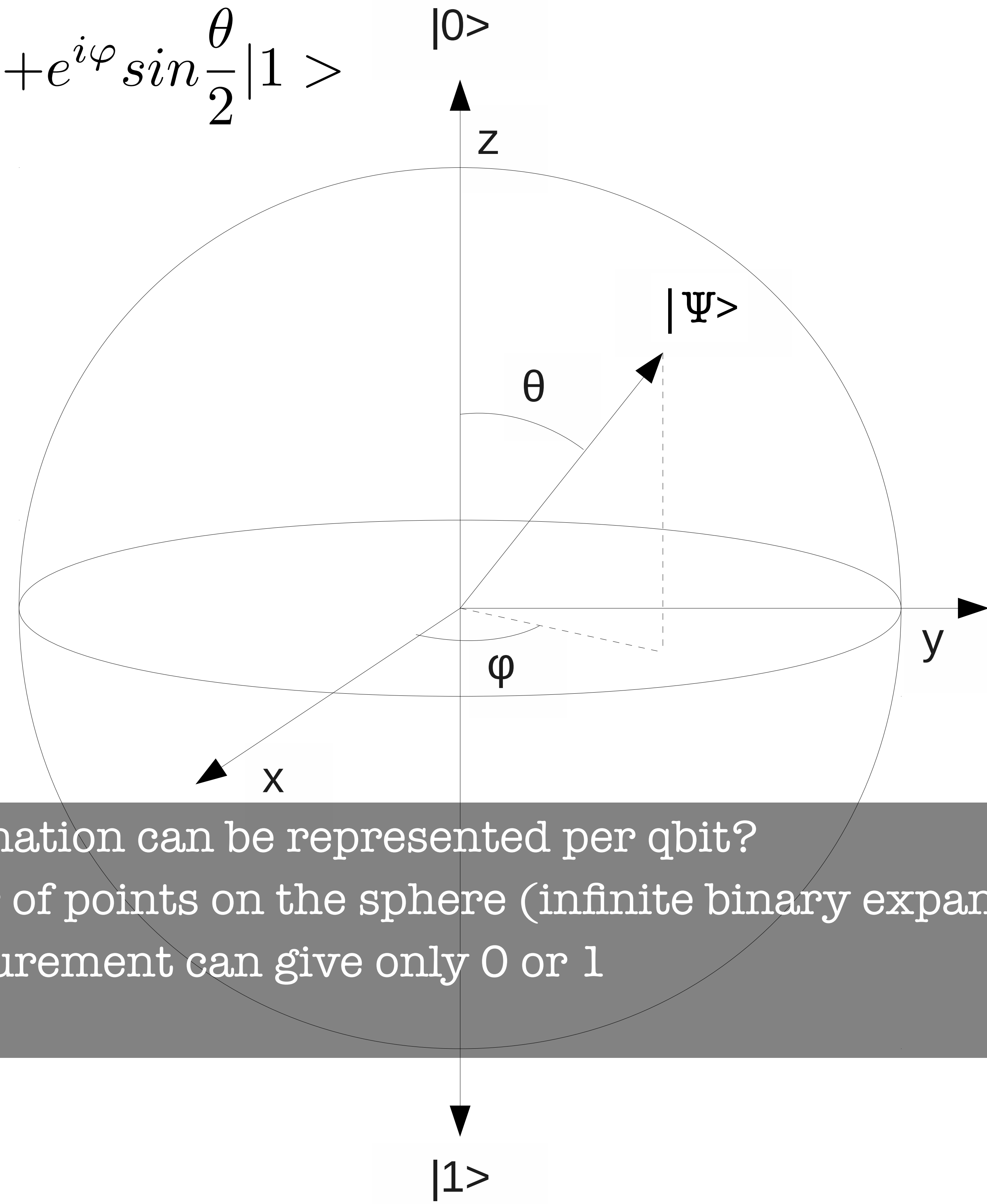
$$|\psi>= e^{i\gamma}\left(cos\frac{\theta}{2}|0> + e^{i\varphi}sin\frac{\theta}{2}|1>\right)$$

Can be ignored
(no observable effects)



Bloch Sphere Representation

$$|\psi>= cos\frac{\theta}{2}|0> +e^{i\varphi}sin\frac{\theta}{2}|1>$$

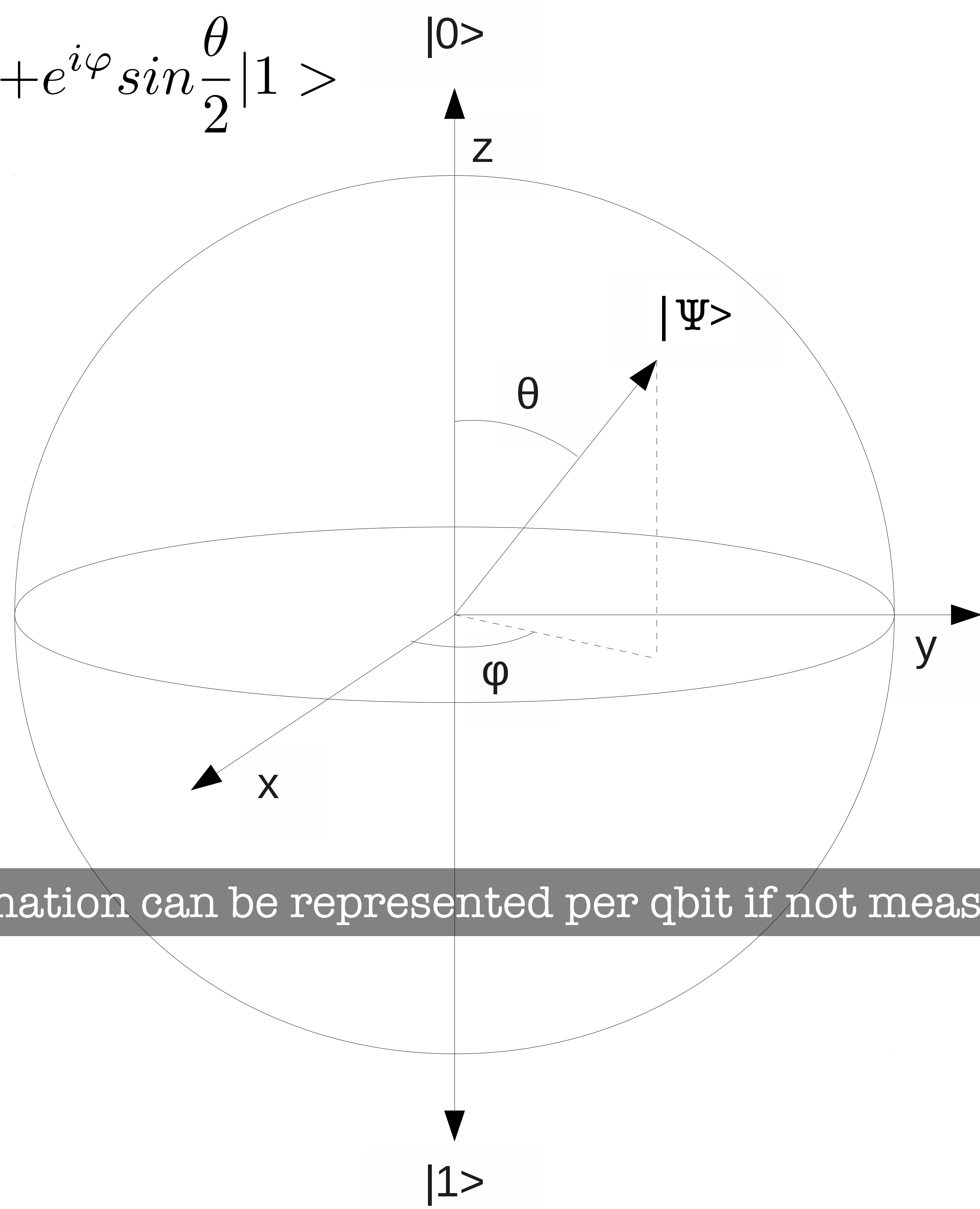


How much information can be represented per qbit?

- Infinite number of points on the sphere (infinite binary expansion for angles)?
- However, measurement can give only 0 or 1

Bloch Sphere Representation

$$|\psi >= cos\frac{\theta}{2}|0> +e^{i\varphi}sin\frac{\theta}{2}|1>$$

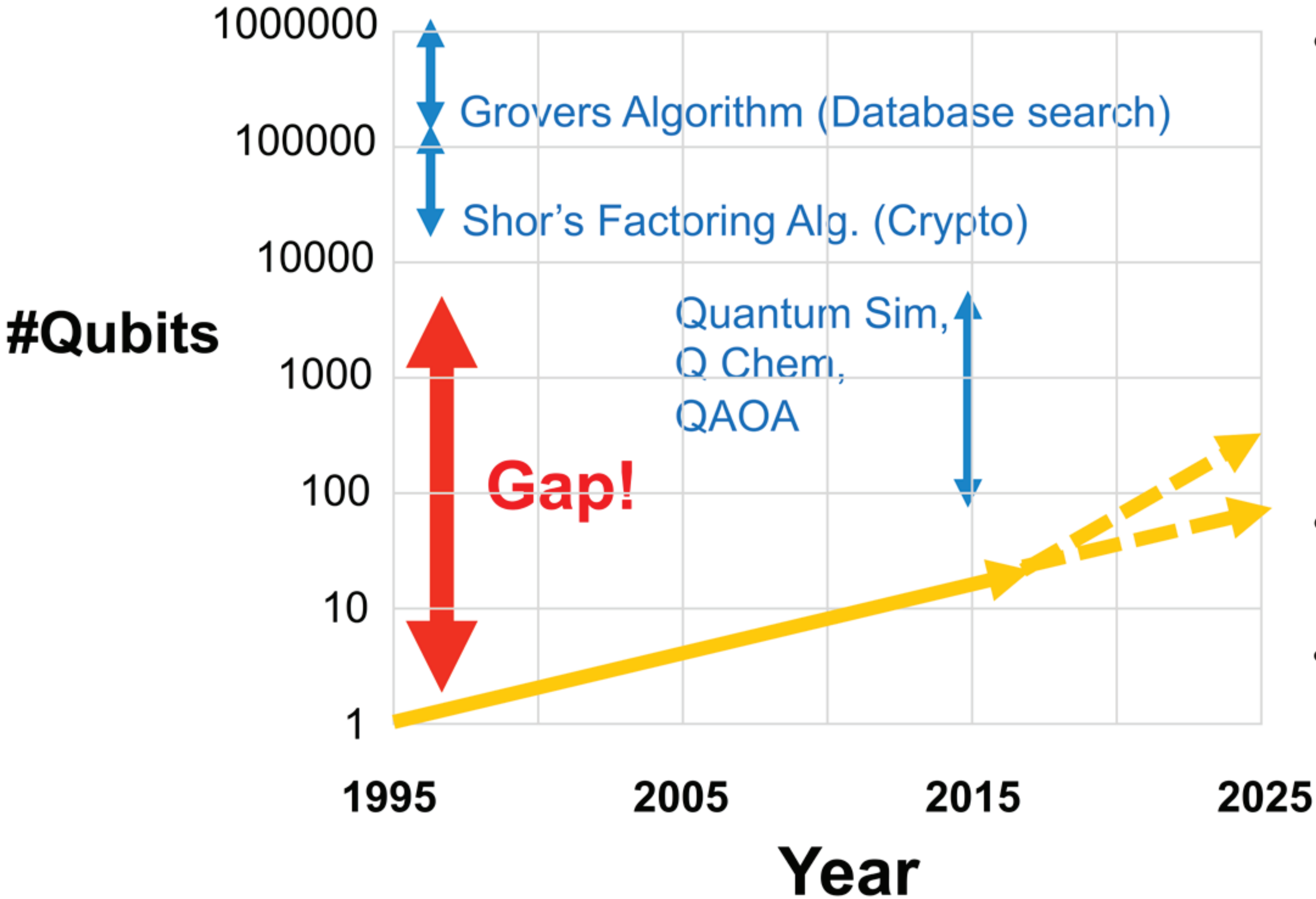


How much information can be represented per qbit if not measured?

Current Status

- Small and intermediate scale quantum computers prototyped
- NISQ: Noisy Intermediate Scale Quantum Machines [Preskill]
  - 20-1000 qubits
  - Insufficient resources for noise tolerance (error correction)

Current State: Algorithms to Machines Gap



Open Questions

- What are quantum systems good at?
  - Quantum algorithm development
- How to build quantum systems?
  - Qbit technologies

Coordinates

- https://canvas.umn.edu/courses/461083
- Instructor
  - Ulya Karpuzcu: ukarpuzc @ umn
  - Office hours: TBA
- Grading Mechanics
  - Assignments & Machine Problems 50%
  - Quizzes 50%
- References
  - Lecture notes & reading material on course website

Quiz

1. Academic background (major/minor) & area of research (if applicable)
2. Have you taken any physics classes?
3. Have you taken any hardware design/computer architecture classes?
4. Have you taken any theory of computing/algorithms classes?
5. Describe briefly:
    1. Von Neumann Machine
    2. Turing Machine
    3. Quantum Mechanics
    4. Entropy
    5. Transistor
    6. Schrödinger's Cat
    7. Adiabatic

Bibliography

- Next Steps in Quantum Computing: Computer Science's Role, Martonosi et al., CCF Report, November 2018
- Nielsen & Chuang, Chapter I

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