VENUS: A Geometrical Representation for Quantum State Visualization









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Agenda

- Background
- Motivation
- Existing work
- VENUS
- Evaluation
- Future work
- Conclusion

Background

Quantum computing

During computation process, no measurement is made

Quantum computing has achieved great success in recent years

Background

Quantum computing

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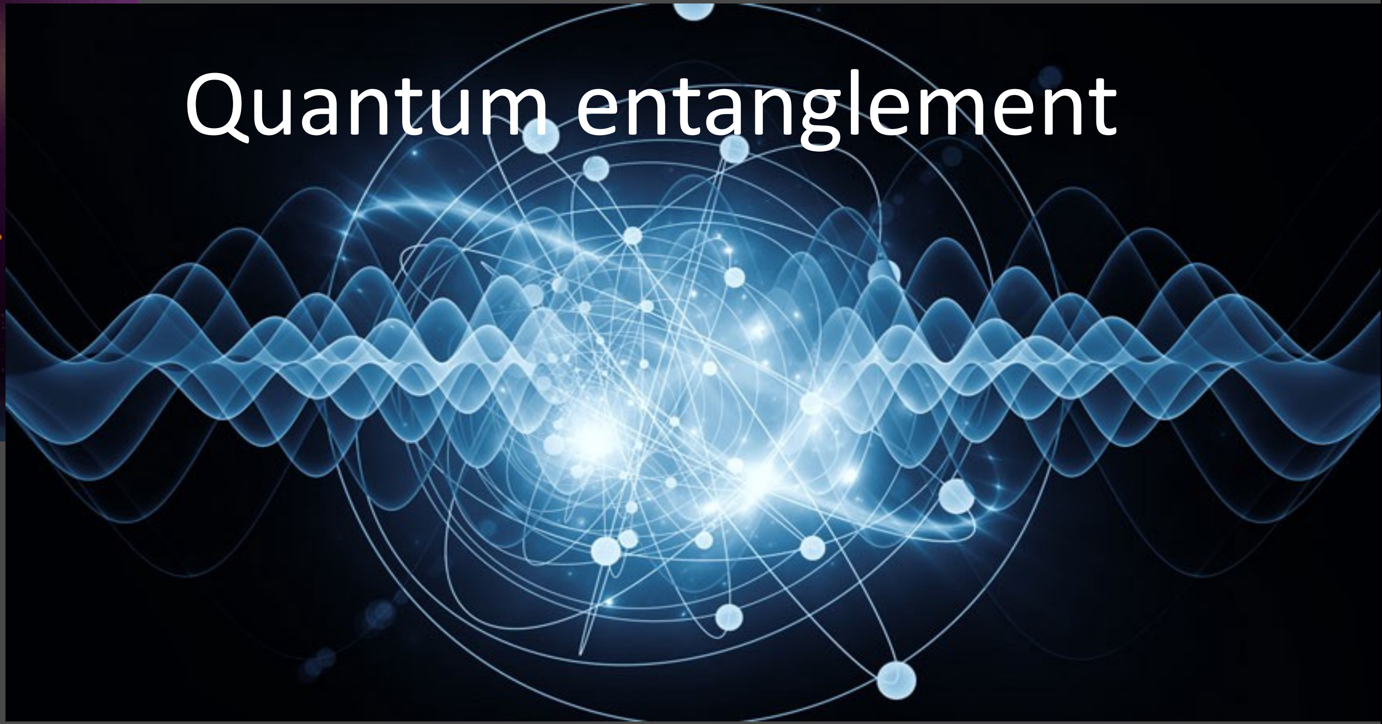


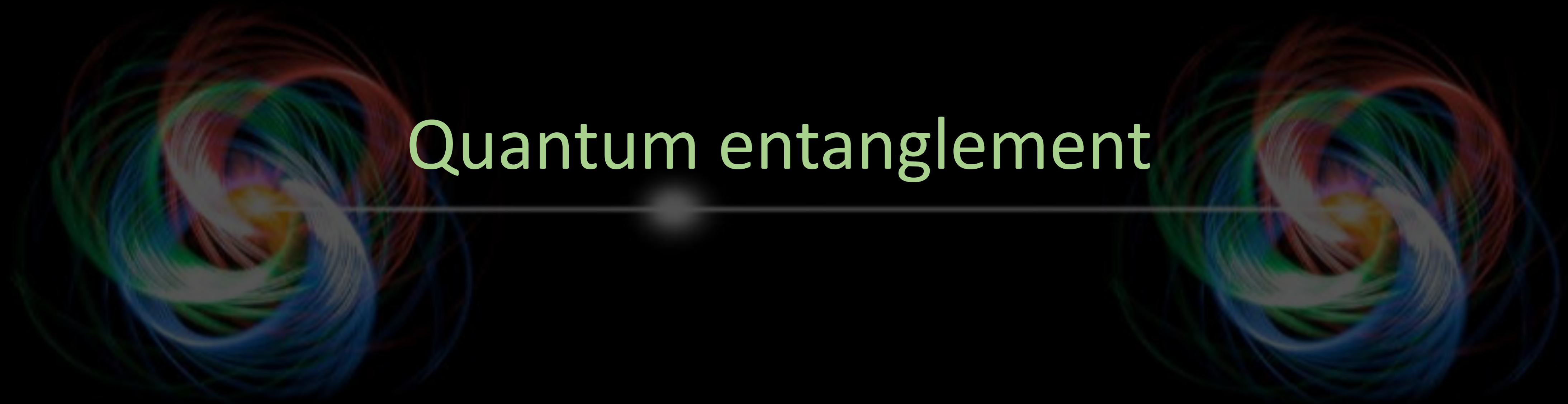
During computation process, no measurement is made

Quantum superposition

a qubit can be in the state $|0\rangle$ or $|1\rangle$ simultaneously

Background

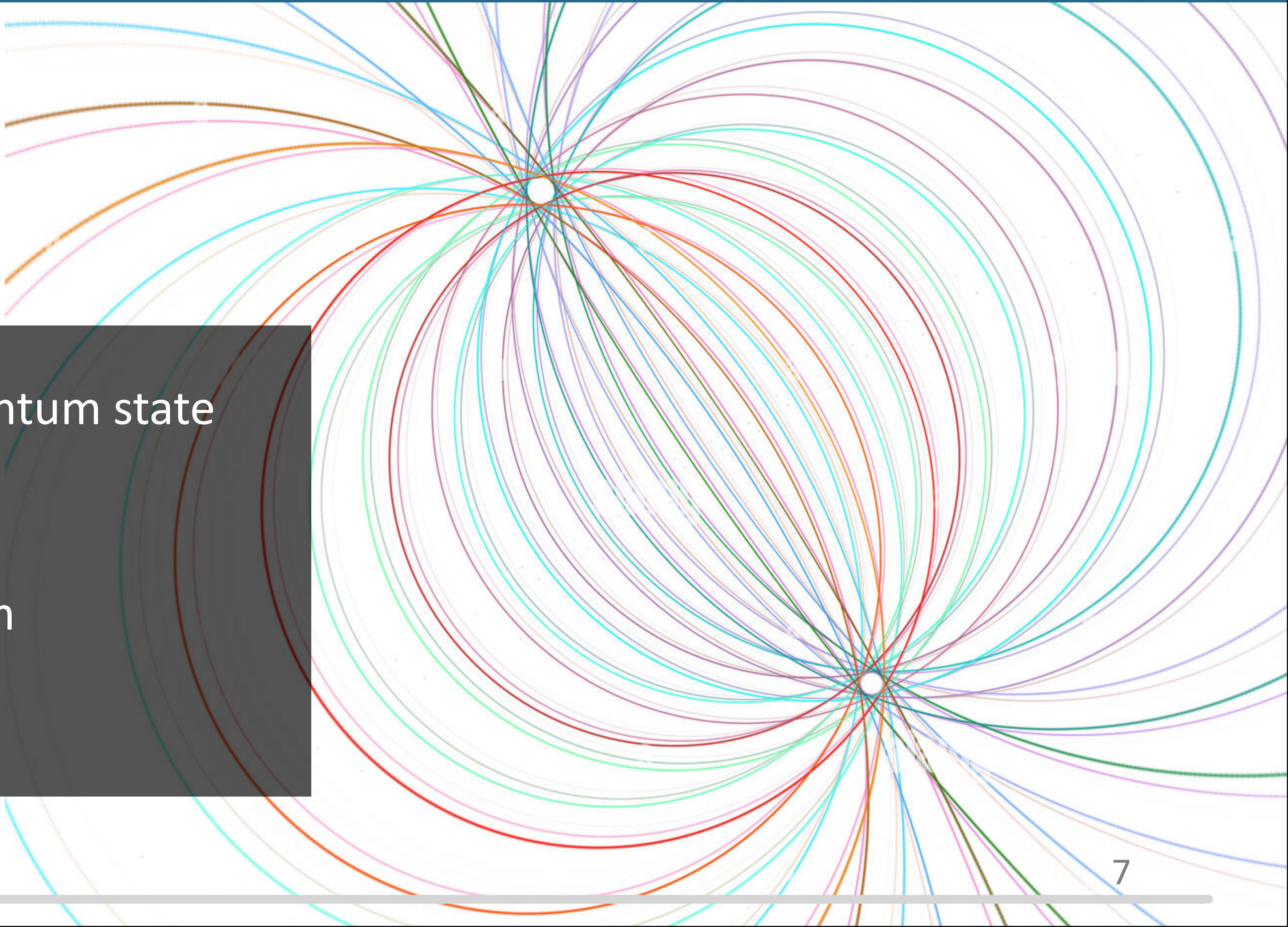
Quantum superposition



one qubit can be impacted by the other entangled qubit directly

Motivation

Visualization for multi-qubit state

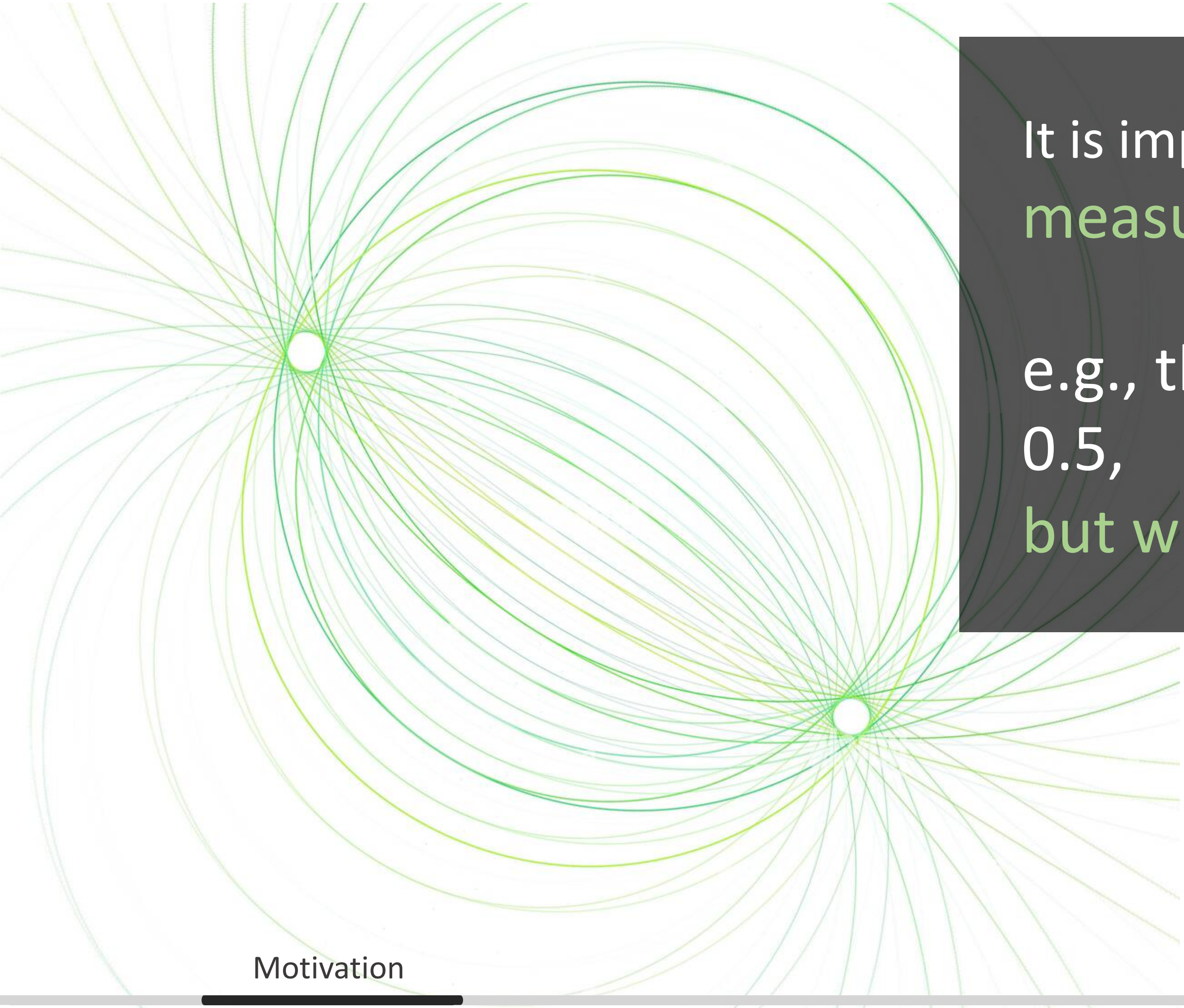


It is important to visualize the quantum state with more than one qubit

the basic requirement for quantum entanglements

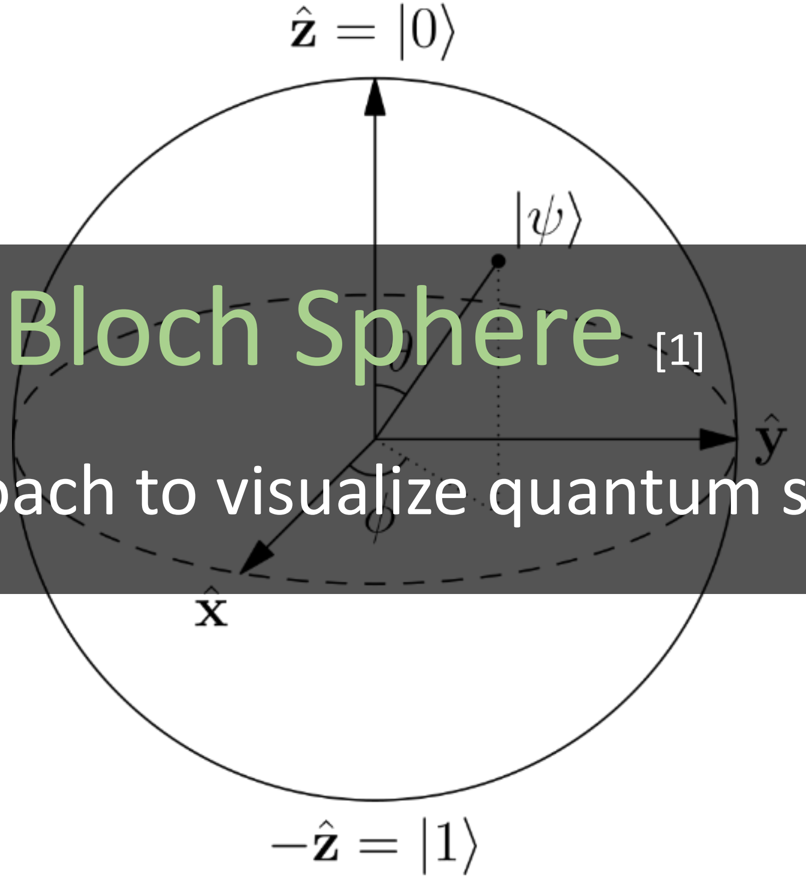
Motivation

Visualization for explaining probability



It is important to visually explain the **measured probability** of basis states

e.g., the probability of state $|0\rangle$ is, say 0.5,
but why?



Bloch Sphere [1]

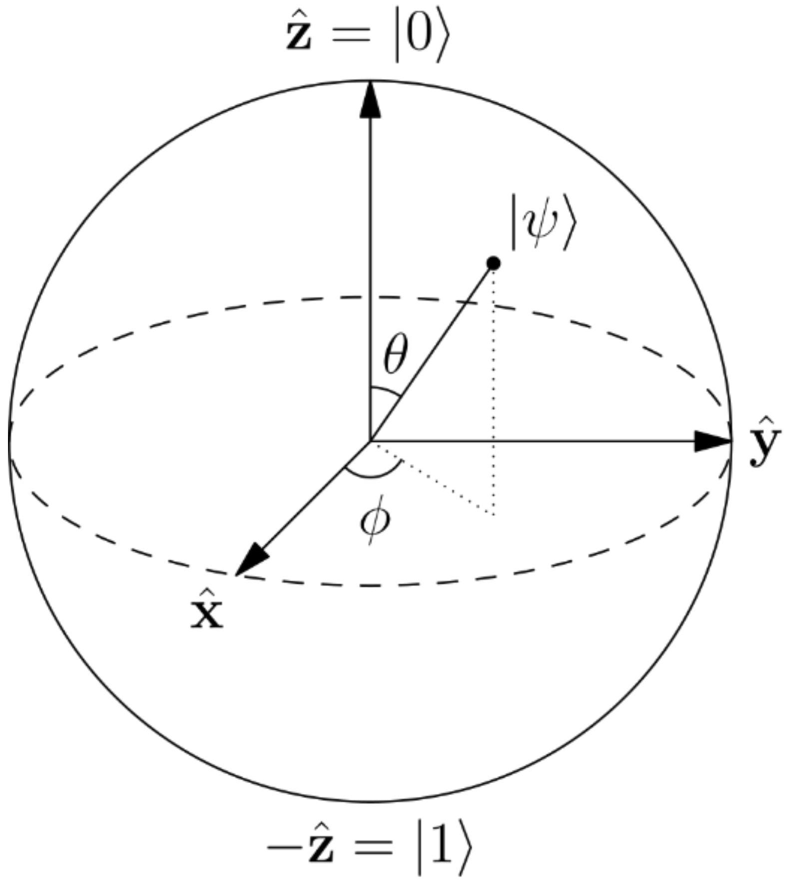
A widely-used approach to visualize quantum states today

[1] Bloch, Felix. "Nuclear induction." Physical review 70.7-8 (1946): 460.

Existing work

Bloch Sphere's issues

- Visualization for only one qubit [2]
- Non-intuitive representation of probability
- Inaccurate measurements [3].



[2] Bardin, Joseph C., Daniel H. Slichter, and David J. Reilly. "Microwaves in quantum computing." IEEE journal of microwaves 1.1 (2021): 403-427.
[3] Tory, Melanie, et al. "Visualization task performance with 2D, 3D, and combination displays." IEEE transactions on visualization and computer graphics 12.1 (2005): 2-13.

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High-level summary

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- VENUS supports the visualization for both single-qubit and two-qubit states
- VENUS visualizes and explains the measured probability

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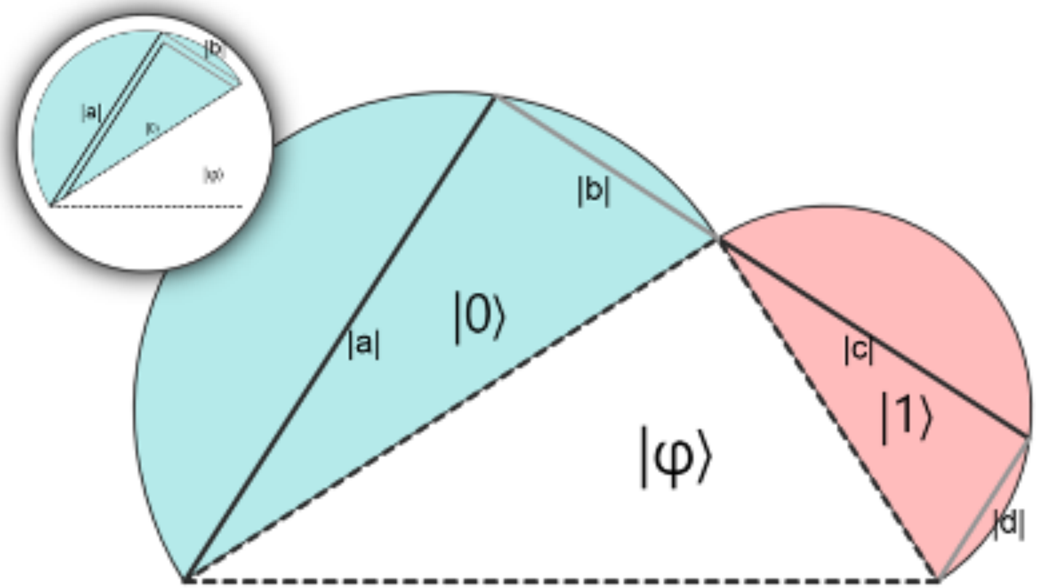
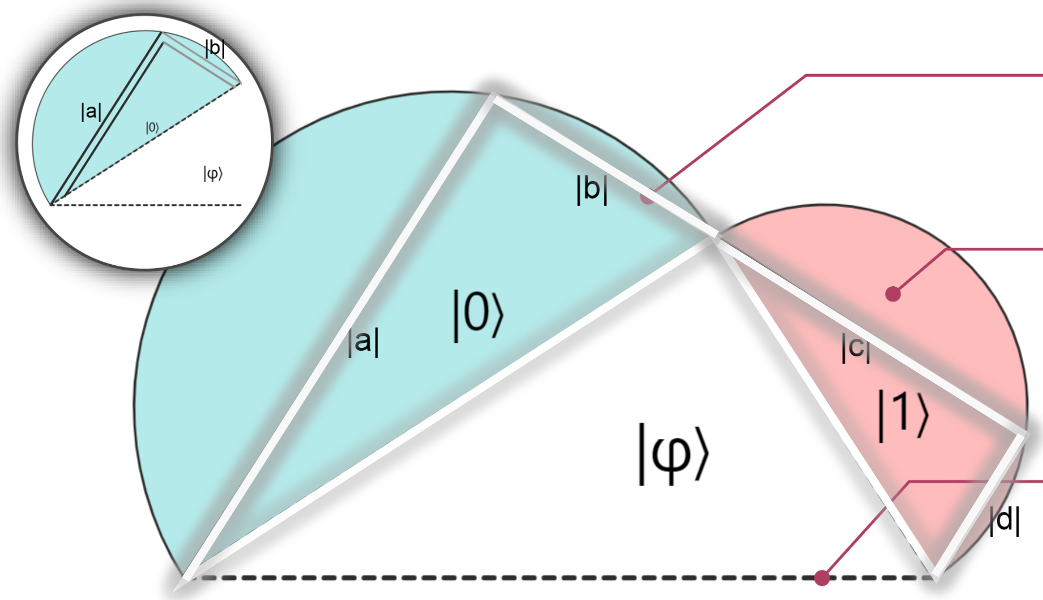
Single-qubit state visualization



$$|\psi\rangle = \alpha\,|0\rangle + \beta\,|1\rangle$$

Single-qubit state visualization



State Vector

α = a + b·i, β = c + d·i

Probability Distribution

$Pr(|0\rangle) = |\alpha|^2 = |a|^2 + |b|^2 = (\pi/8) \cdot S_{|0\rangle}$

Normalization

$|\alpha|^2 + |\beta|^2 = 1$

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

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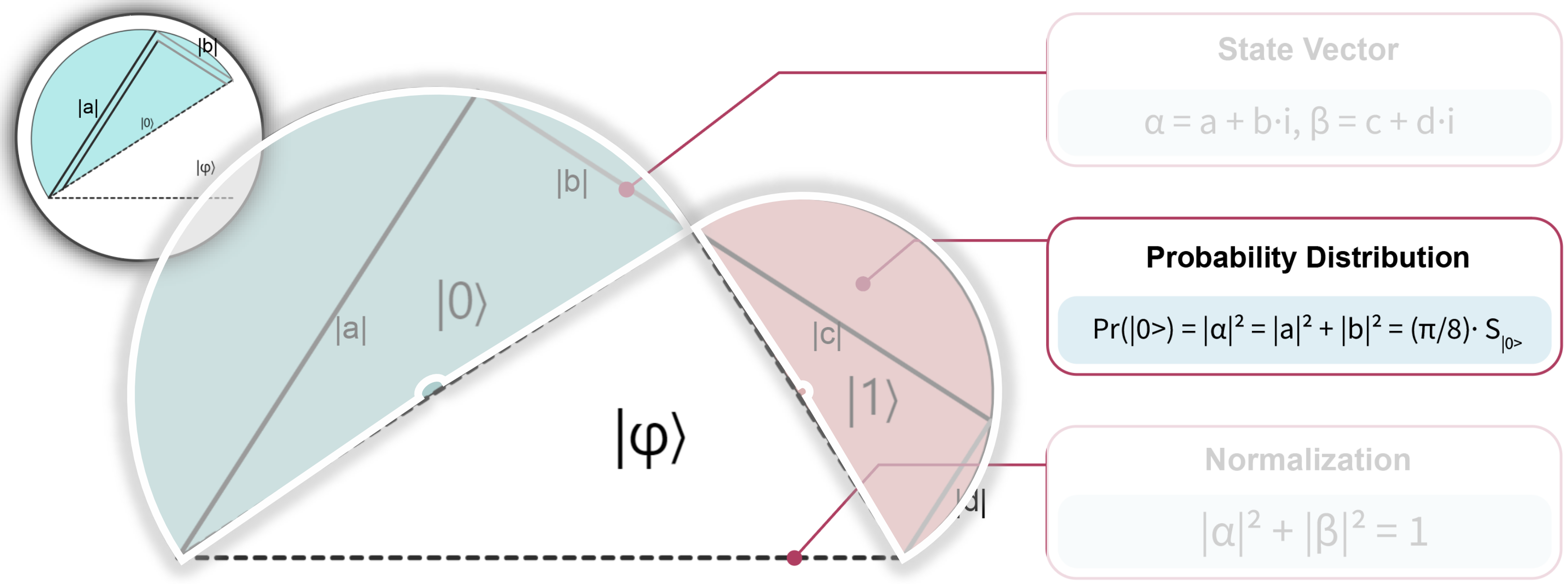
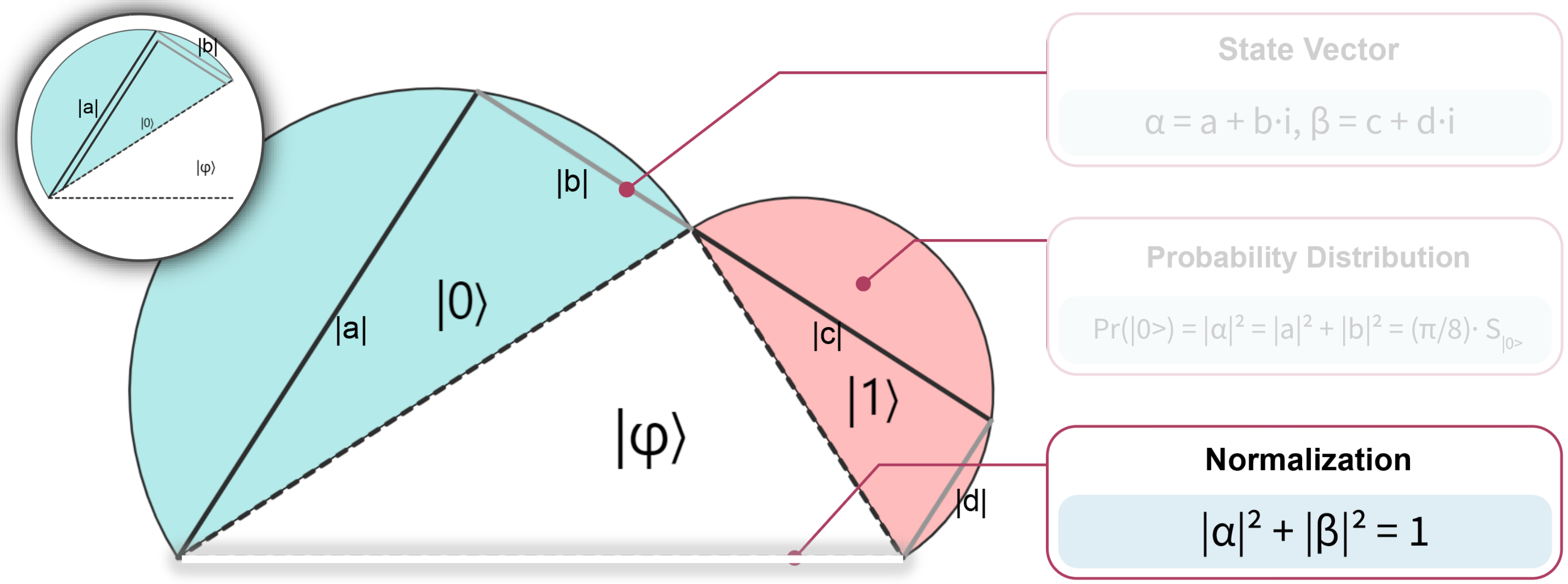
Single-qubit state visualization



$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

$$S_{semicircle} = \frac{\pi}{8} \cdot (|a|^2 + |b|^2)$$

Single-qubit state visualization



$$|\psi\rangle = \alpha\,|0\rangle + \beta\,|1\rangle$$

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Visual design

Two-qubit state visualization

State Vector

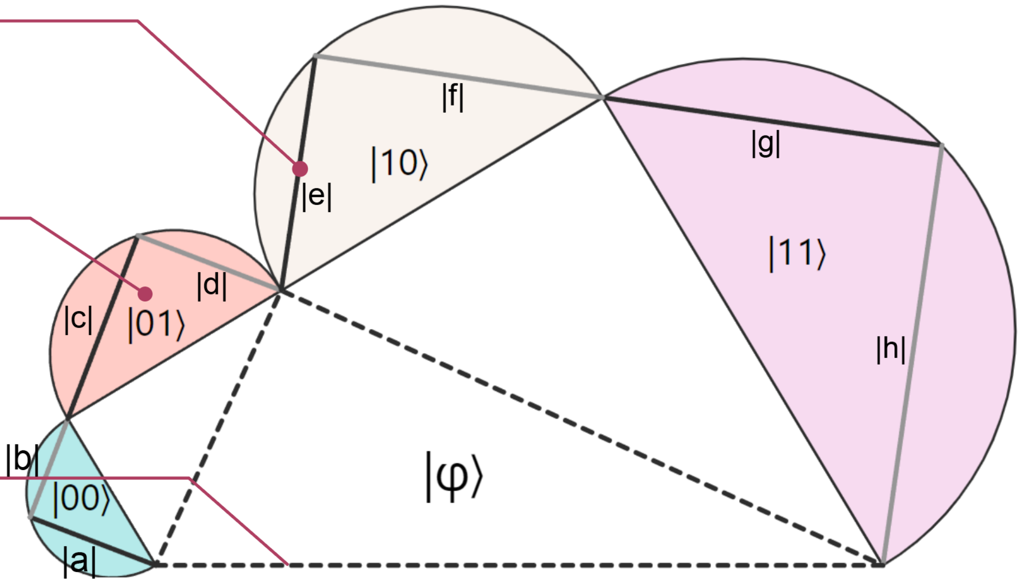
$\alpha = a + b \cdot i,\ \beta = c + d \cdot i,\ \gamma = e + f \cdot i,\ \delta = g + h \cdot i$

Probability Distribution

$Pr(|10\rangle) = |\gamma|^2 = |e|^2 + |f|^2 = (\pi/8) \cdot S_{|10>}$

Normalization

$|\alpha|^2 + |\beta|^2 + |\gamma|^2 + |\delta|^2 = 1$



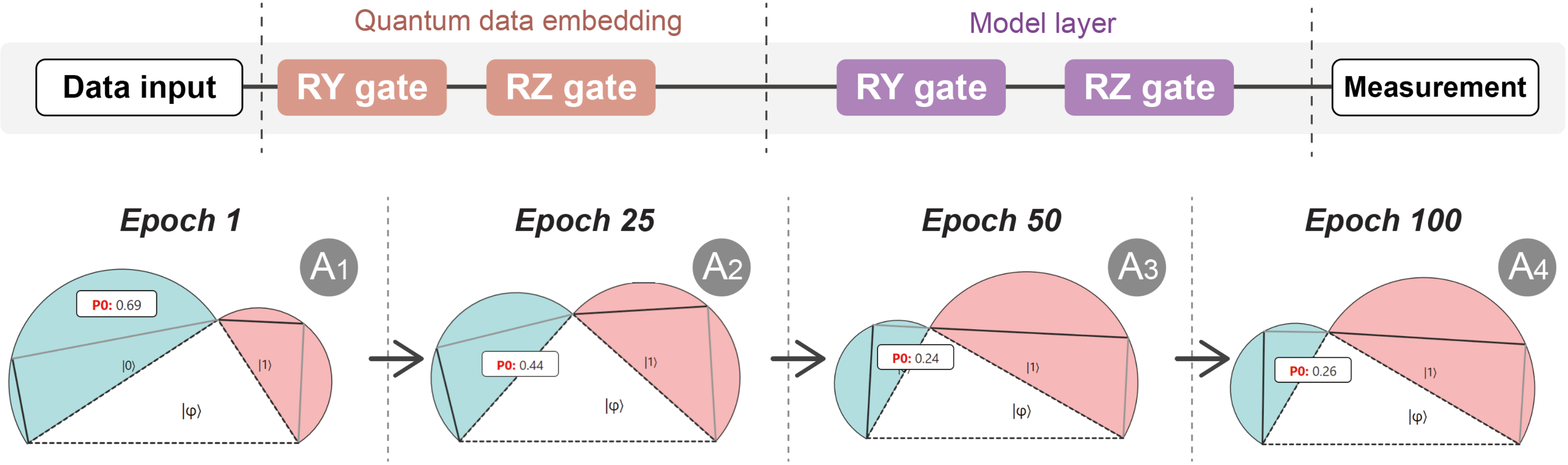
$$|\psi\rangle = \alpha|00\rangle + \beta|01\rangle + \gamma|10\rangle + \delta|11\rangle$$

Quantum classifier

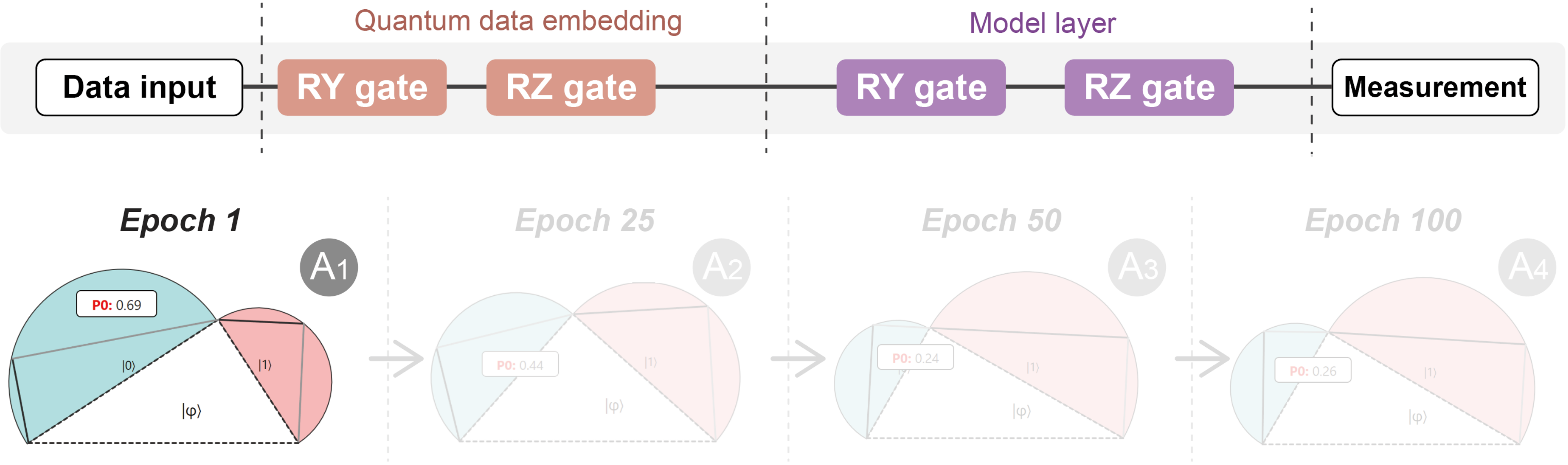
- Iris dataset [4]

[4] Iris dataset. https://archive.ics.uci.edu/ml/datasets/iris

Quantum classifier example



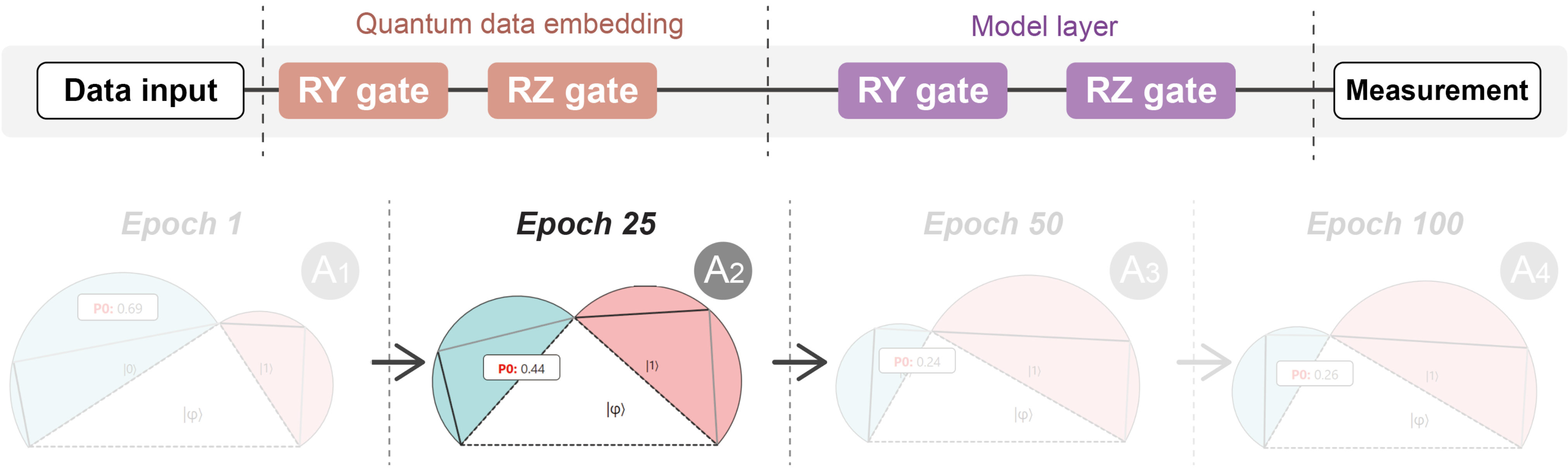
Quantum classifier example



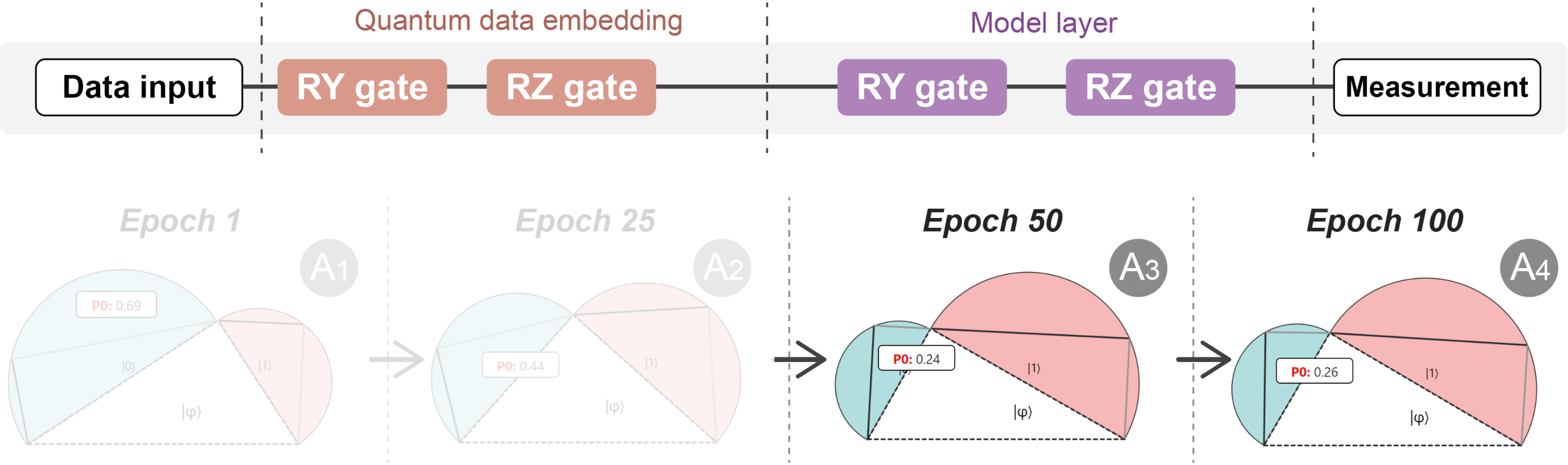
Evaluation

Demo showcase

Quantum classifier example



Quantum classifier example



Evaluation

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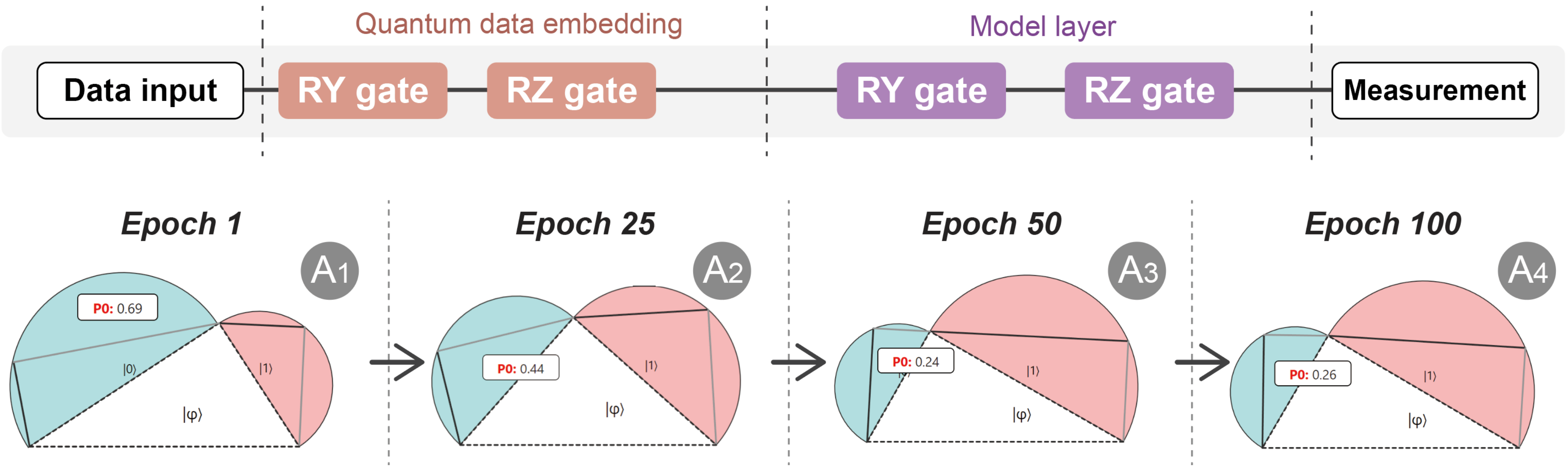
Quantum classifier example



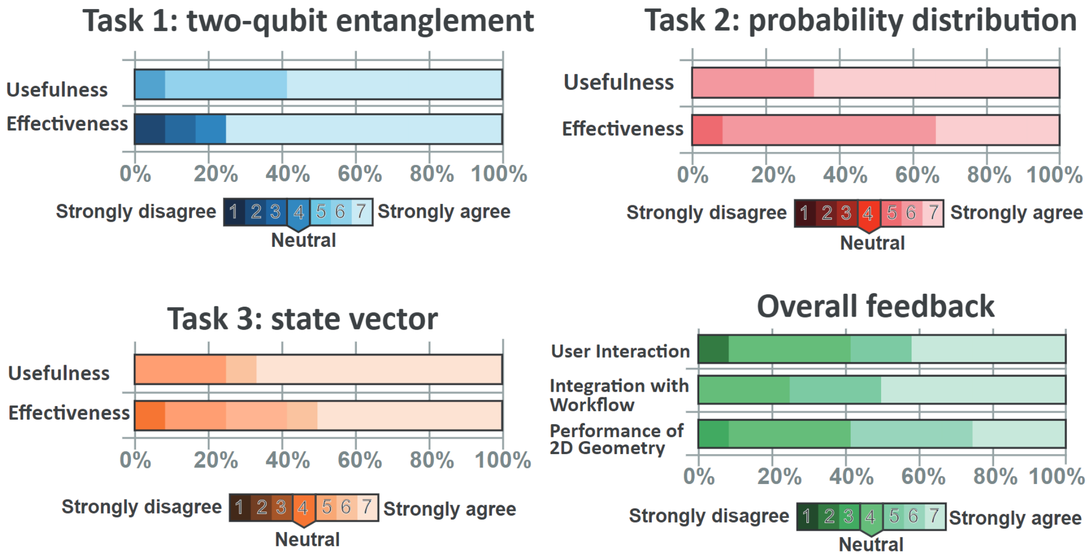
Evaluation

Expert interview

Tasks:

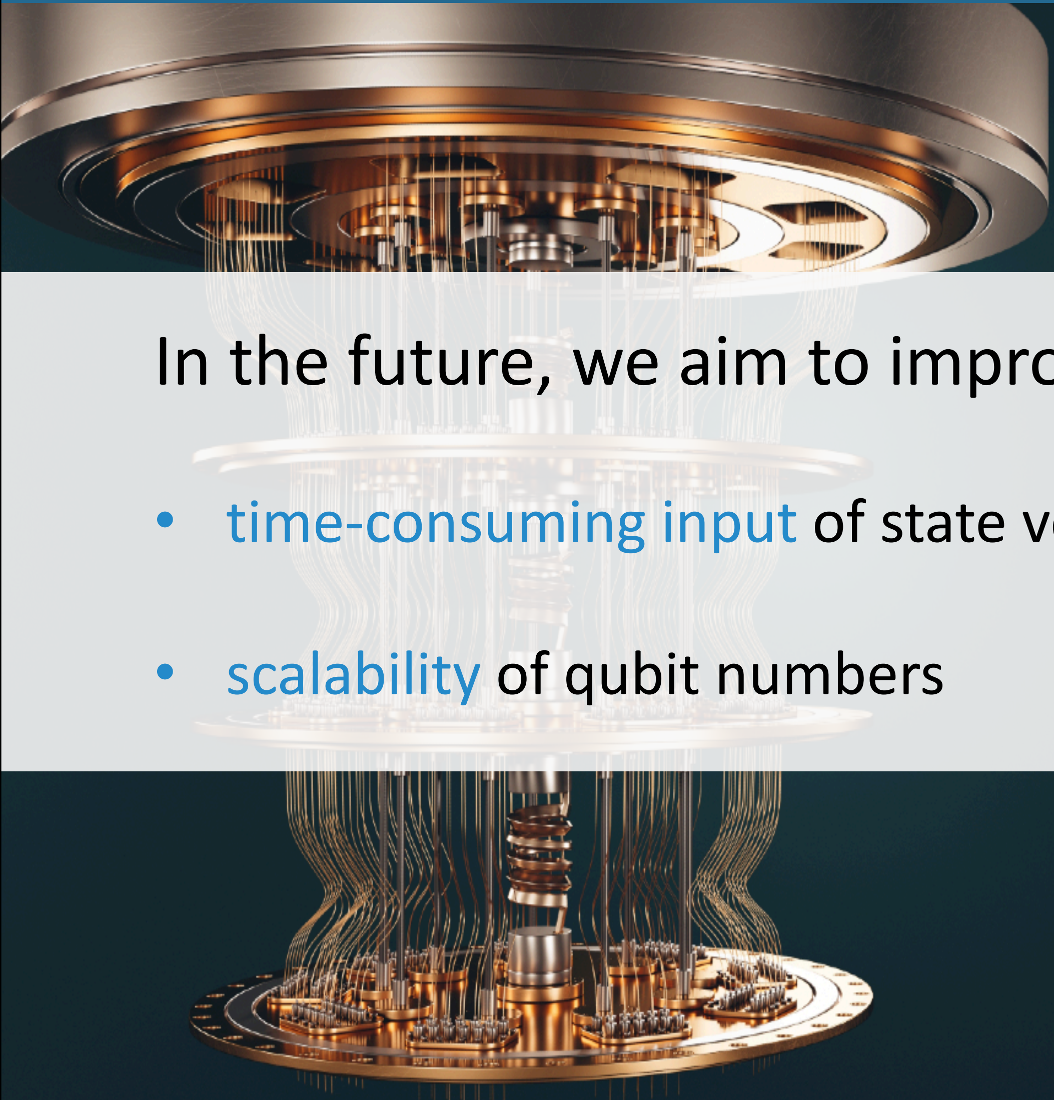
Q1	It is useful to show the quantum entanglement when observing quantum states.
Q2	It is easy to identify the entangled states via the visually correlated semicircles.
Q3	It is helpful to show the probability distribution of each state.
Q4	It is intuitive to show probability distribution via the semicircle area.
Q5	It is informative to represent states via the state vectors.
Q6	It is easy to identify the state vectors via the line pairs within each semicircle.
Q7	The user interactions in the interface are useful and smooth.
Q8	The design can be integrated into the workflow well.
Q9	The 2D visual design is easy to view.

Results:



"I like the idea of using the probability calculation equation to naturally visualize the probability distribution. I can directly check the probability without any manual calculation."

Future work



In the future, we aim to improve

- time-consuming input of state vectors
- scalability of qubit numbers

Conclusion

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We propose VENUS, a geometrical visualization for quantum state visualization

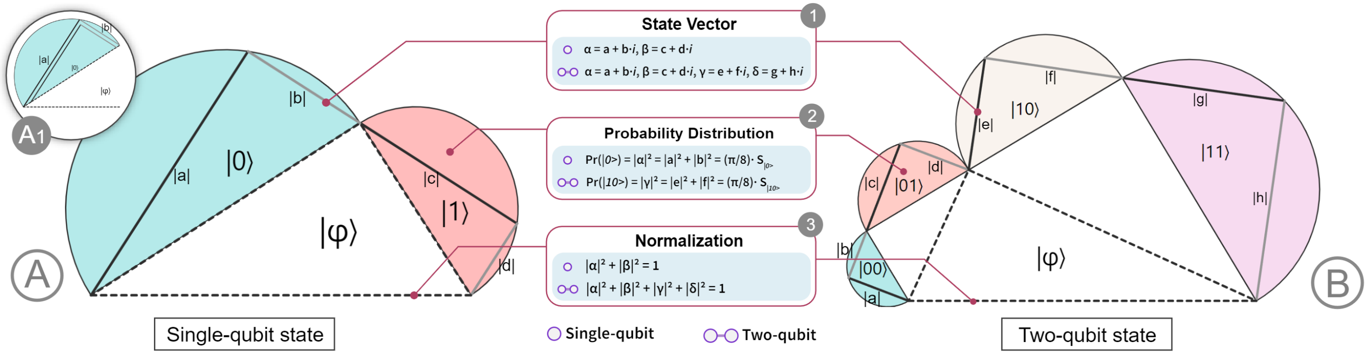
1. Probability visualization

   Allow the explicit representation of measured probability

   Visually explain the probability via the state vectors

2. Two-qubit state visualization

   Support the single-qubit and two-qubit state visualization



Thank you for your attention!

Q&A

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