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Title: Quantum Resources for Information Processing

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Issued: 2019-03-05

Quantum Resources for Information Processing

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Hoboken, 11 March 2019

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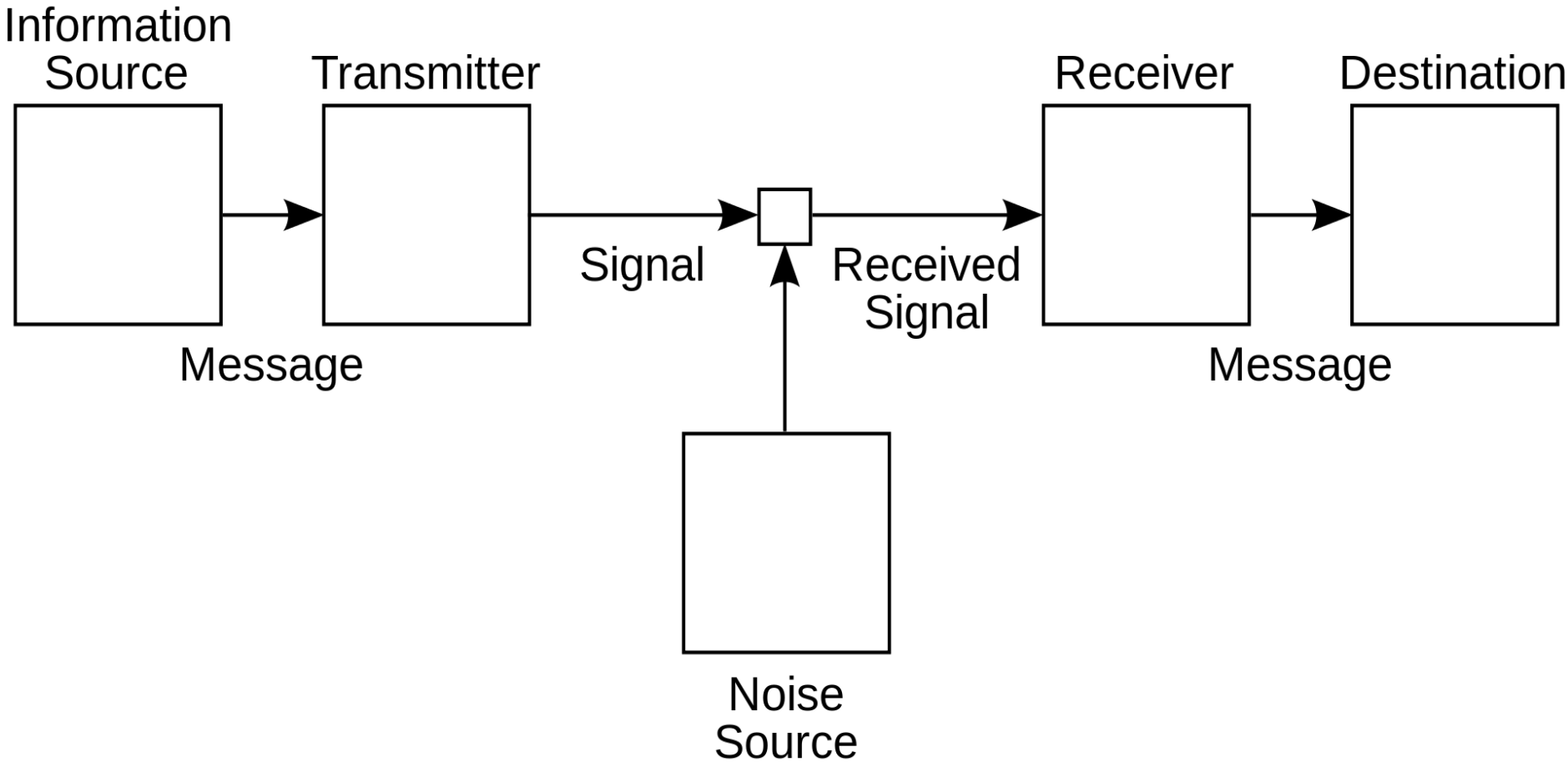
1A Quantum Information Science

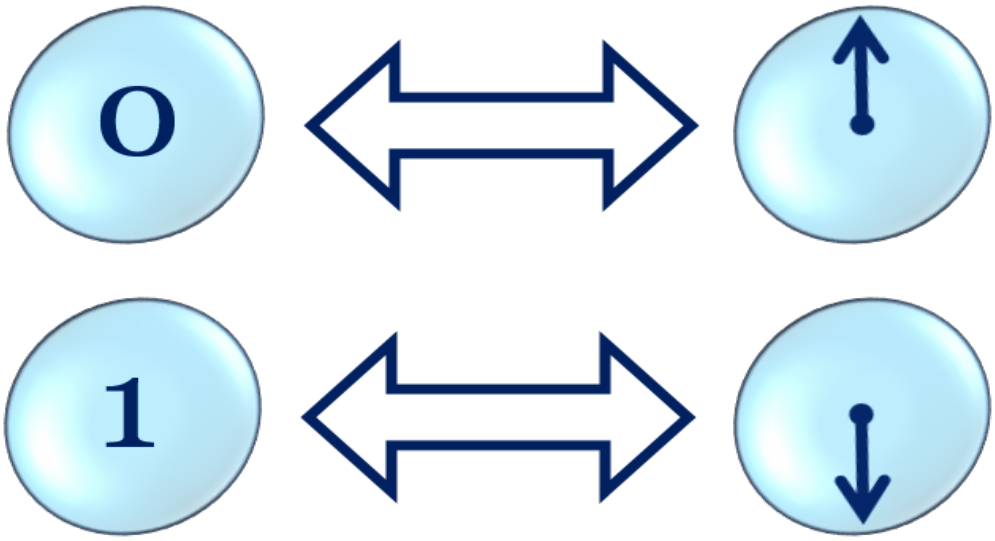
Information Theory

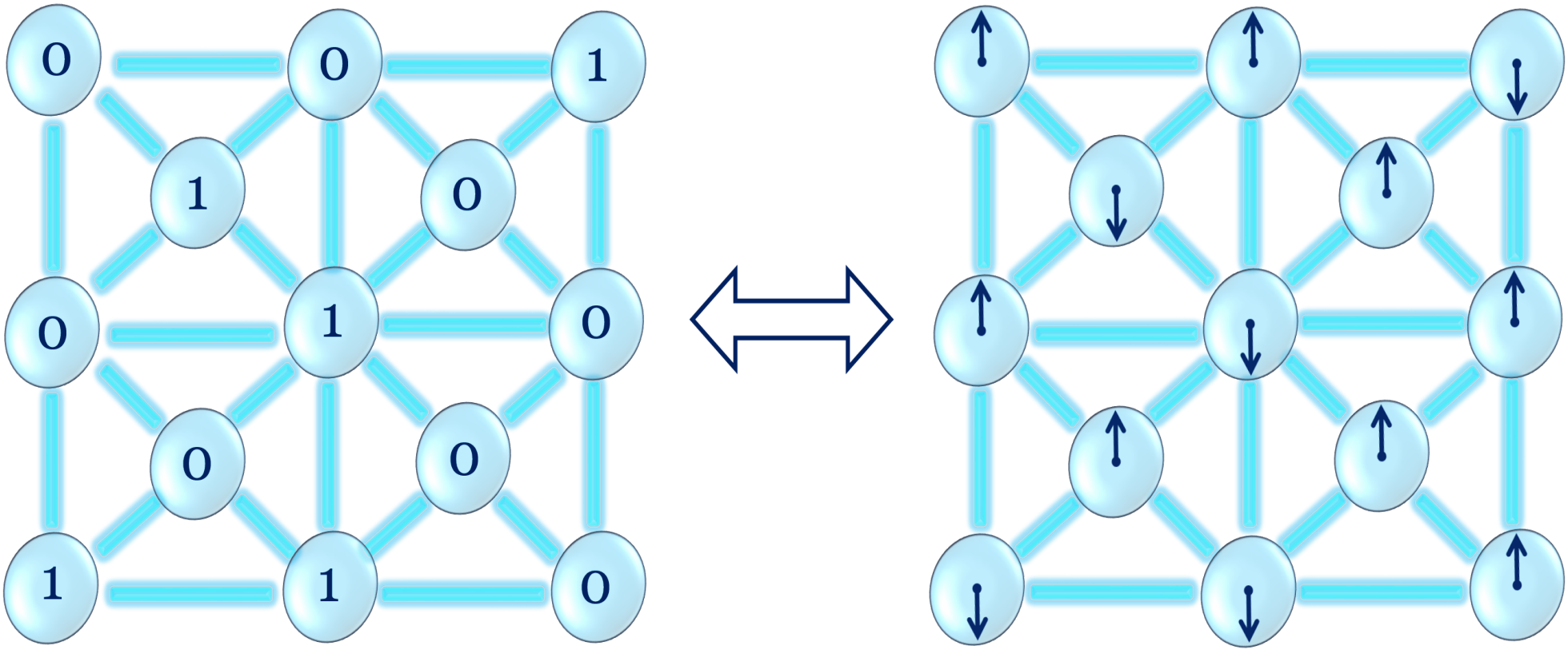


C. Shannon, Bell Syst. Tech. J. 27, 379 (1948)

Classical Information

- ⋆ Information measured in bits: $0, 1$
- ⋆ Encoded in two-level classical systems

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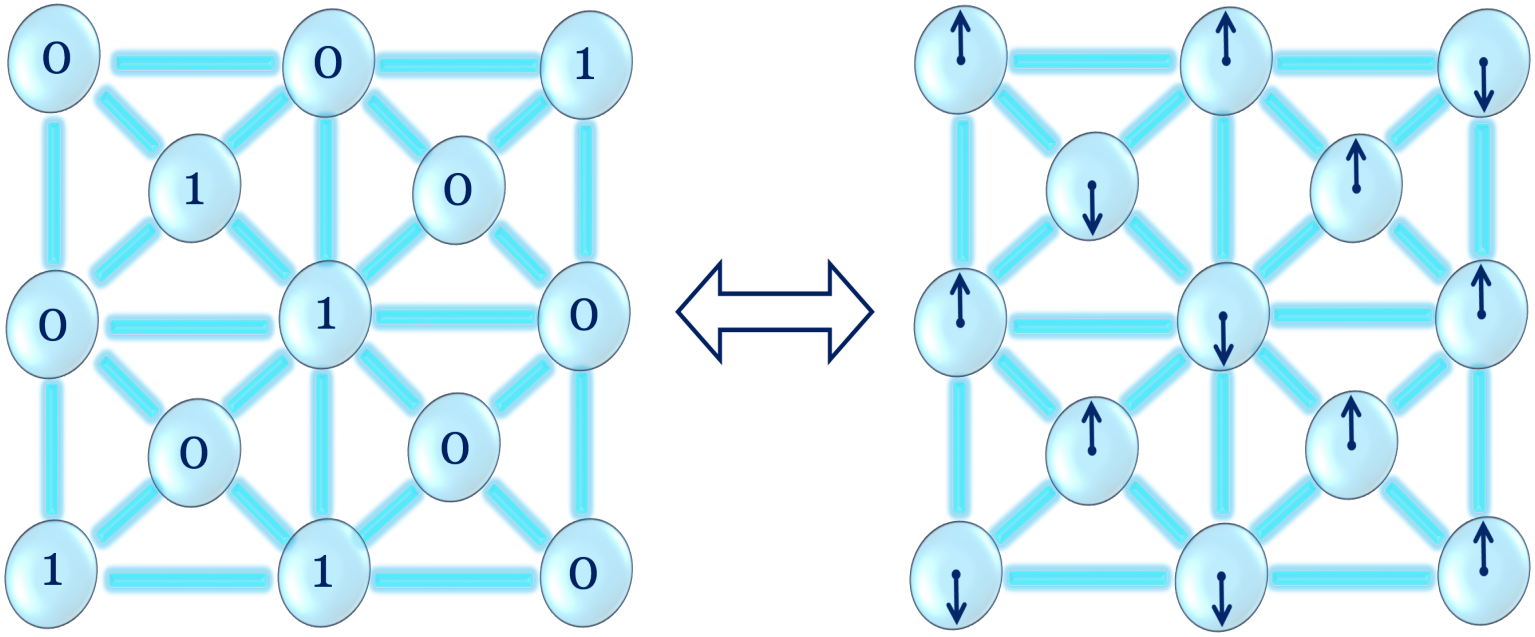
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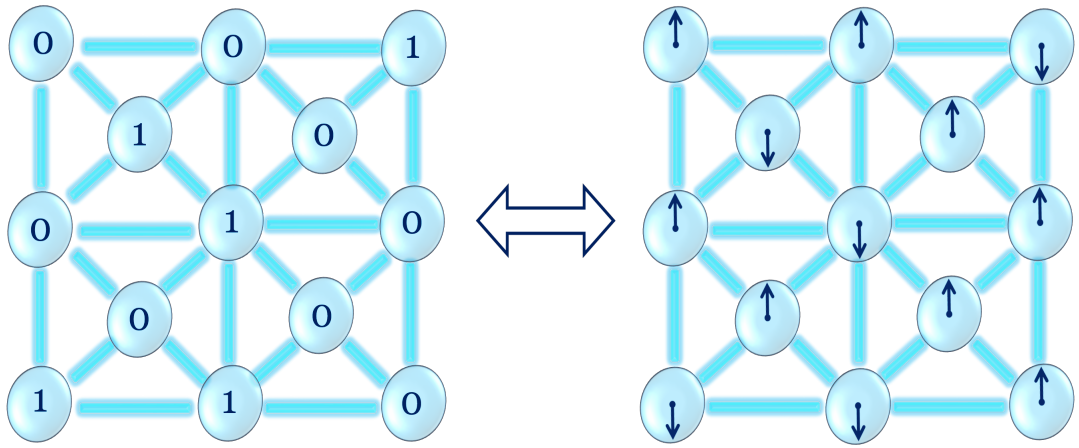
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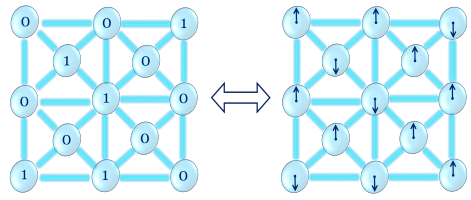
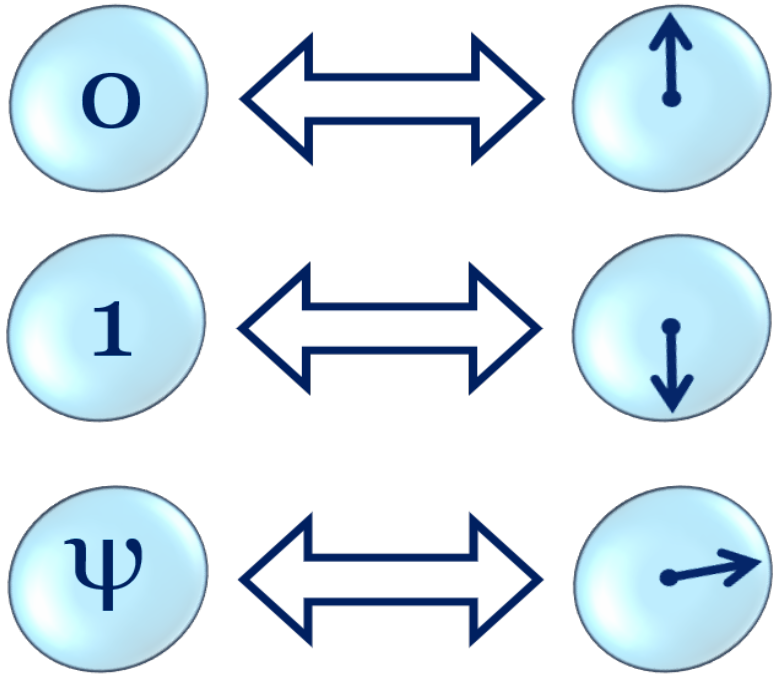

0 0 1
1 0
0 1 0
0 0
1 1 0

Quantum Information

- Information encoded in qubits

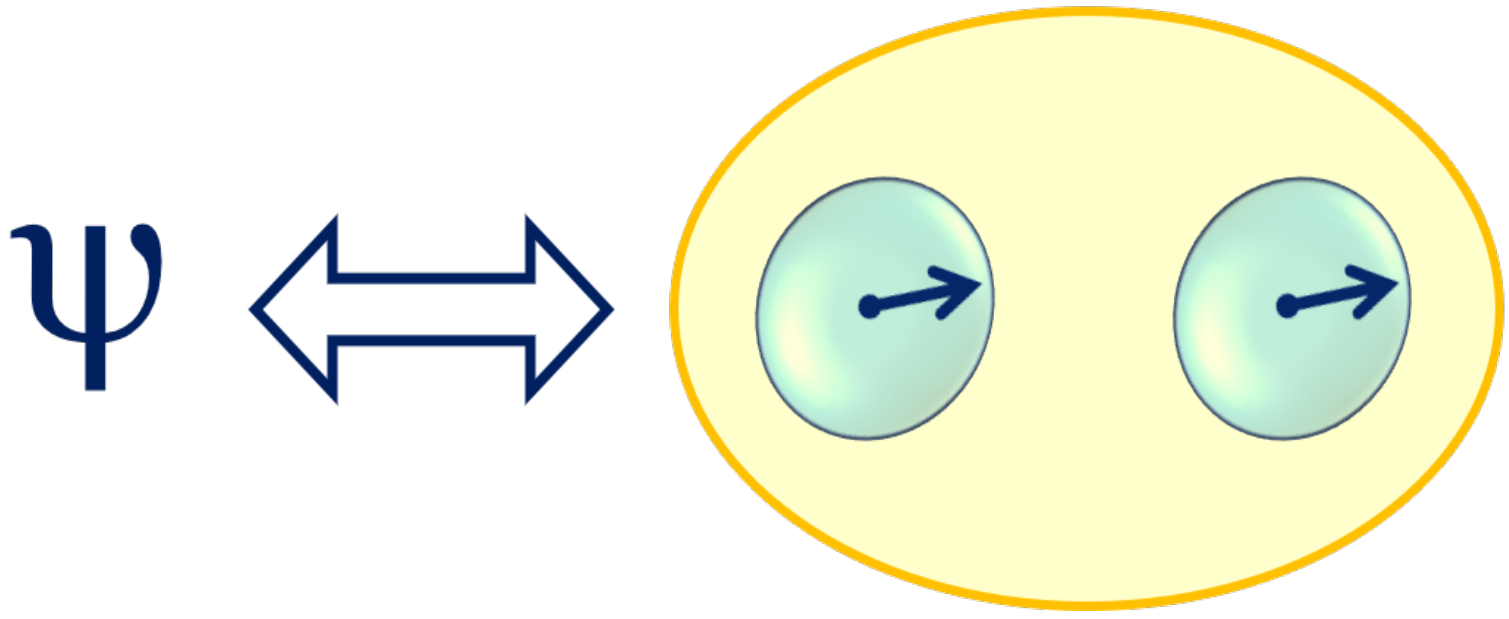
$$|\psi\rangle = a\,|0\rangle + b\,|1\rangle,\ a, b \in \mathbb{C}$$

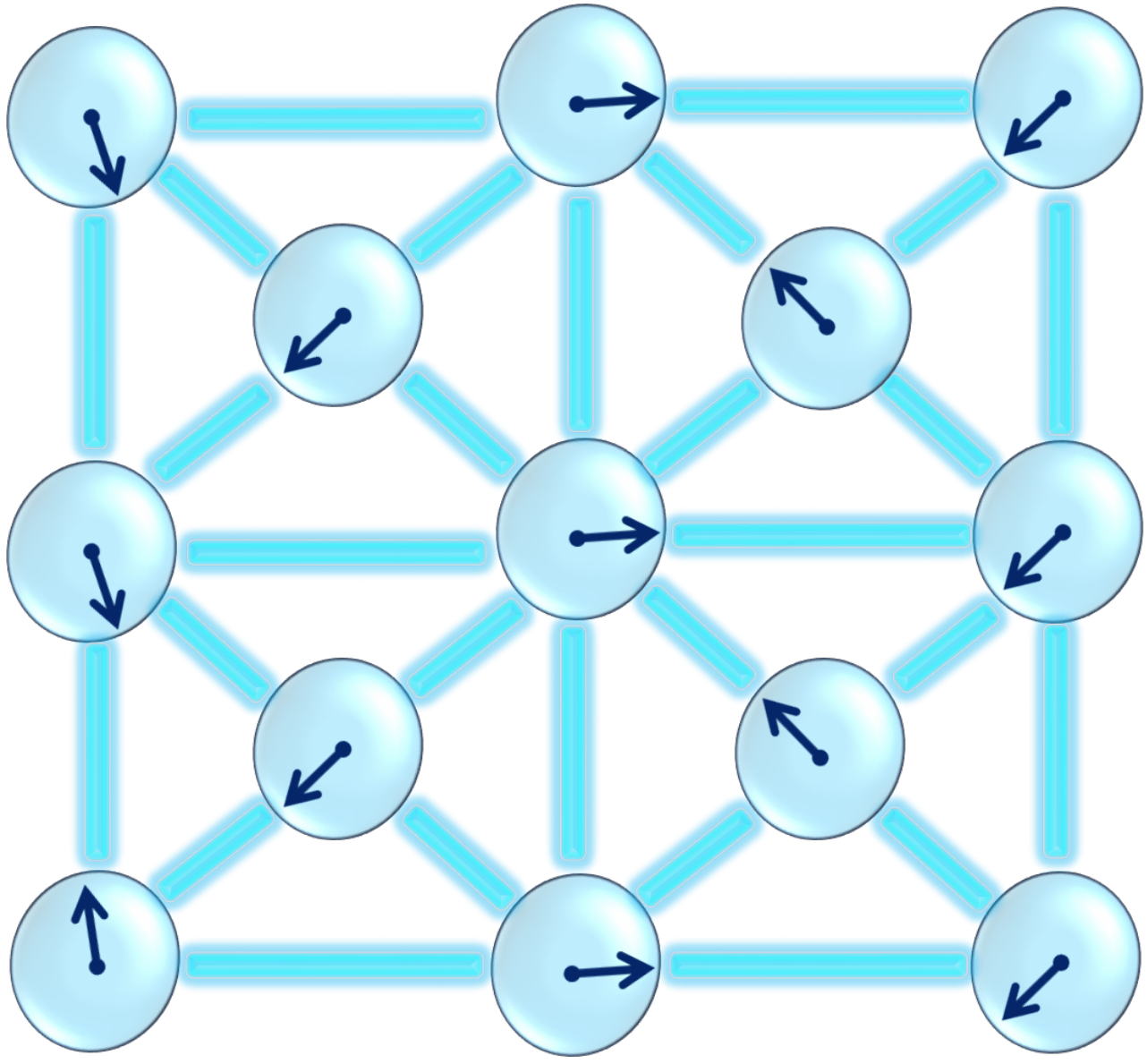


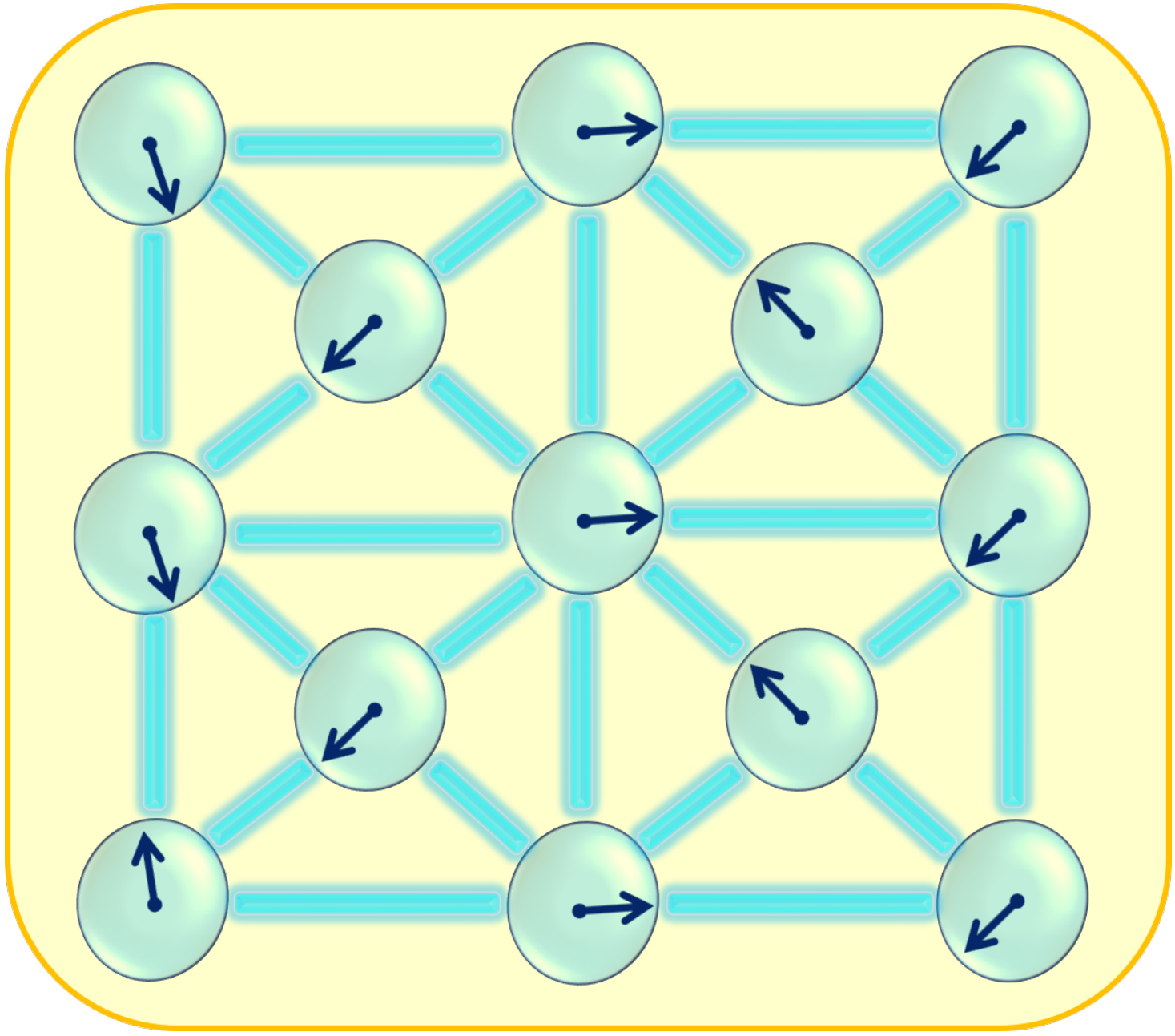
Quantum Information

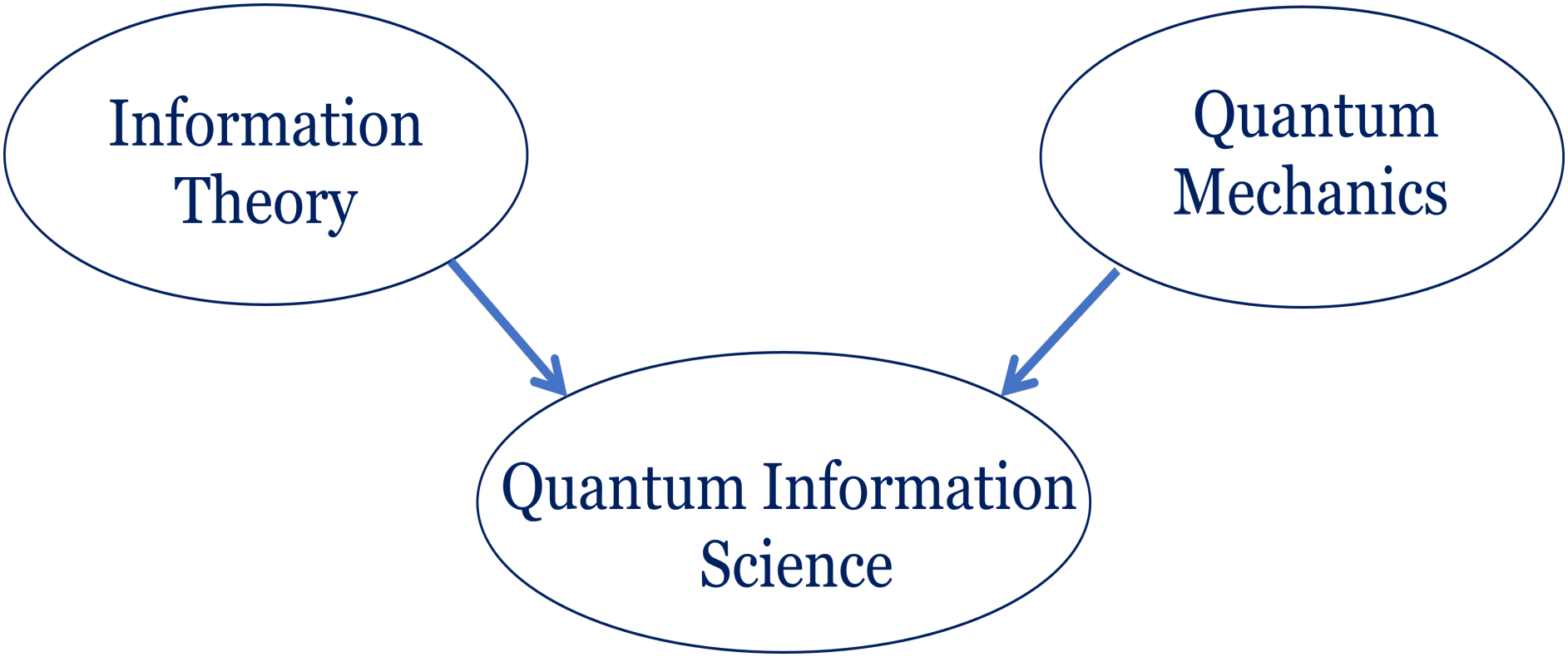
- Information encoded in entangled qubits

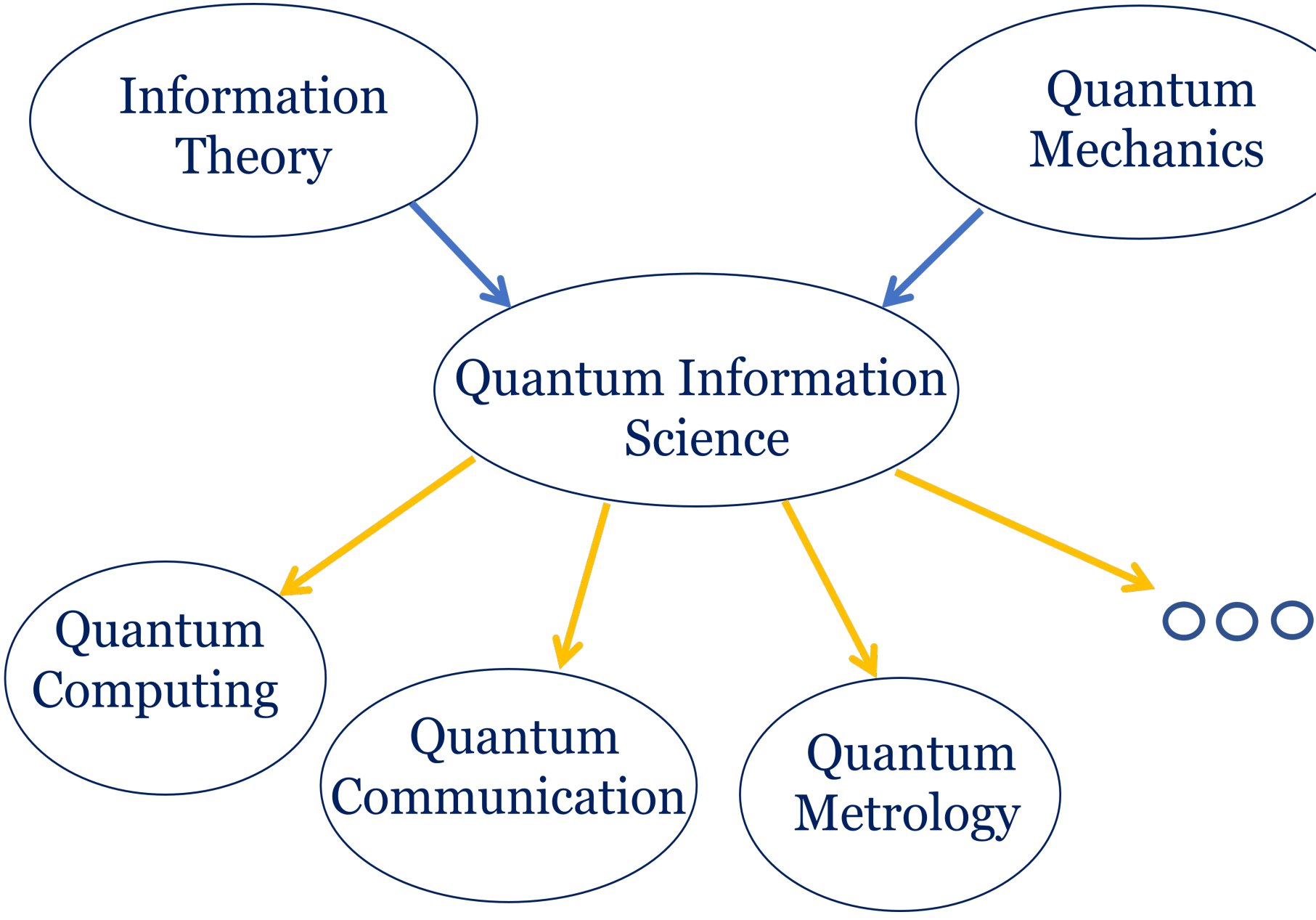
$$|\psi\rangle = a\,|00\rangle + b\,|11\rangle,\ a, b \in \mathbb{C}$$

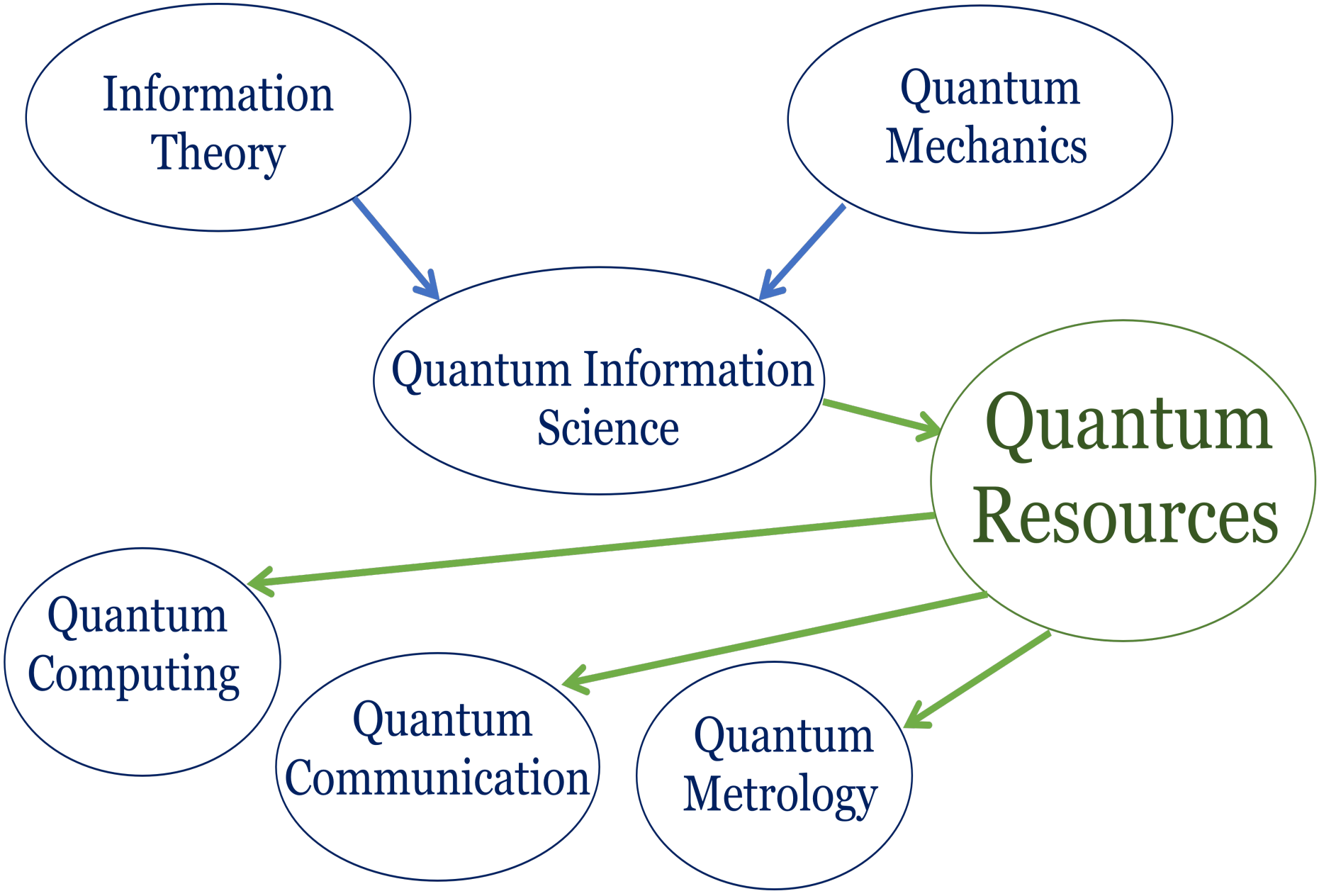







Information Theory
Quantum Mechanics
Quantum Information Science


Information Theory
Quantum Mechanics
Quantum Information Science
Quantum Computing
Quantum Communication
Quantum Metrology

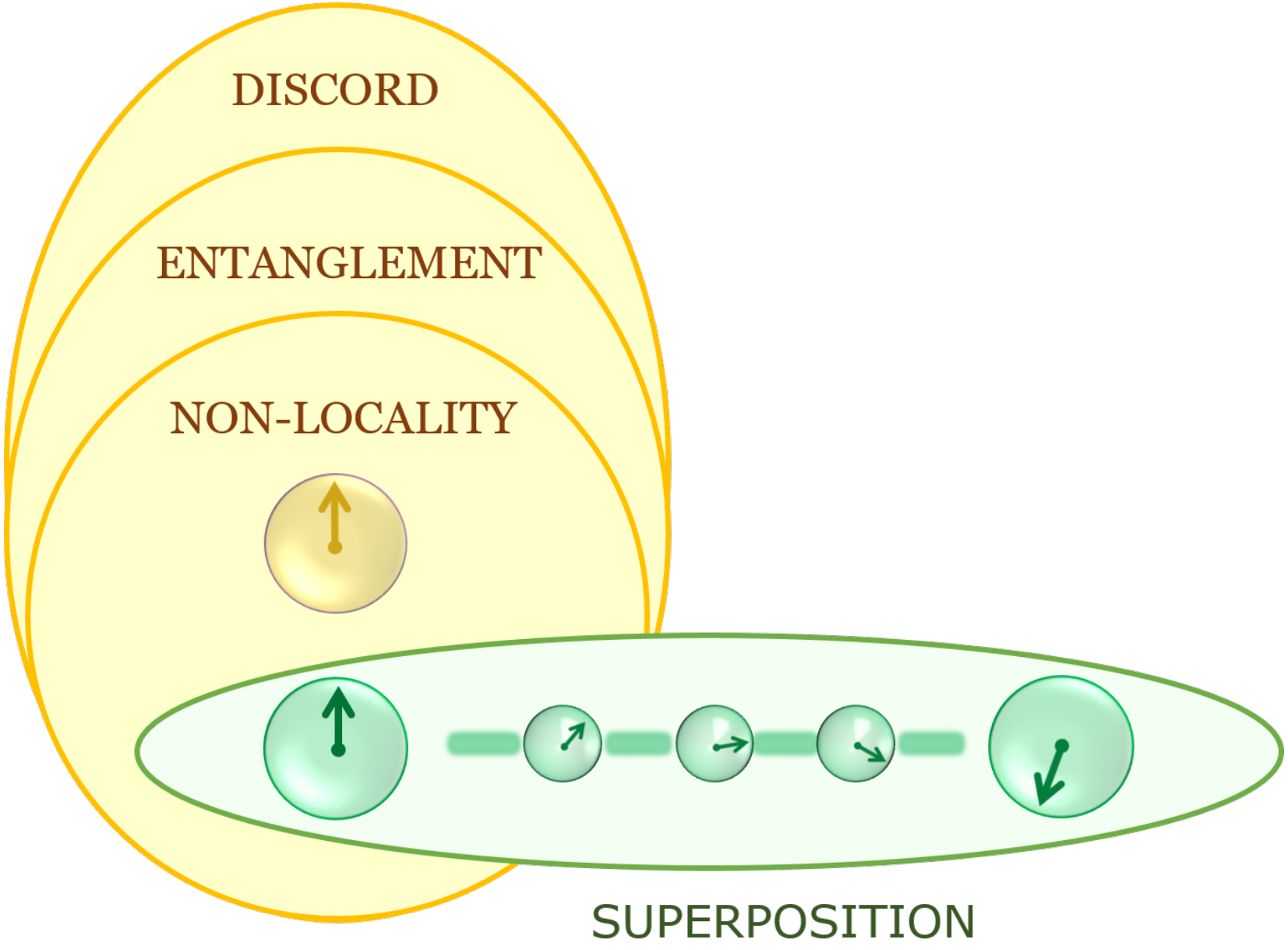

Information Theory
Quantum Mechanics
Quantum Information Science
Quantum Resources
Quantum Computing
Quantum Communication
Quantum Metrology

1B Quantum Resources

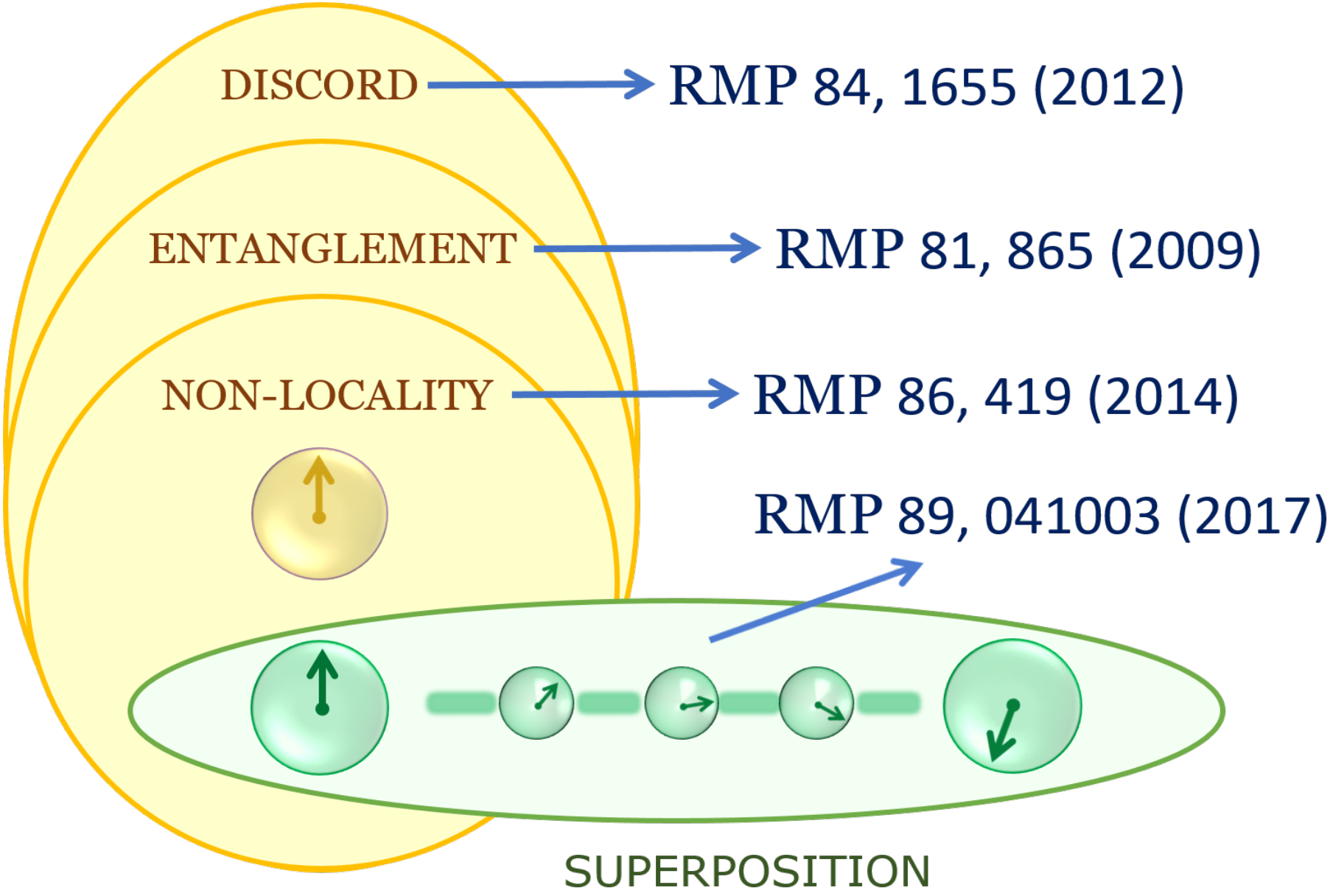
Quantum Physics

- States: $\rho = \sum_i p_i \left|\psi_i\right\rangle \left\langle\psi_i\right|, \rho \geq 0, \mathrm{Tr}[\rho] = 1$
- Dynamics: $\Lambda(\rho) \geq 0, \mathrm{Tr}[\Lambda(\rho)] = 1$
- $a\left|0\right\rangle + b\left|1\right\rangle \rightarrow$ how to define coherence in ρ?
- $a\left|00\right\rangle + b\left|11\right\rangle \rightarrow$ how to define correlations in ρ?

Resource hierarchy in bipartite systems



Resource hierarchy in bipartite systems

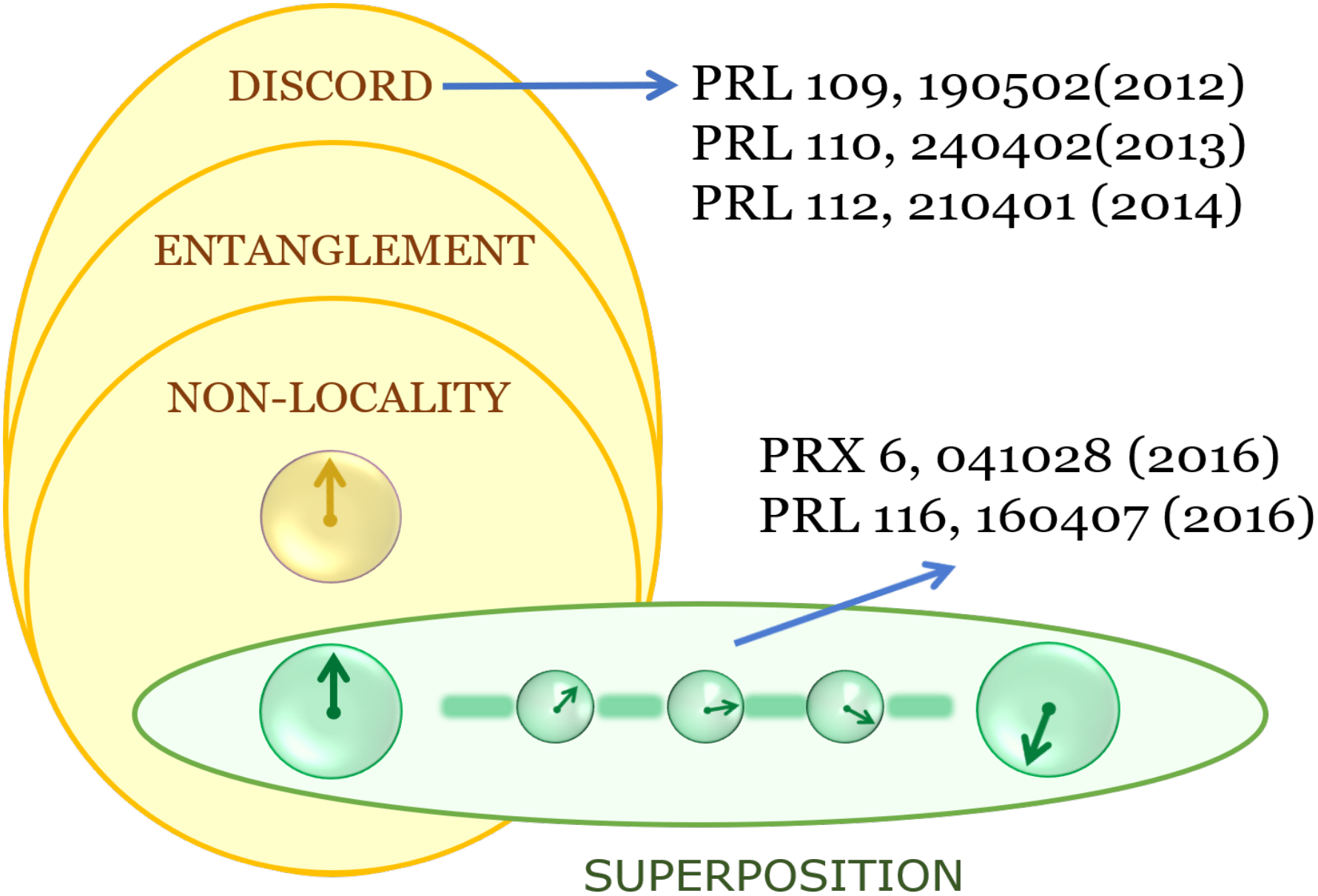


2A Resources in bipartite noisy systems

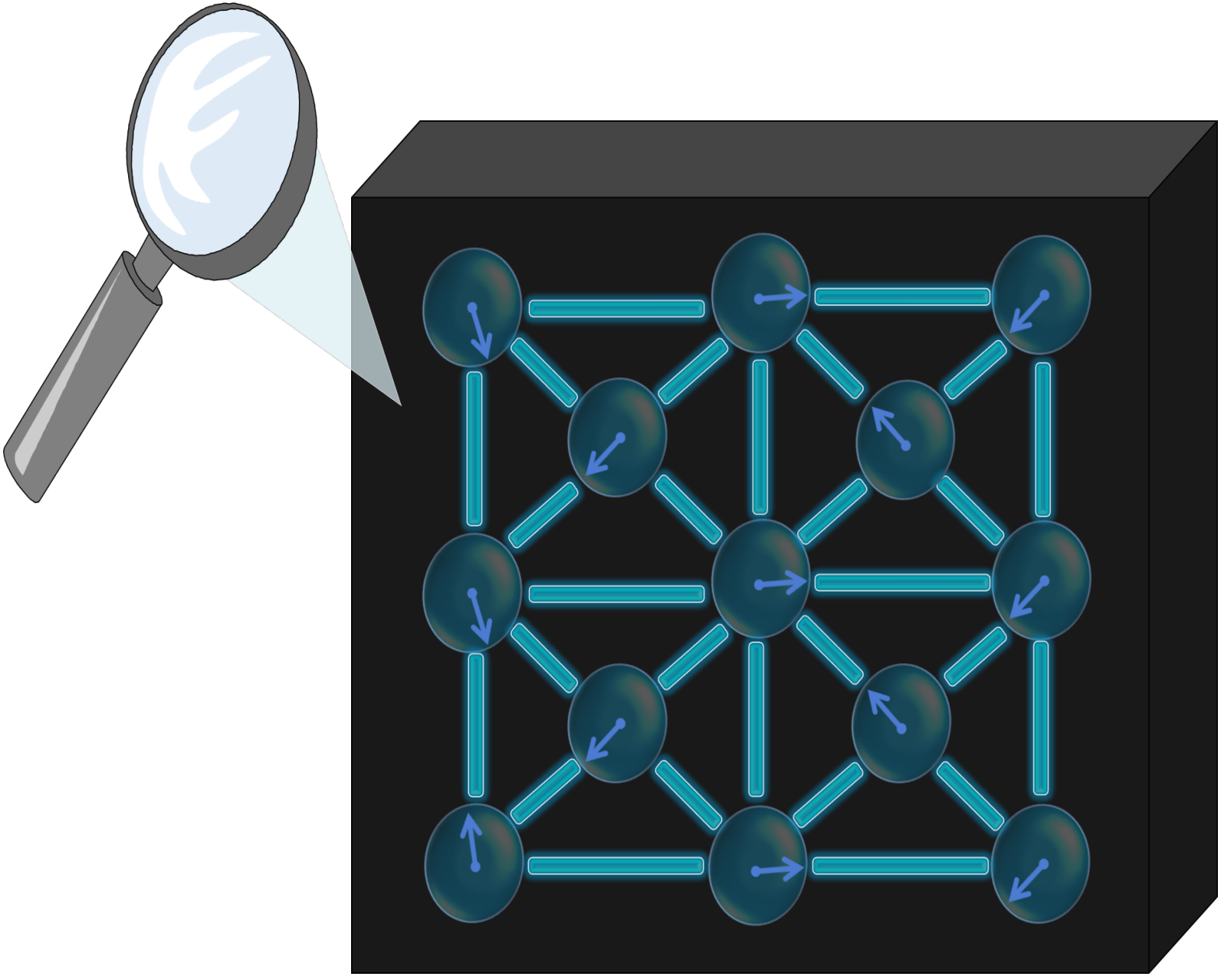
Quantification

- $f(\rho) \geq 0$
- $f(\rho) = 0 \iff \rho$ doesn't have the property
- $f(\rho)$ is the figure of merit in some protocol

Quantification



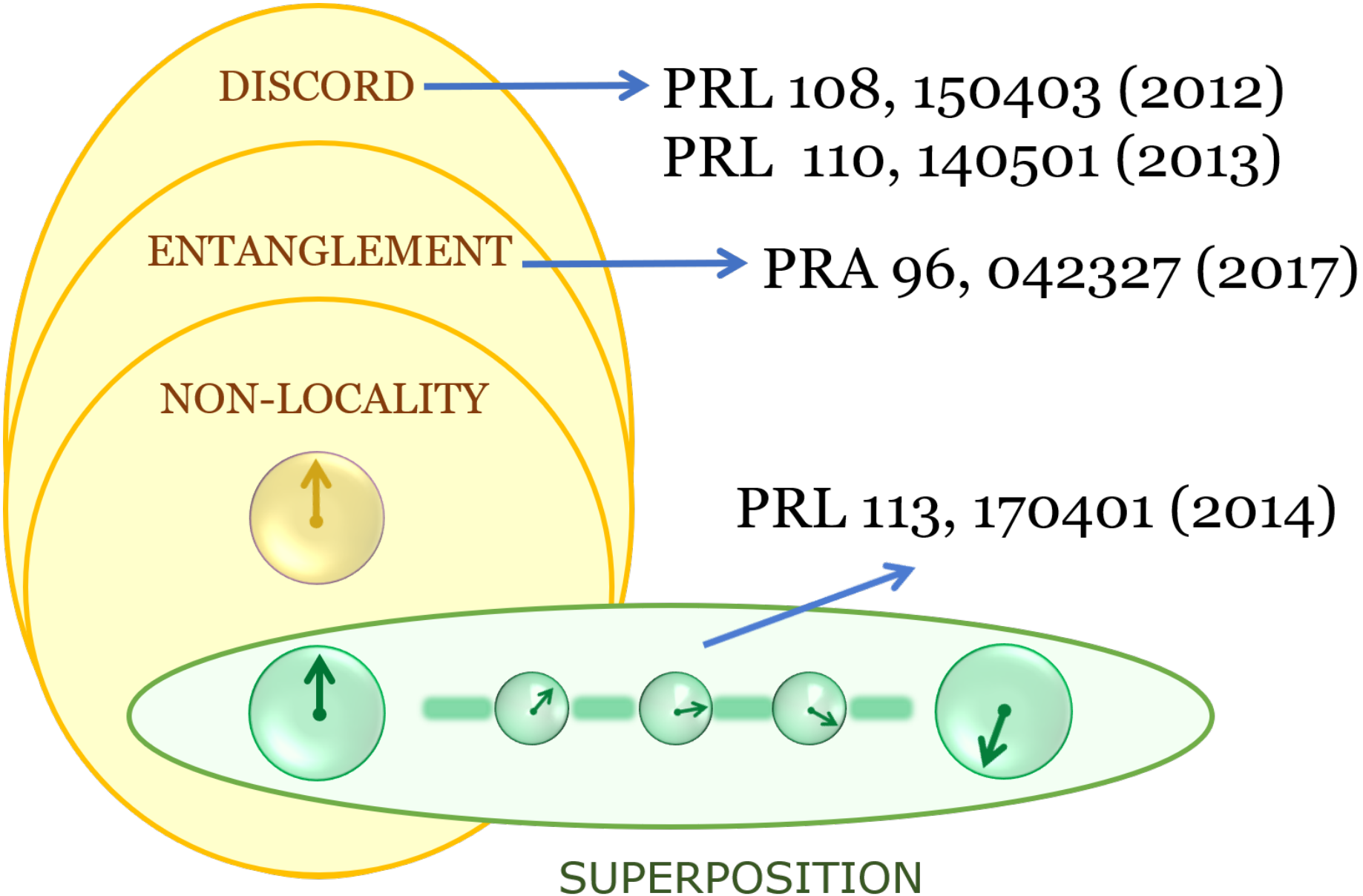
Detection



Detection

- $\star$ $O(4^n)$ measurements to reconstruct ρ
- $\star$ $f(\rho)$ is never linear!
- $\star$ Witness $\langle O \rangle \geq 0 \Rightarrow f(\rho) > 0$
- $\star$ Experimental scheme to evaluate $\langle O \rangle$ with $O(2^n)$ measurements

Detection


DISCORD
ENTANGLEMENT
NON-LOCALITY
SUPERPOSITION
PRL 108, 150403 (2012)
PRL 110, 140501 (2013)
PRA 96, 042327 (2017)
PRL 113, 170401 (2014)

2B How difficult is it to prepare a quantum state?

PRL 122, 010505 (2019), Editors' Suggestion

Creation of Resources

- $|001010\rangle \rightarrow |101011\rangle$ is free
- $Had\,|0\rangle = (|0\rangle + |1\rangle)/\sqrt{2} := |+\rangle$
- $U_{CNOT}\,|+\rangle\,|0\rangle = (|00\rangle + |11\rangle)/\sqrt{2}$
- How many gates for $\rho \rightarrow \tau$?

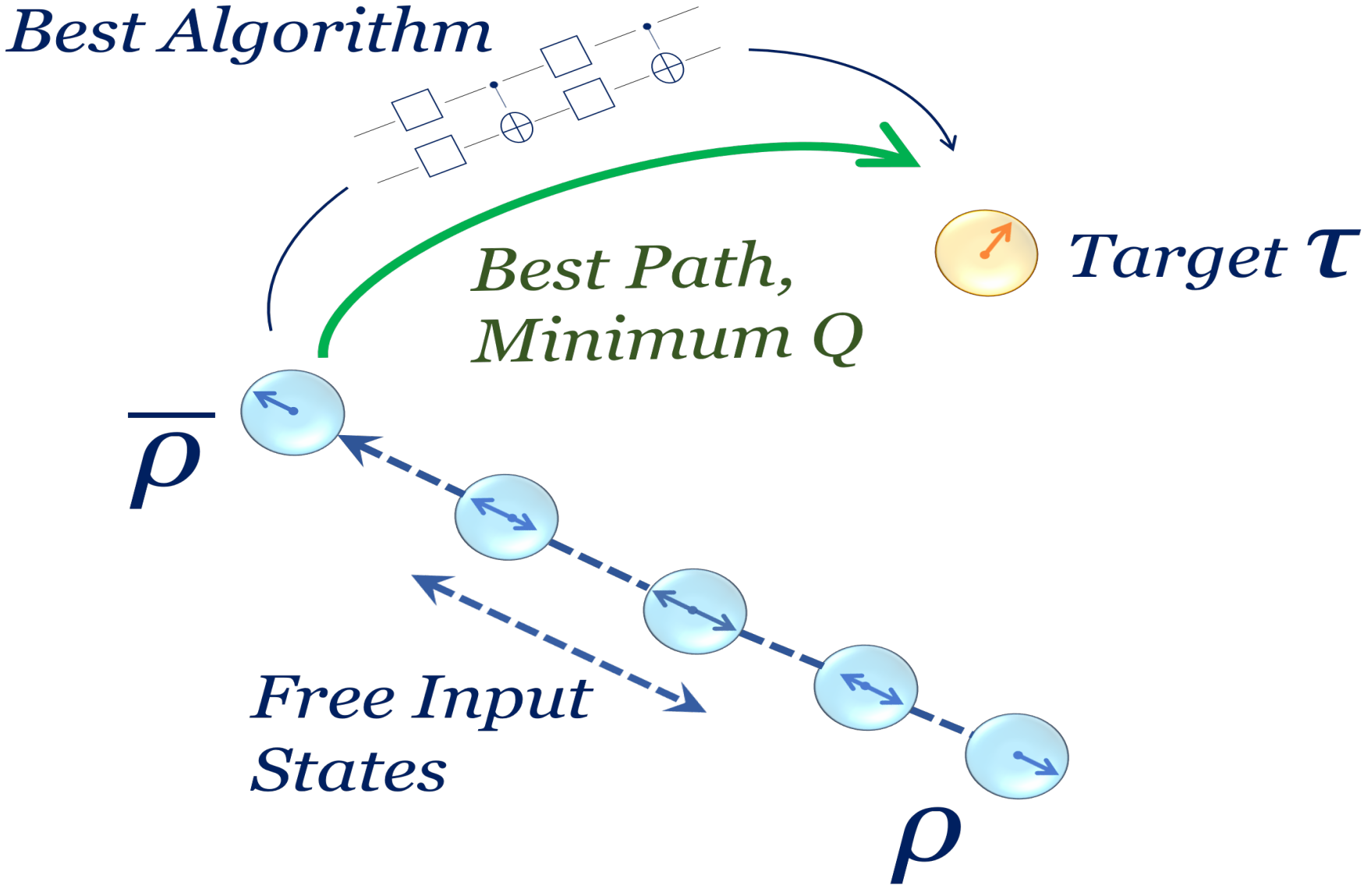
Problem

- ⋆ Task: $\rho \to \tau, [\rho, \tau] \neq 0$
- ⋆ Quantumness of the process?
- ⋆ Bound on coherence creation?
- ⋆ Bound on gates?

- ⋆ Classical, free processes: $[\Lambda_t(\rho), \rho] = 0, \forall t$

- ⋆ Split in classical + quantum process
  $\Lambda_T^c : \rho \to \bar{\rho}, [\bar{\rho}, \rho] = 0$
  $\Lambda_T^q : \bar{\rho} \to \tau = U_T \rho U_T^\dagger$

- ⋆ $C_\rho(\tau) = \min_\sigma d(\tau, \sigma), [\sigma, \rho] = 0$


Best Algorithm
Target τ
Best Path,
Minimum Q
ρ̄
Free Input
States
ρ

Quantumness of the process

$$\begin{aligned} \boldsymbol{Q}_\tau(\rho) &= \min_{\Lambda_t^q} \int_0^T ||d_t \Lambda_t^q||^2 dt \\ &\geq \boldsymbol{C}_\rho^2(\tau)/\boldsymbol{T} \end{aligned}$$

Bound for commuting gates

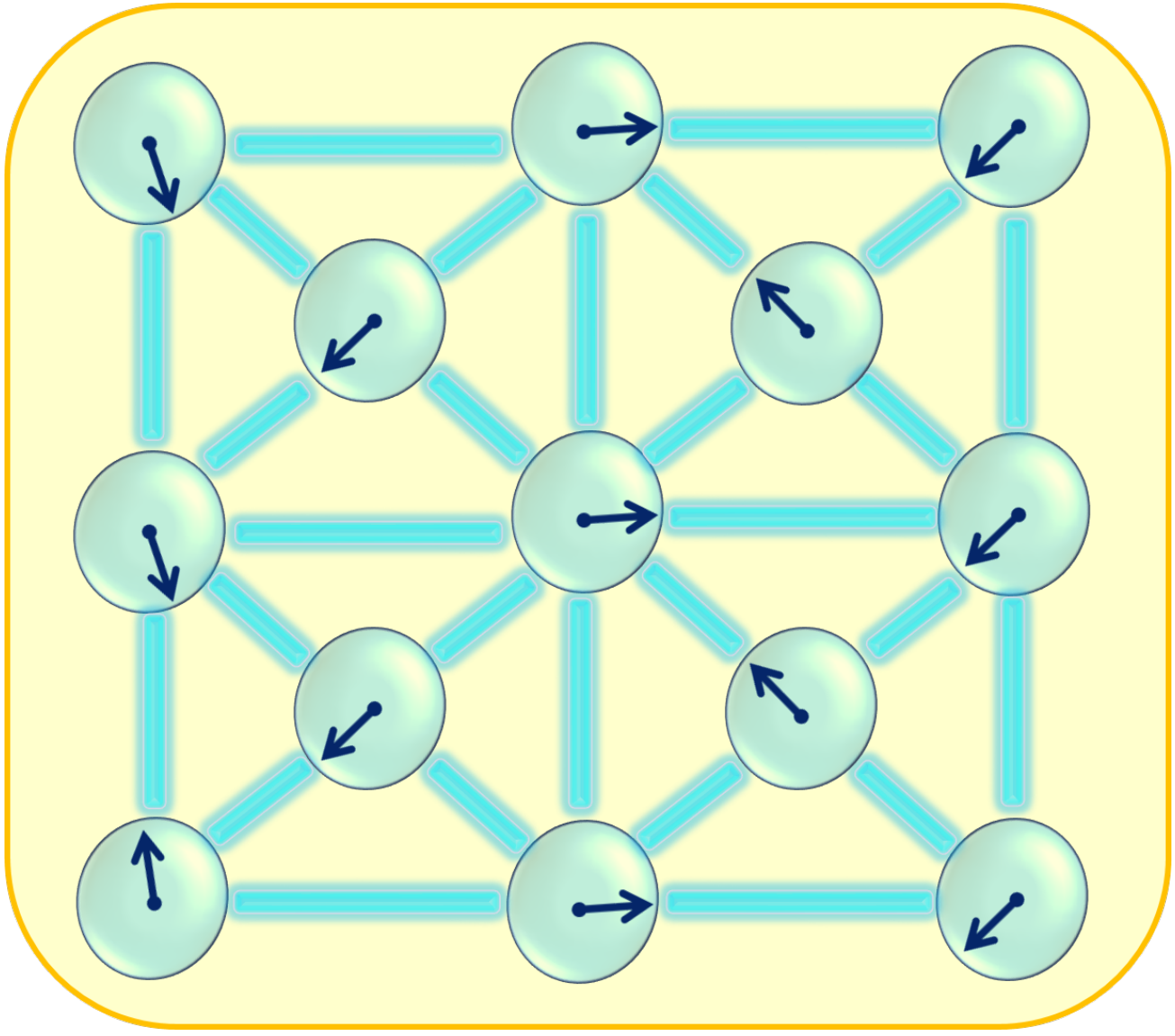
$\star\ \tau = \Lambda_T^q(\bar{\rho}) = e^{-iHT}\ \bar{\rho}\, e^{iHT}$,
$H = \sum_i H_i, [H_i, H_j] = 0$

$\star\ h^i = |h^i_{max} - h^i_{min}|$

$$N \geq \frac{2}{\bar{h}} \left(\frac{Q_\rho(\tau)}{T} \right)^{1/2} \geq C(\tau)/T$$

2C Future

Multipartite Quantum Resources

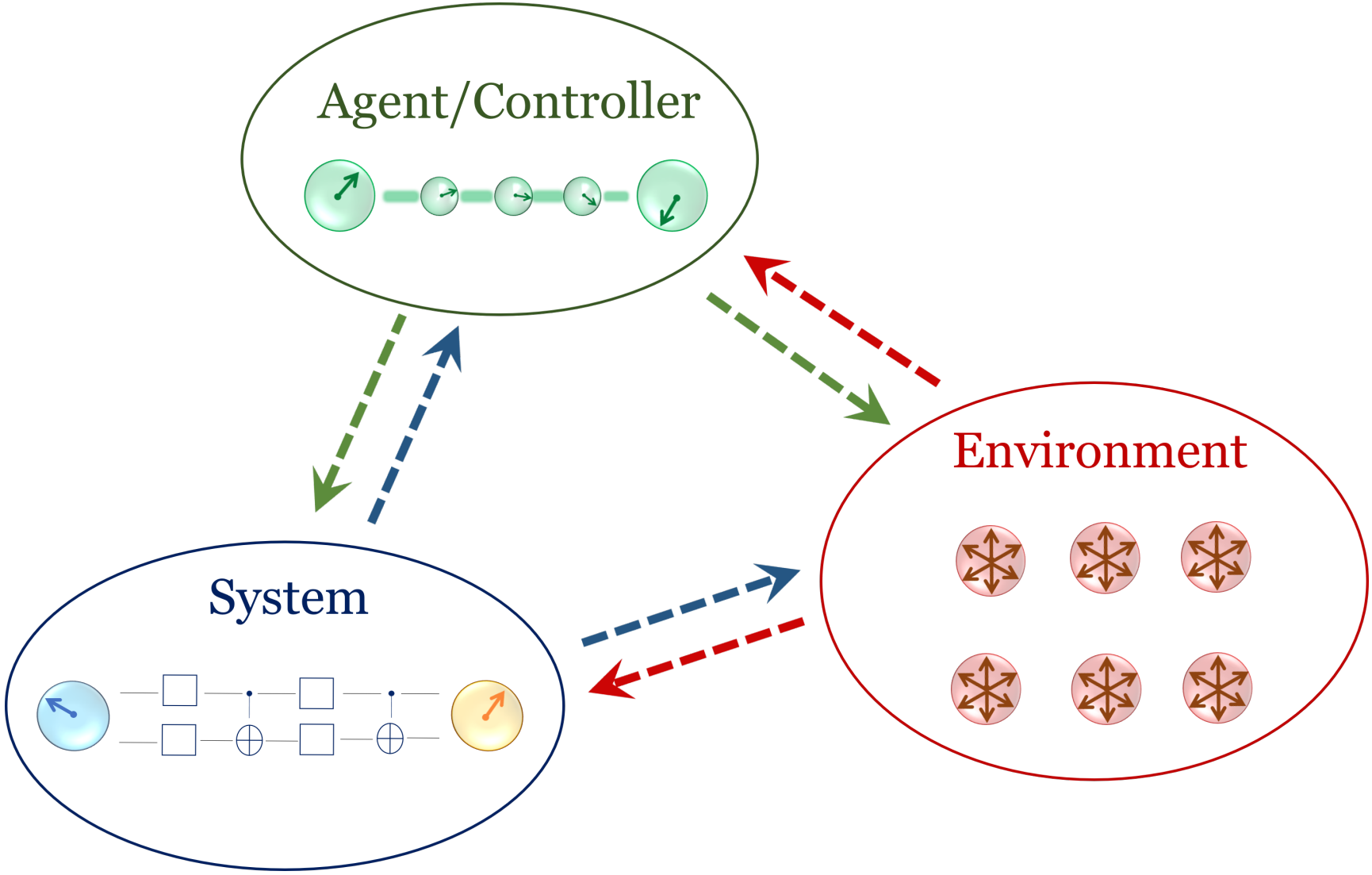


Questions

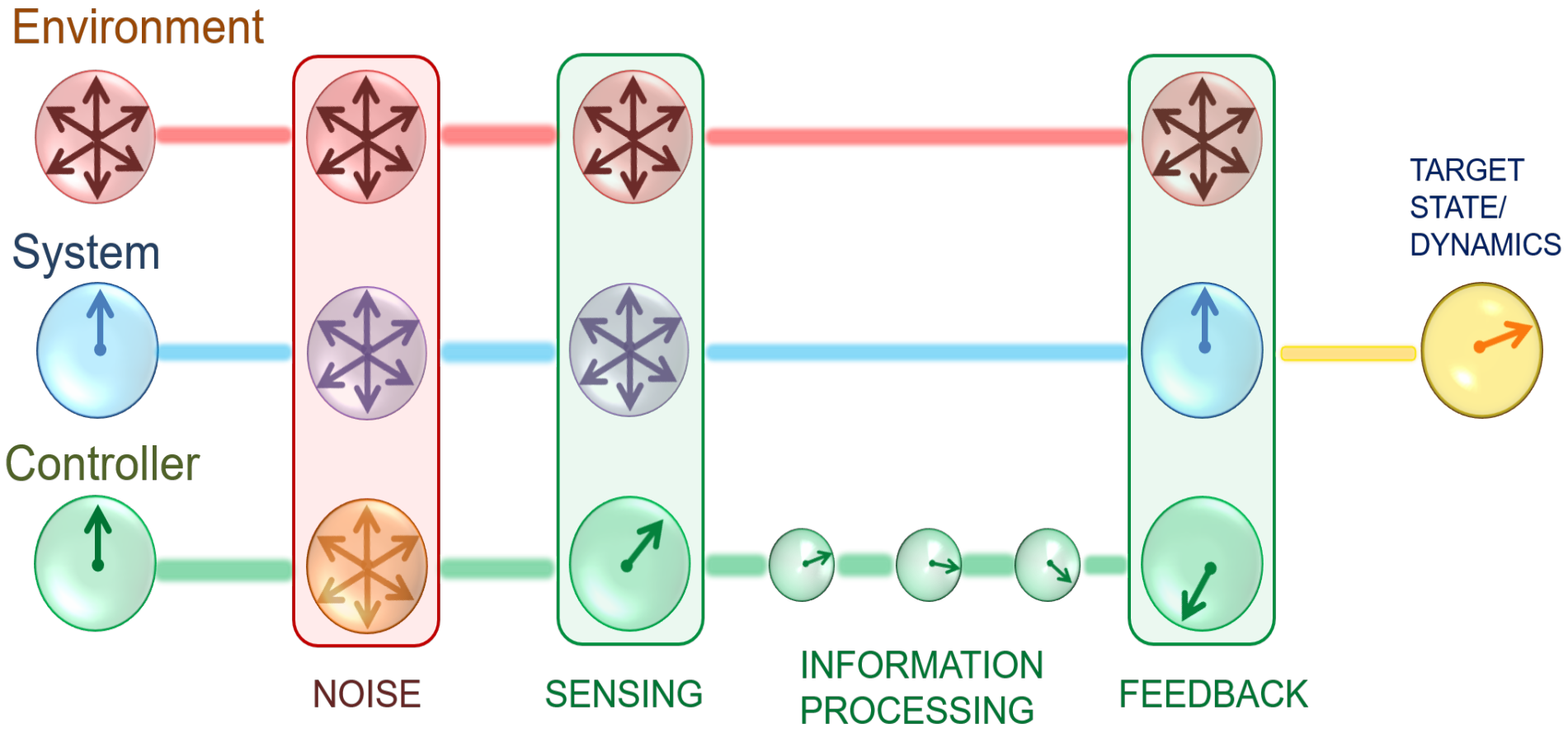
- ⋆ Quantifying k-partite correlations (some results)
- ⋆ Detection
- ⋆ Structure as power
- ⋆ Manipulation

D. Girolami, C. Susa and T. Tufarelli, PRL 119, 140505 (2017)

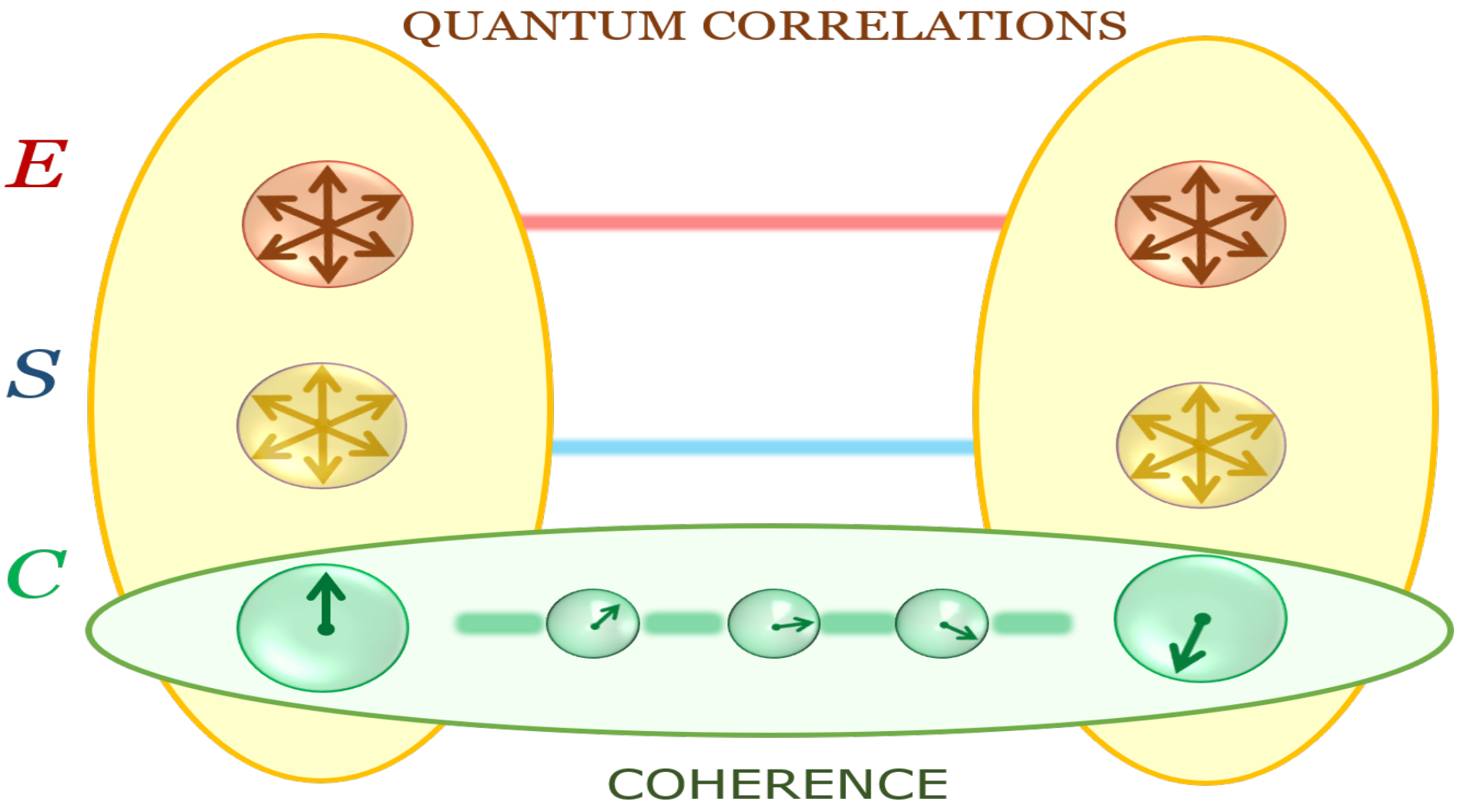
Quantum Resources for Control



How do quantum systems think?



How do quantum systems think?



Causality vs Correlations

- ⋆ Controllability: Correlations or Causality?
- ⋆ Quantifying Controllability
- ⋆ Classical Systems (robots), Quantum Systems, Networks

Summary

- ⋆ Quantum Information Science
- ⋆ Quantum Resources
- ⋆ Resources in bipartite noisy devices
- ⋆ How difficult is it to prepare a quantum state?
- ⋆ Future: Resources for many-body processes, control

The End

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