Title: An Introduction to One-Way Patterns

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Abstract: The one-way measurement model is a model of quantum computation which is intriguing for its' potential as a means of implementing quantum computers, but also for theoretical purposes for the different way in which it allows quantum operations to be described. Instead of a sequence of unitary gates on an array of ``wires'', operations are described in terms of emph{patterns}, consisting of a graph of entanglement relations on a set of qubits, together with a collection of measurement angles for these qubits (except possibly for a subset which will support a final quantum state). In this introductory talk, I describe the relationship between patterns in the one-way measurement model to quantum circuits, and explore patterns which represent unitary operations but which emph{don't} have direct analogues in the circuit model.

An introduction to one-way patterns

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CQISC 2007, Waterloo

Outline

1. Easily understood patterns
   - A somewhat different set of elementary gates
   - Unitary transformations via measurements
   - Building “measurement patterns”
   - Geometries with flows

2. [illegible]
   - A pattern which doesn't have a flow
   - Adaptation − correction = postselection
   - Finding correction schemes
   - My current research

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Universal quantum computation

Controlled-not ($\wedge X$) and the set of all one-qubit operations are universal for quantum computation

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- These can be generated by controlled-Z, Hadamard, and arbitrary phase gates:

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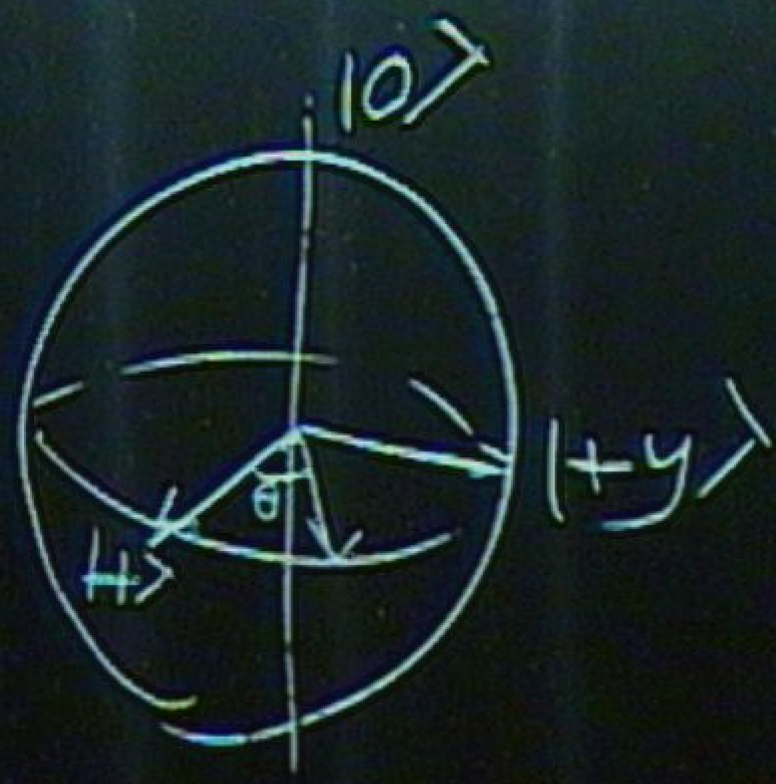
Unitary transformations via measurements

$J(-\theta)$ can be performed using $|\pm_\theta\rangle \propto |0\rangle \pm e^{i\theta}|1\rangle$ measurements



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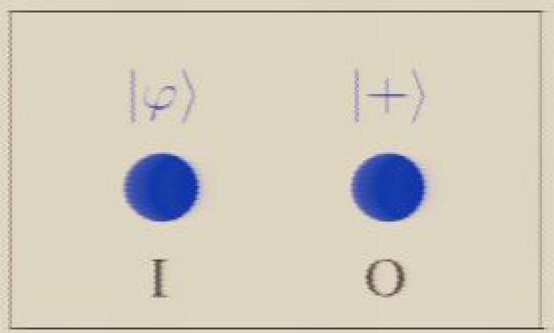

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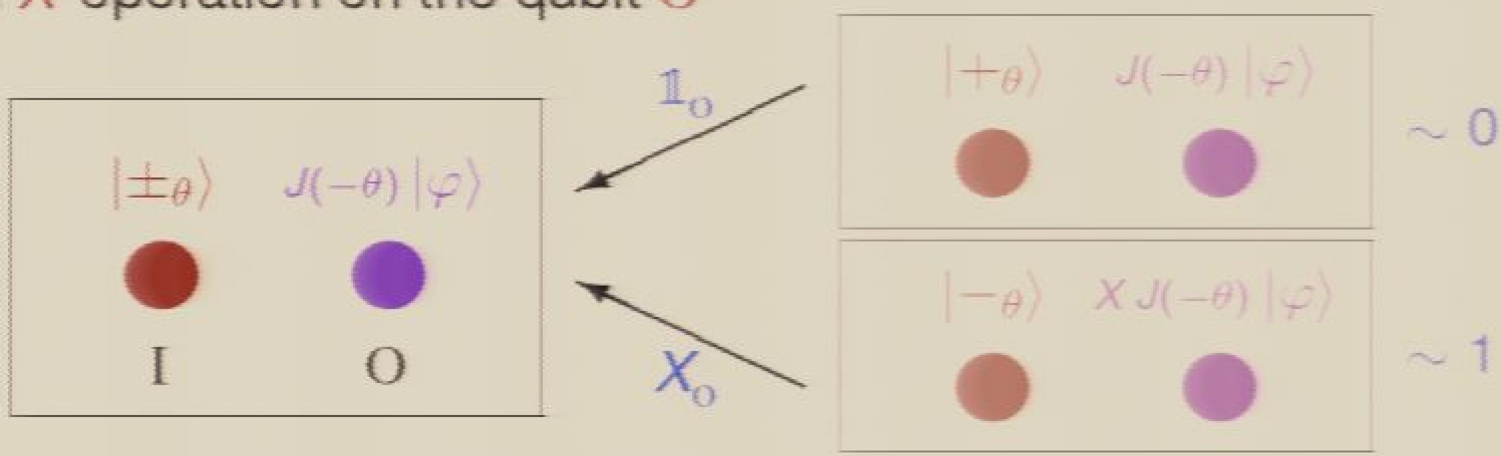

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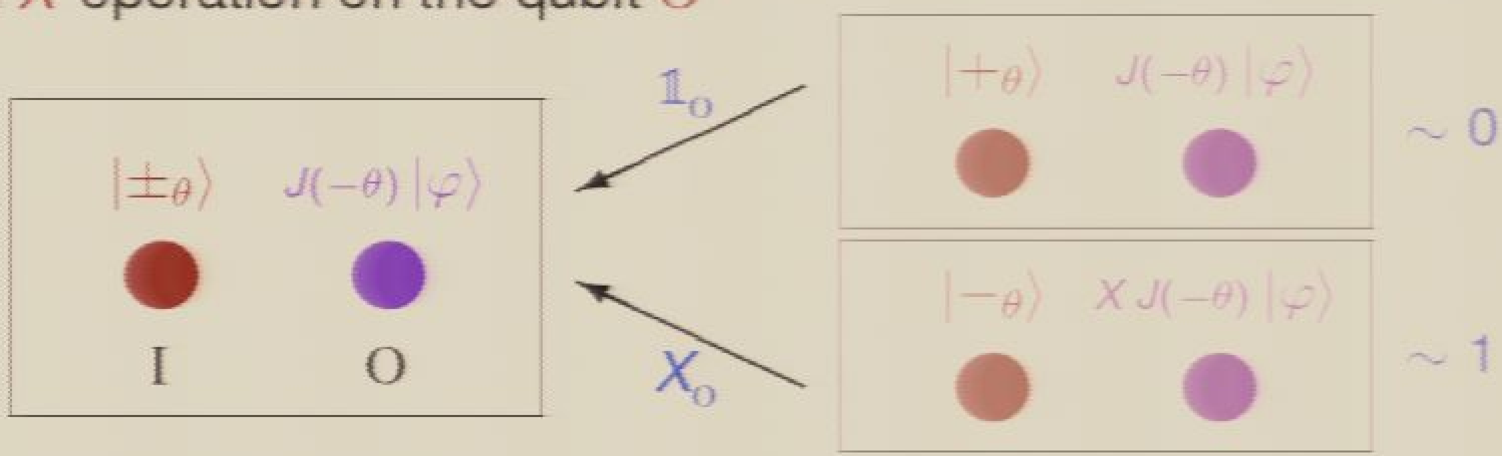

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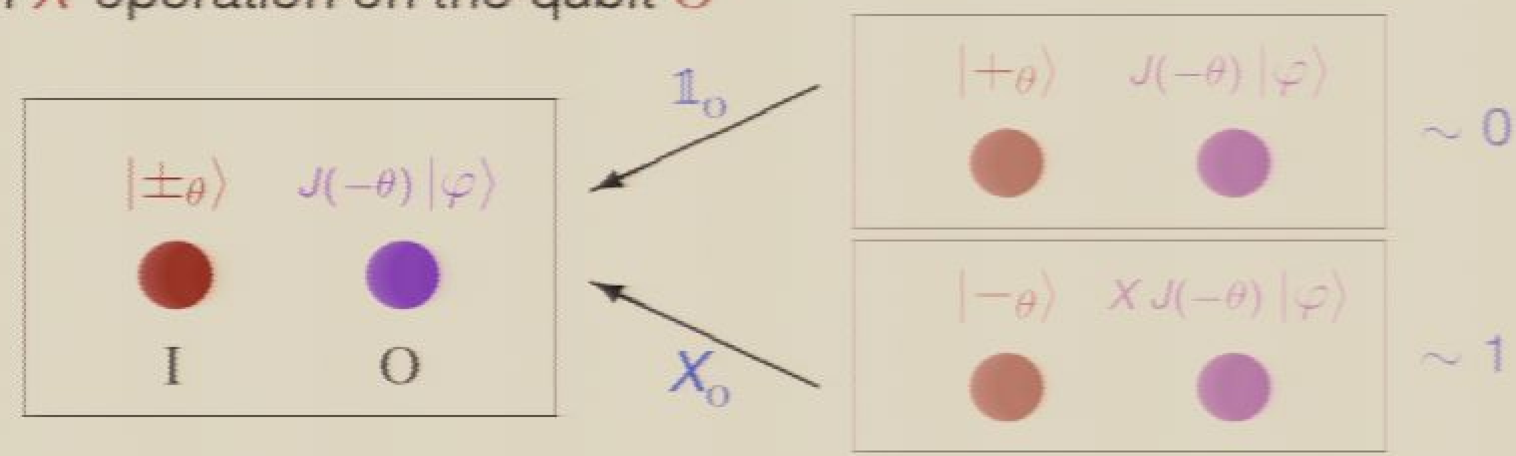

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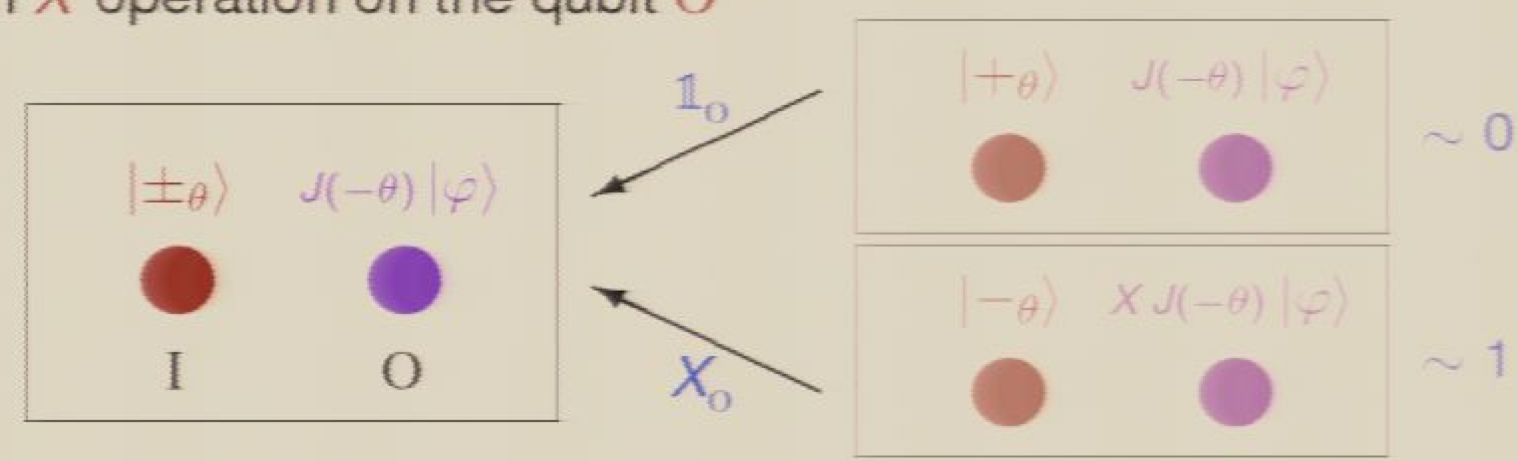

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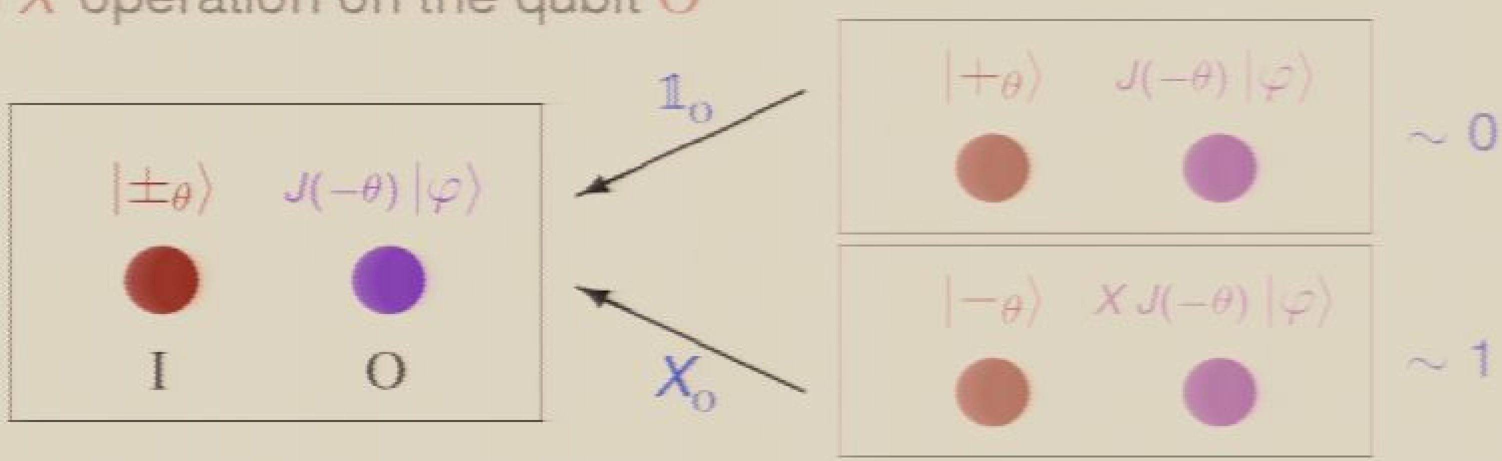

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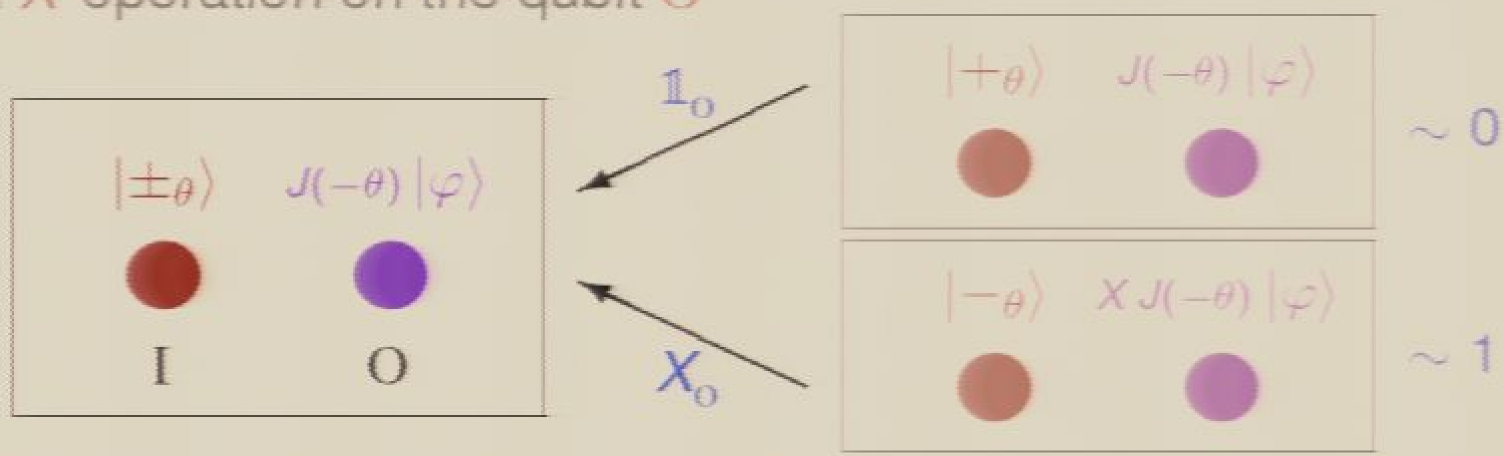

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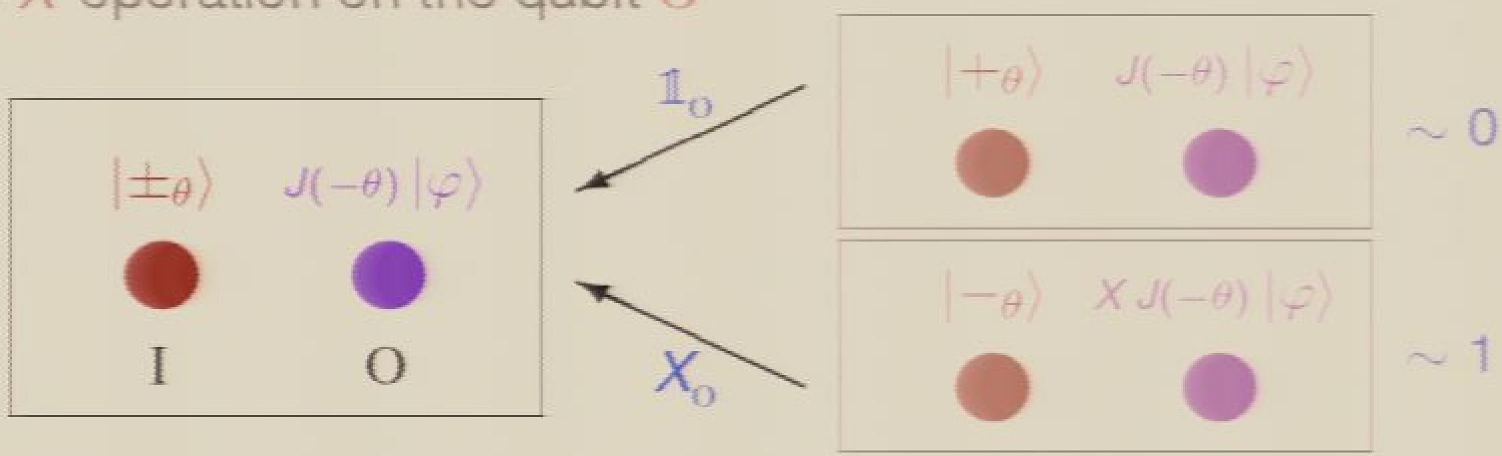

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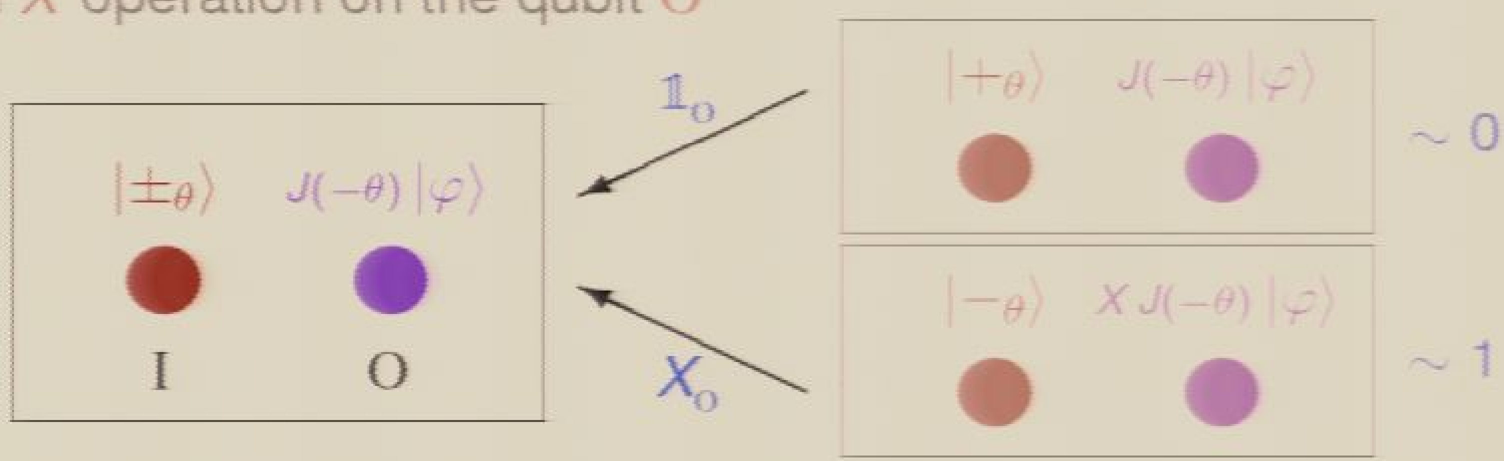

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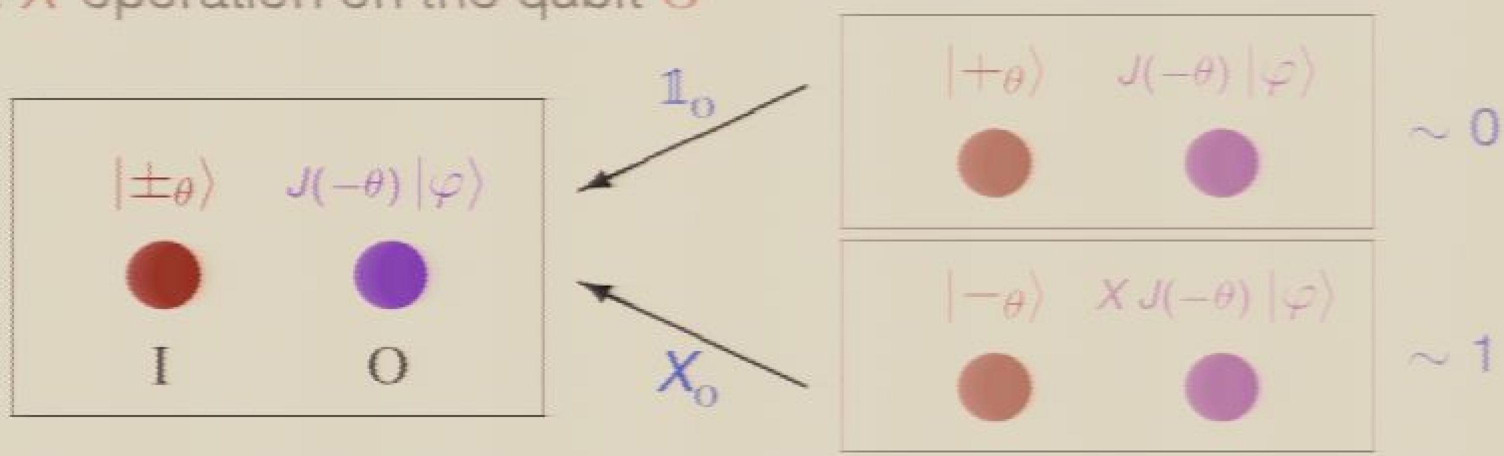

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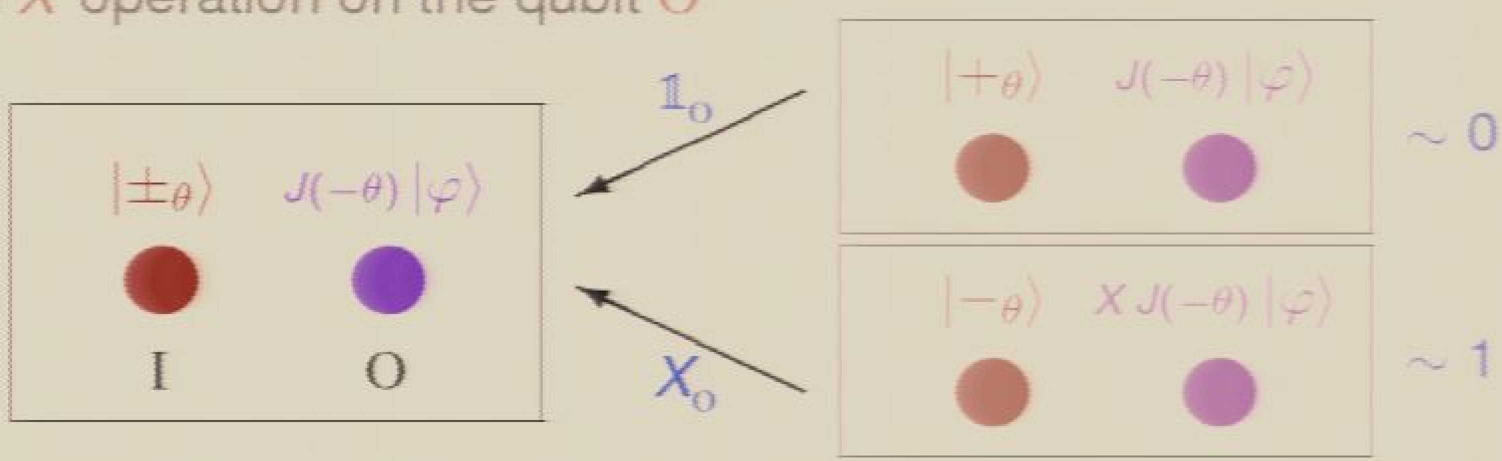

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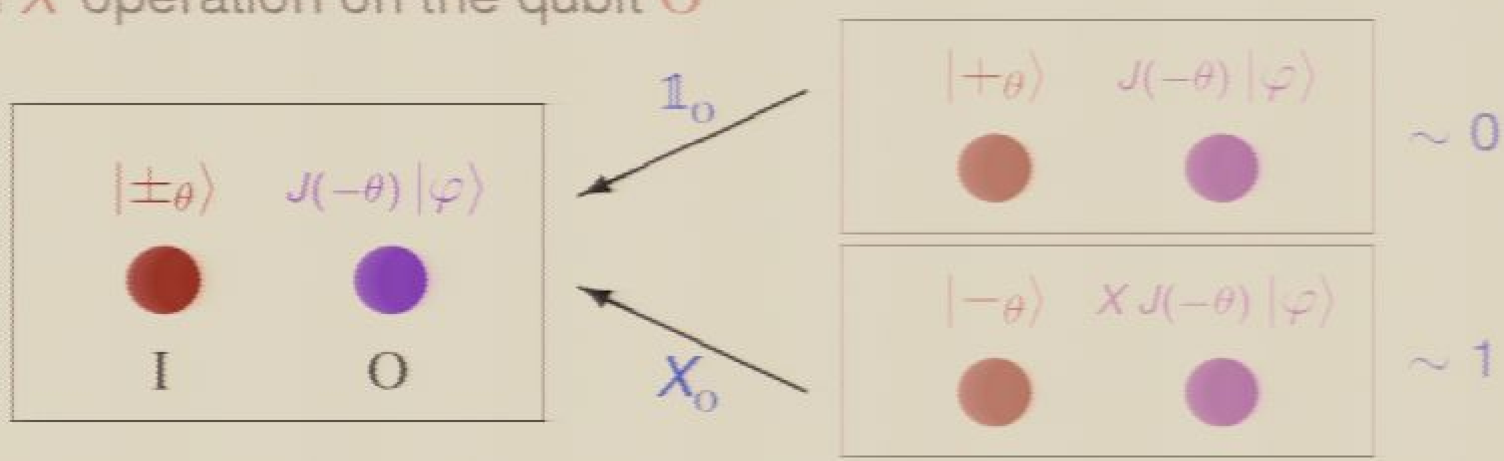
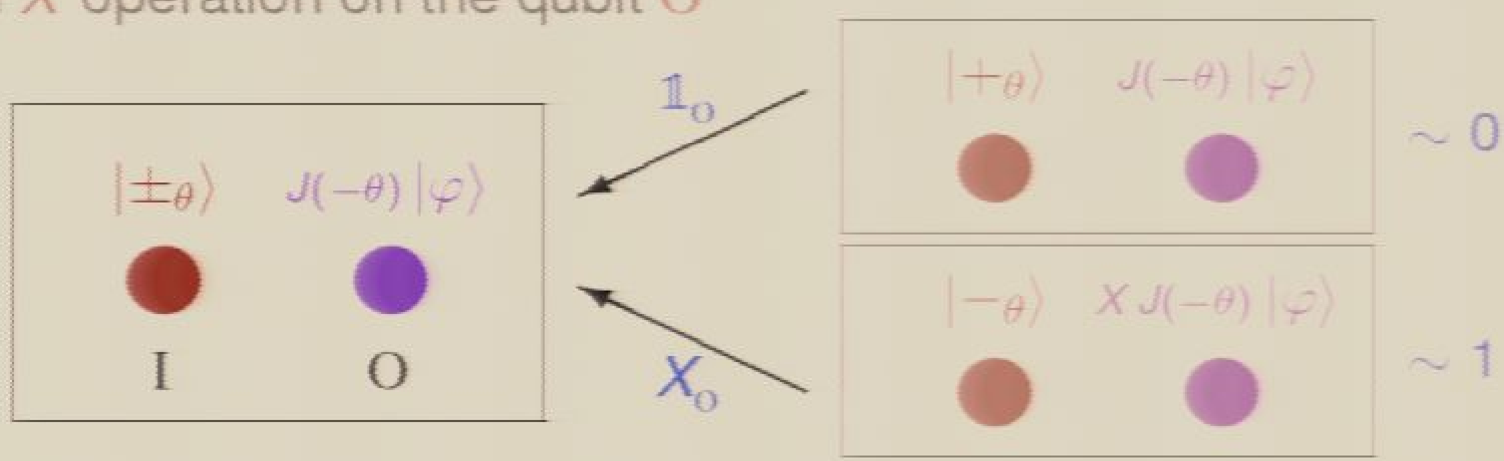


Unitary transformations via measurements

$J(-\theta)$ can be performed using $|\pm_\theta\rangle \propto |0\rangle \pm e^{i\theta}|1\rangle$ measurements

- Take a state $|\varphi\rangle$ on an *input qubit* I, and prepare an *output qubit* O in the state $|+\rangle$
- Perform a controlled-Z operation on I and O
- *Measure* the qubit I in the $|+_\theta\rangle$, $|-_\theta\rangle$ basis
  …record the result as 0 for $|+_\theta\rangle$, and 1 for $|-_\theta\rangle$
- If the measurement result is 1, perform an X operation on the qubit O

… and also $\wedge Z$
… and Pauli operations



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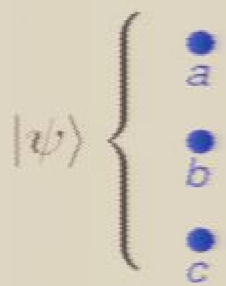

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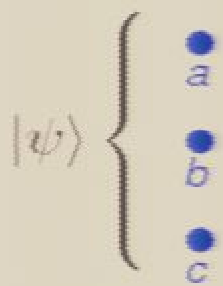

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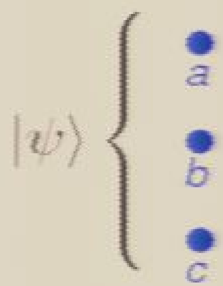

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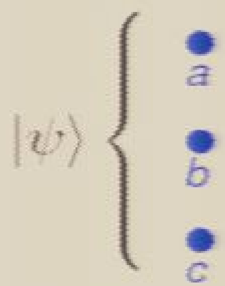

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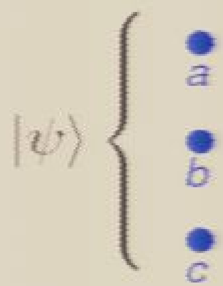

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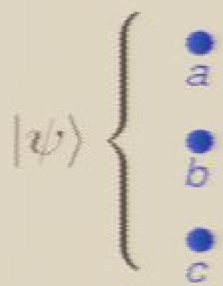

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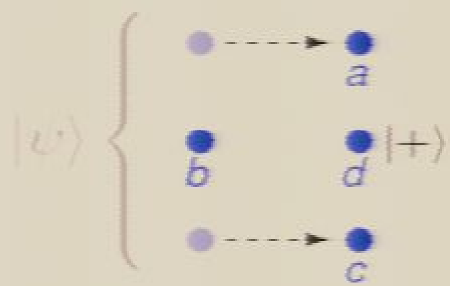

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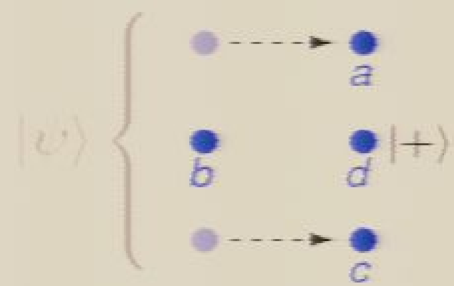

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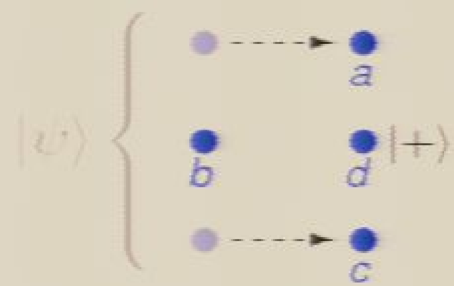

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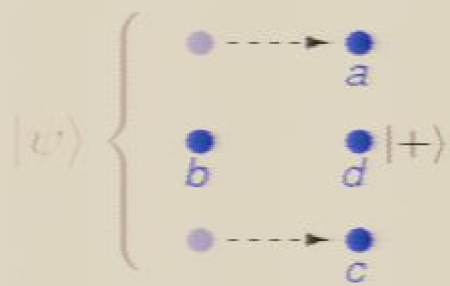

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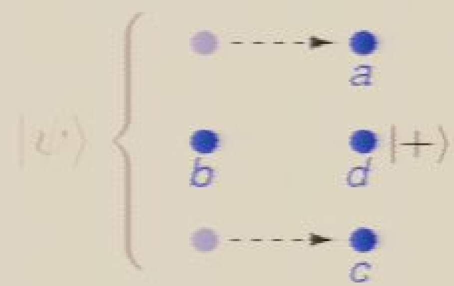

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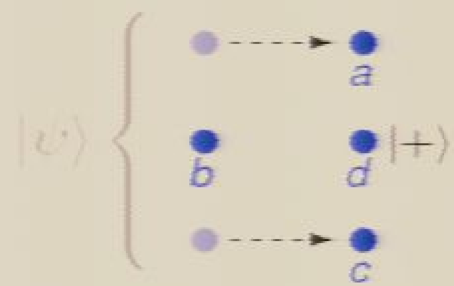

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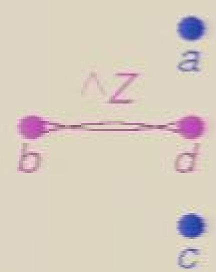

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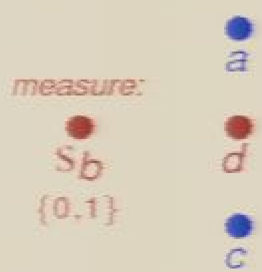

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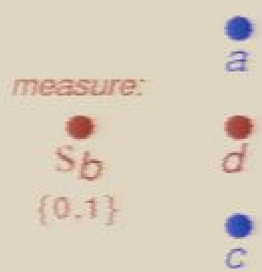

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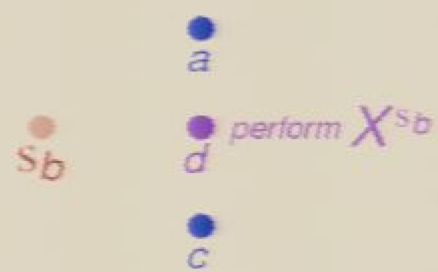

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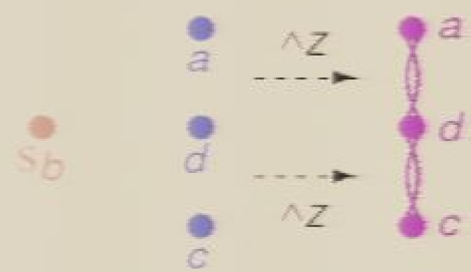

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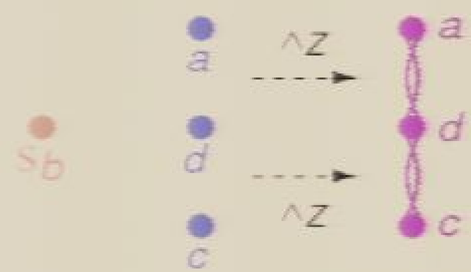

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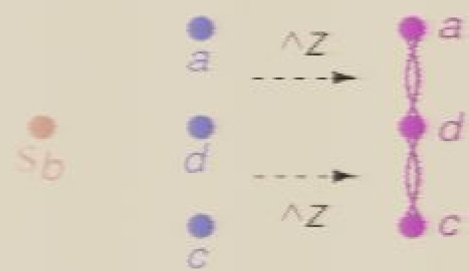

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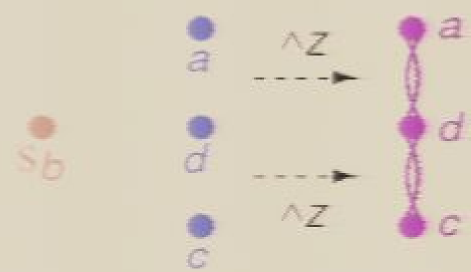

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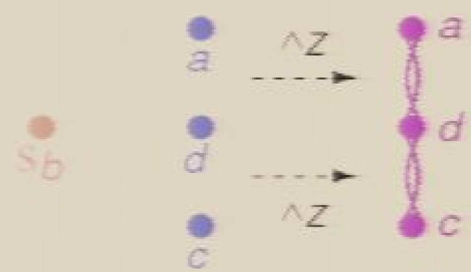

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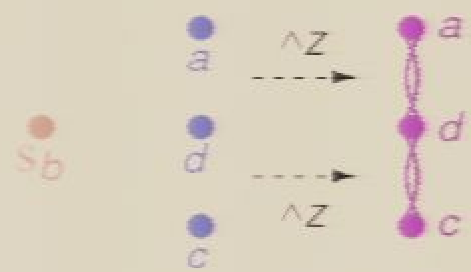

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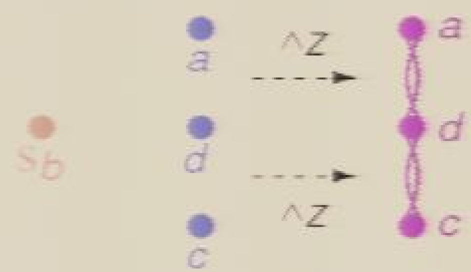

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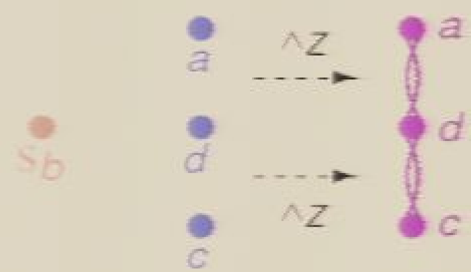

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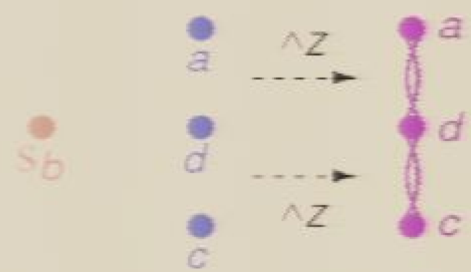

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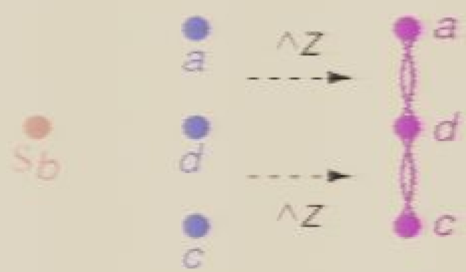

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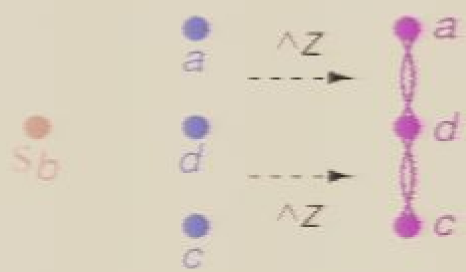

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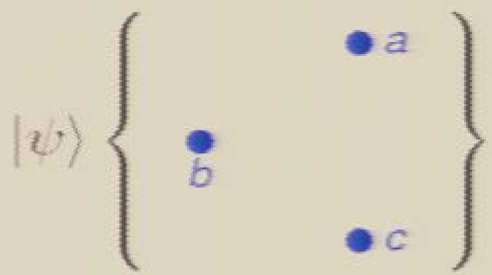

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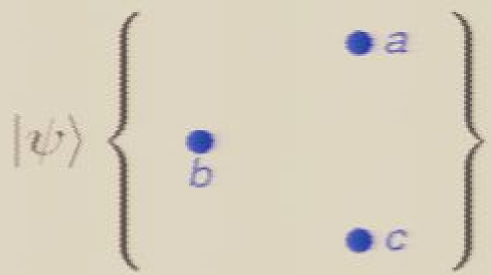

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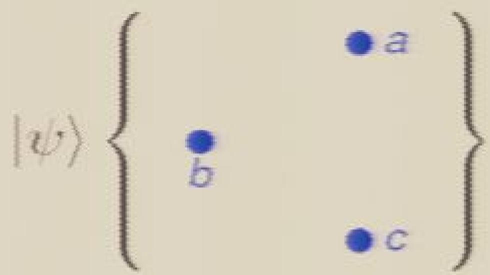

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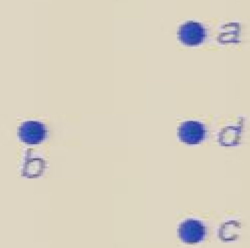

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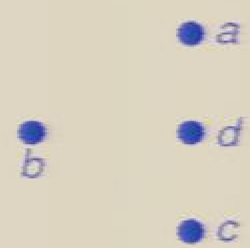

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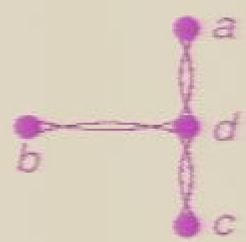

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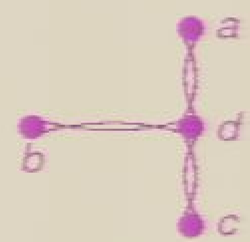

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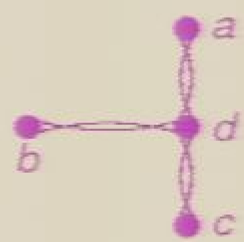

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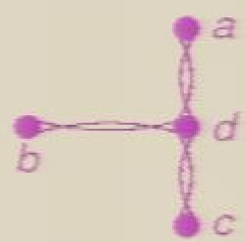

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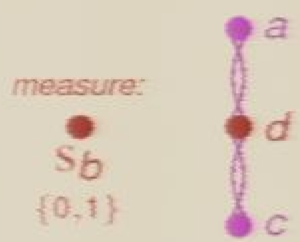

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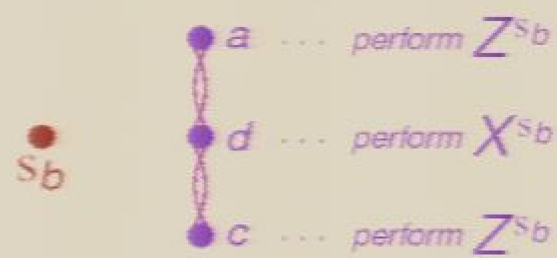

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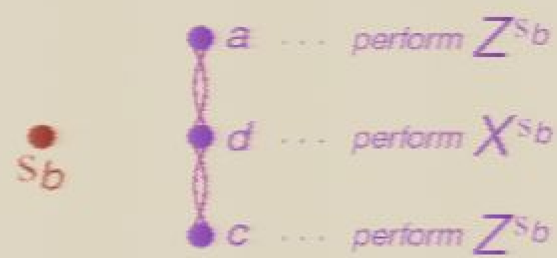

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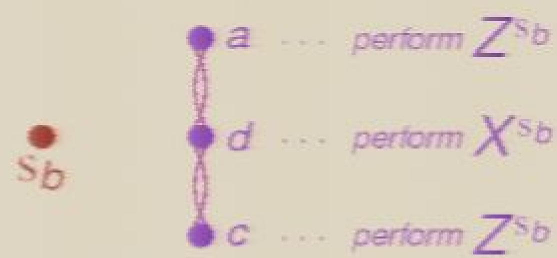

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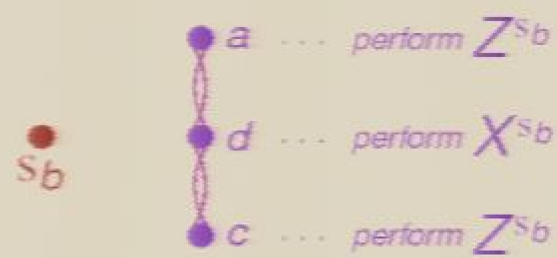

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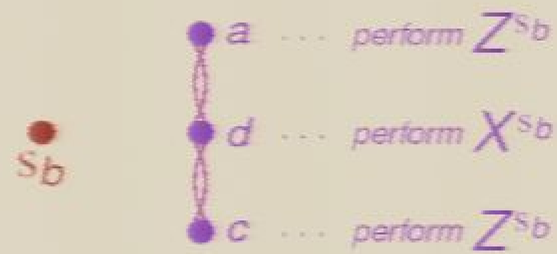

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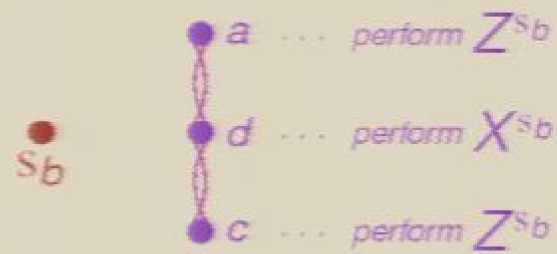

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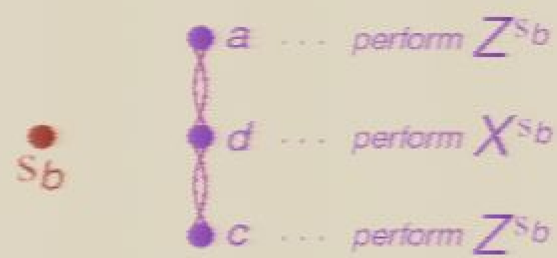

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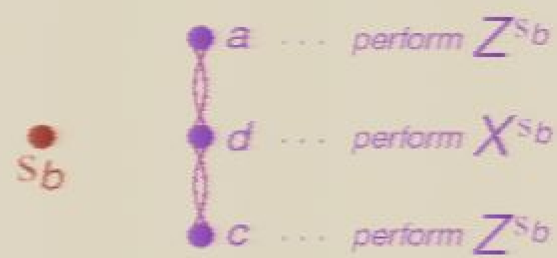

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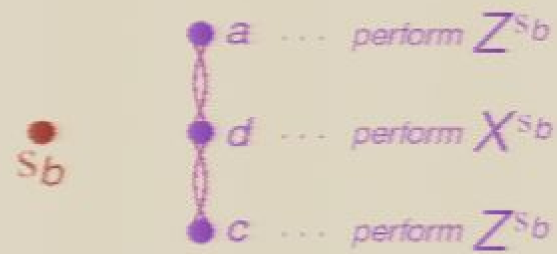

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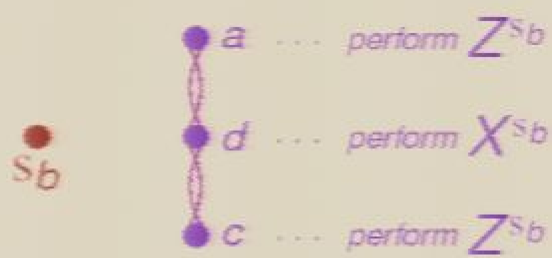

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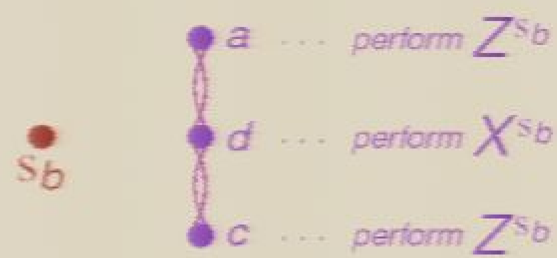

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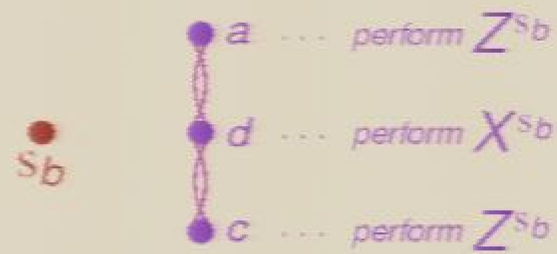

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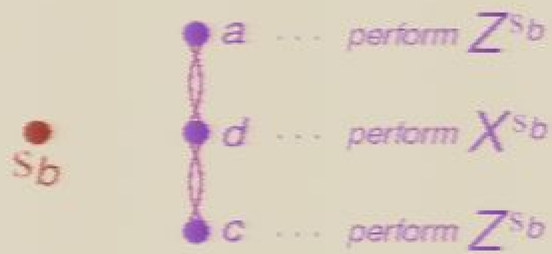

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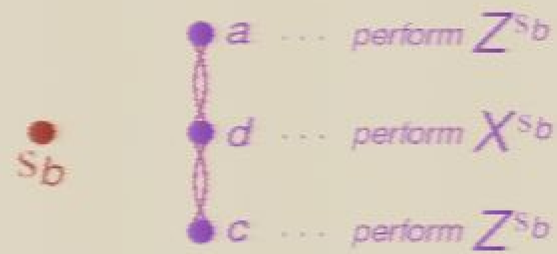

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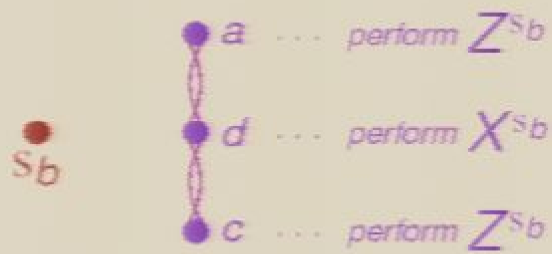

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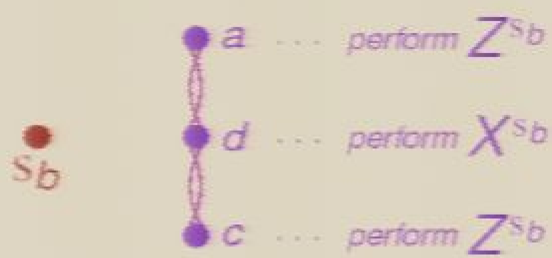

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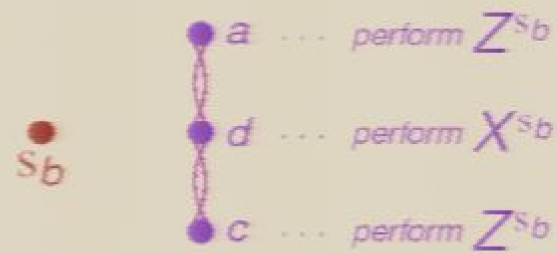

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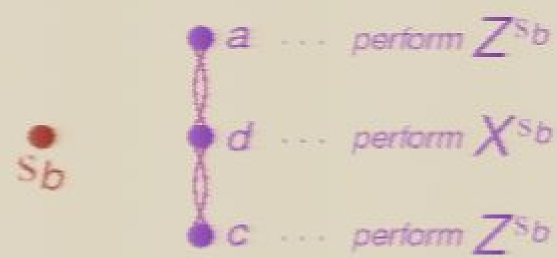

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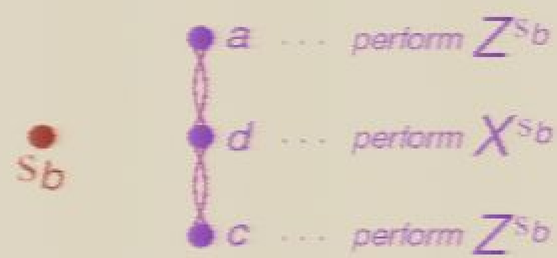

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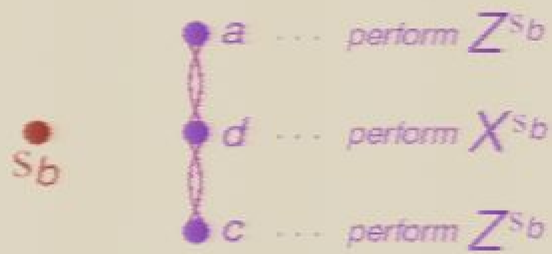

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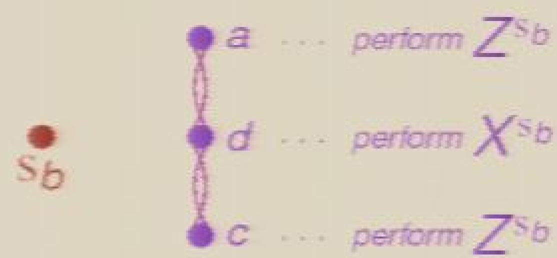

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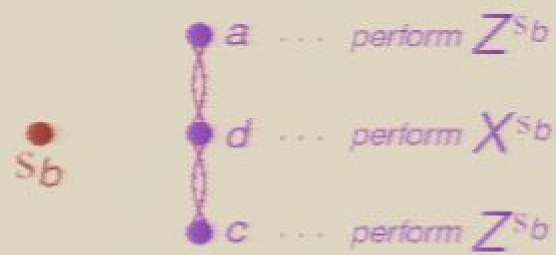

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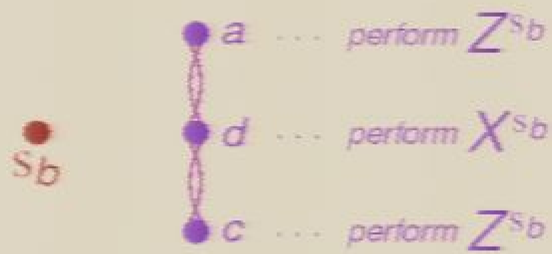

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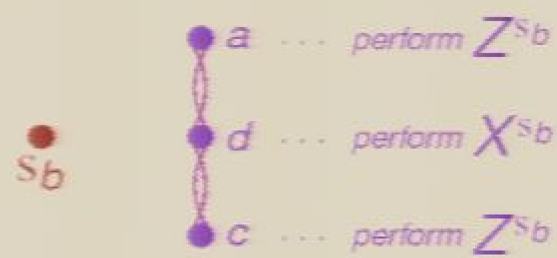

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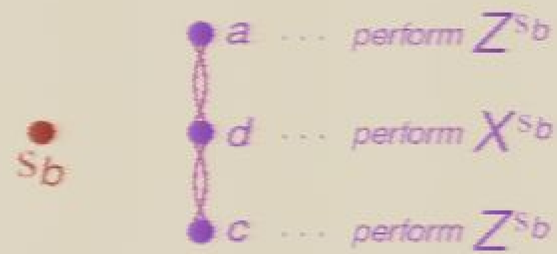

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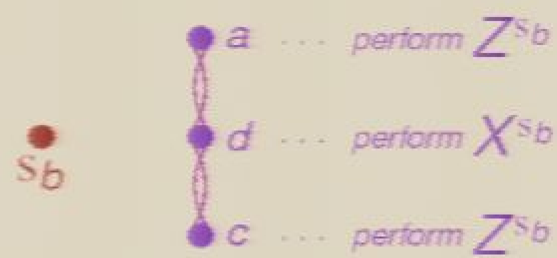

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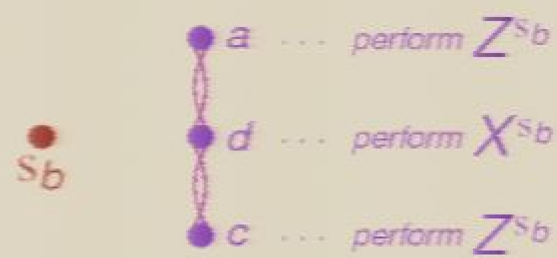

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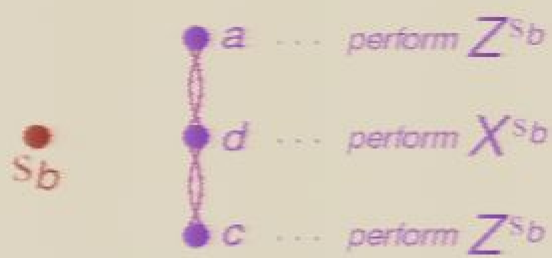

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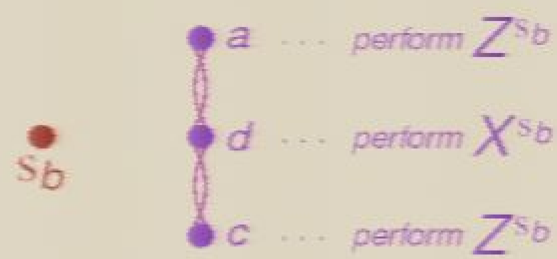

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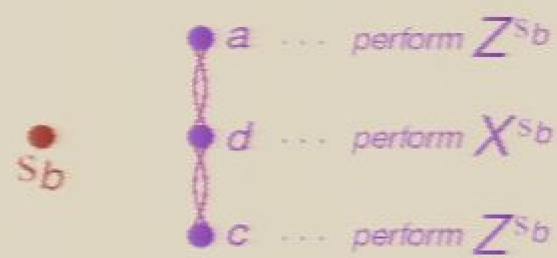

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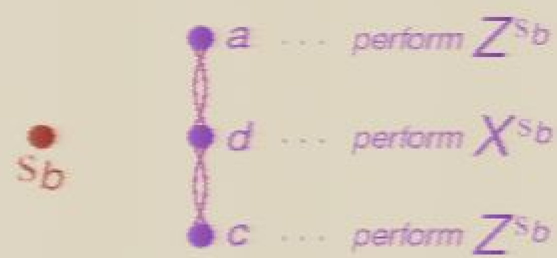

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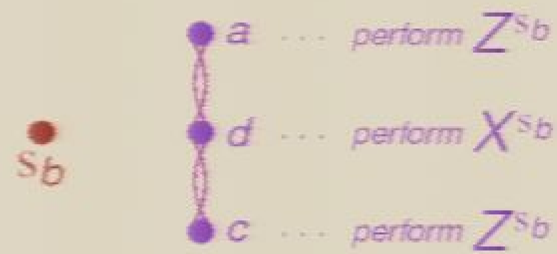

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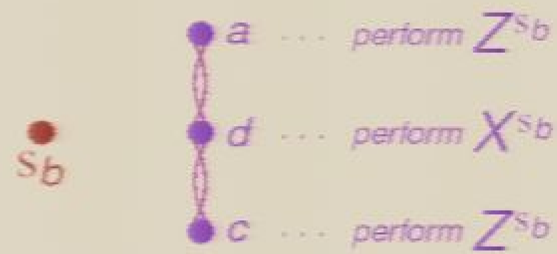

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What questions can we ask about this as a *model of computation*?

- Is the measurement order unique?
- Usually not: independent chains of qubit measurements...

- Can you discover a measurement order from partial information? (just the input/output sets and the entanglement operations)
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- Sometimes, yes — e.g. if the pattern has a flow.

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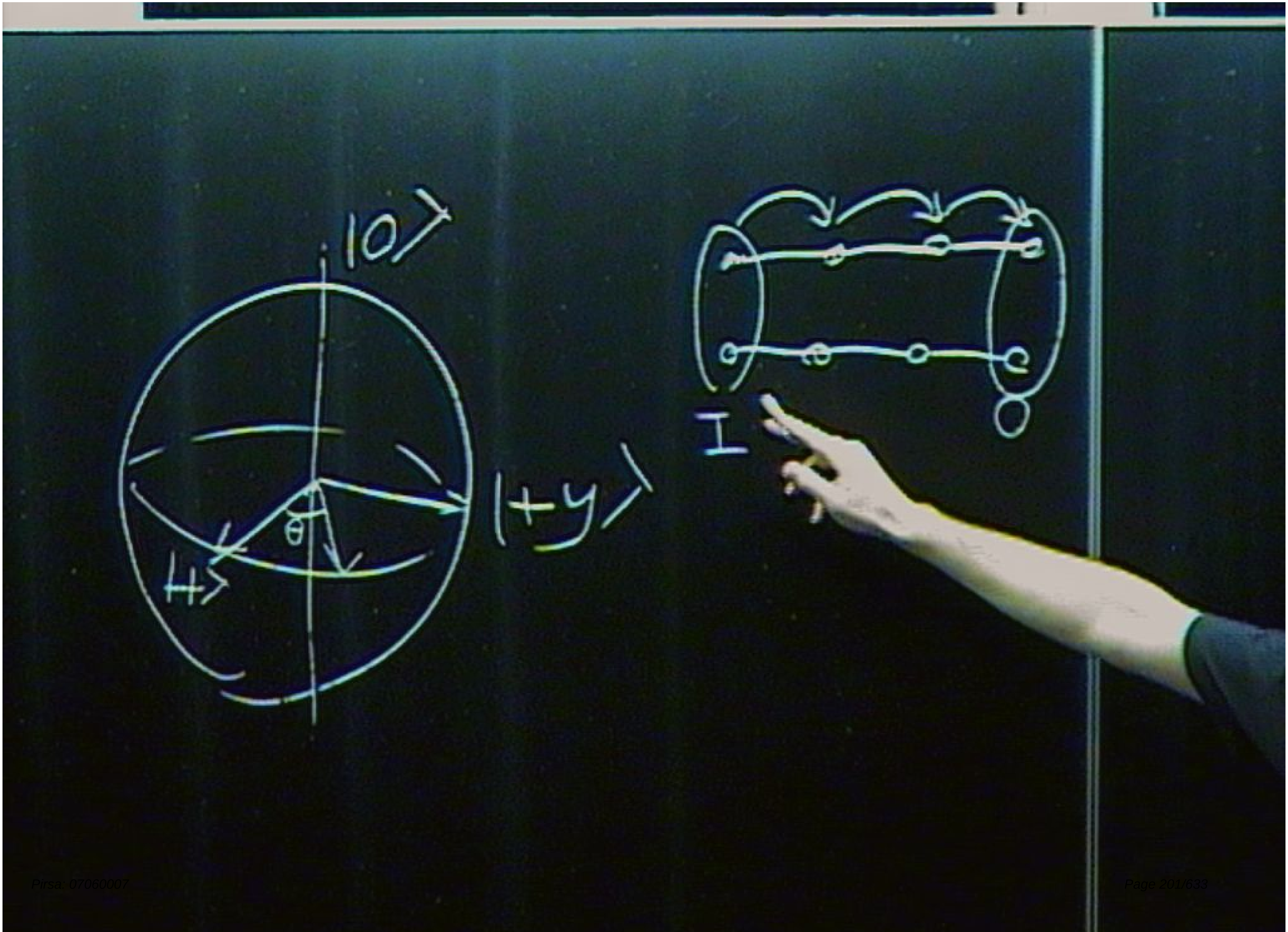
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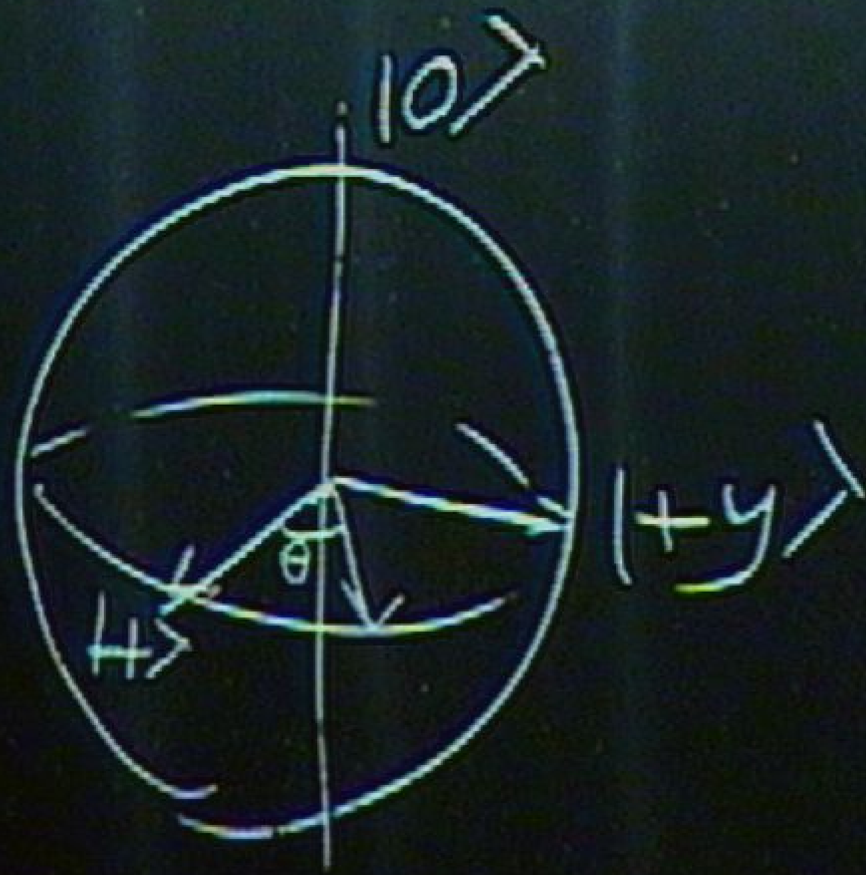
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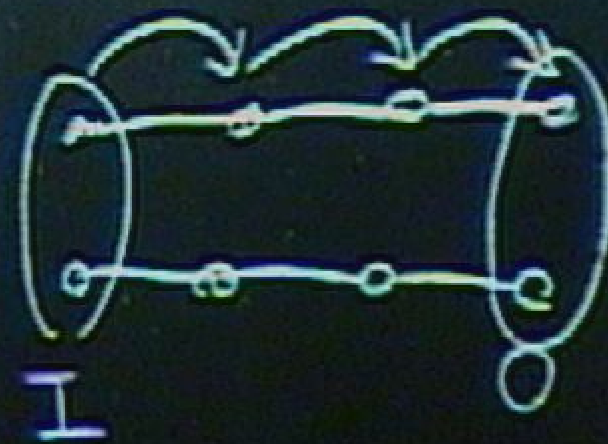
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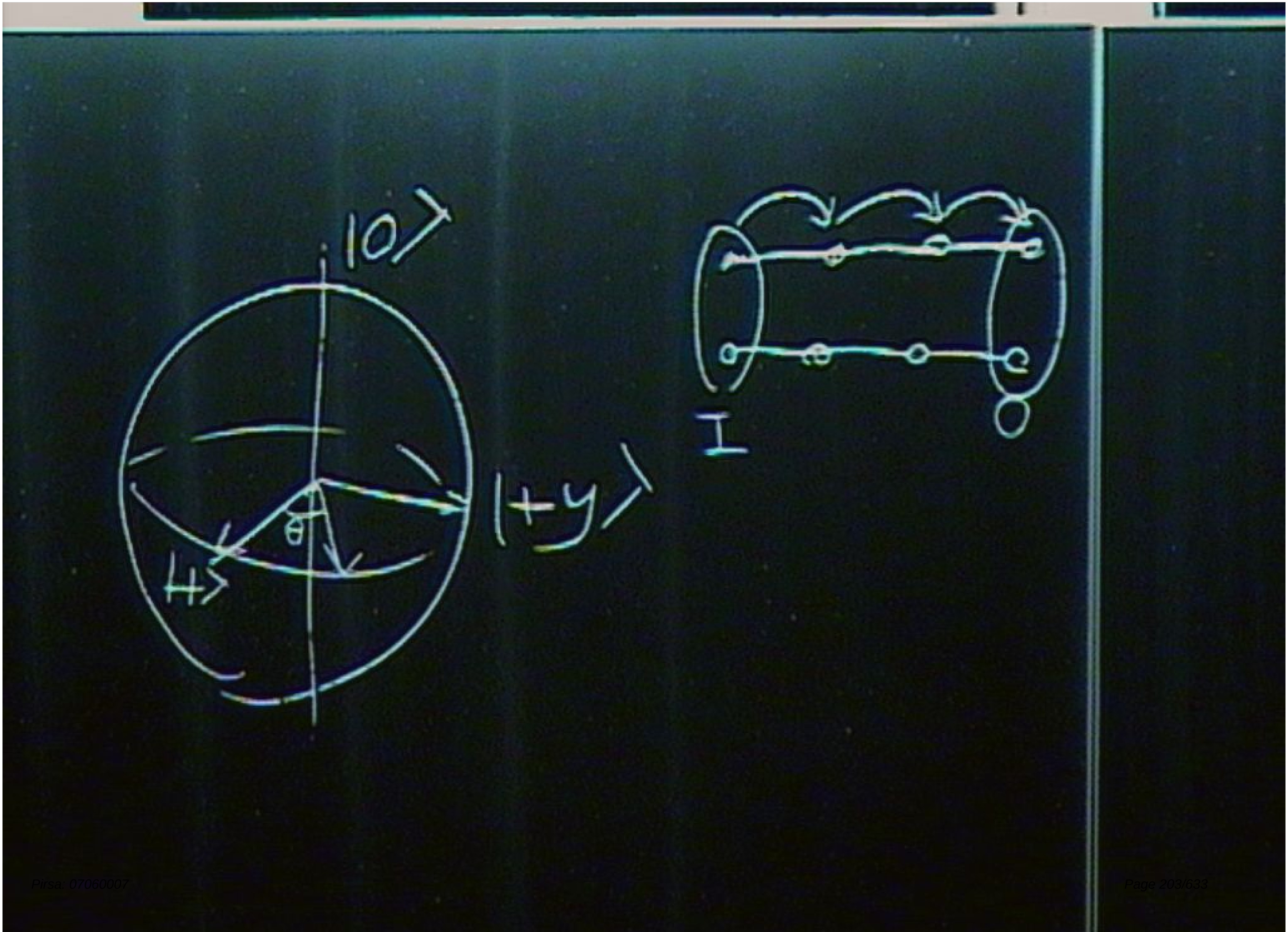
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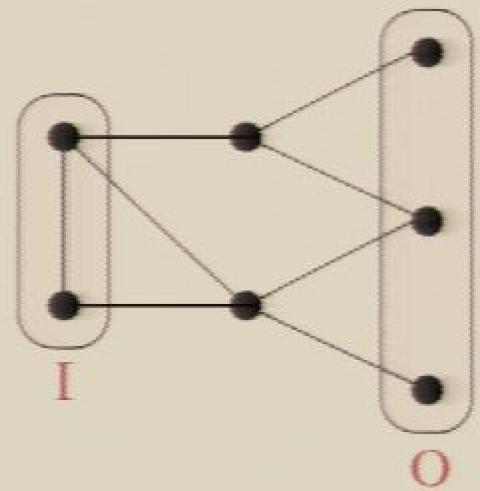

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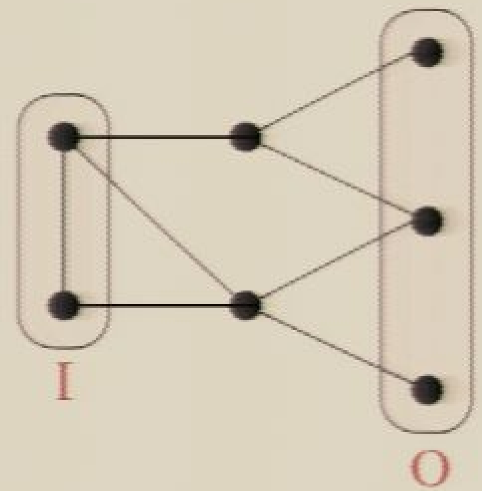

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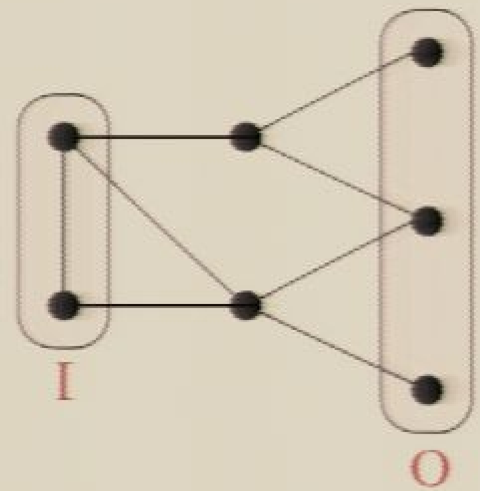

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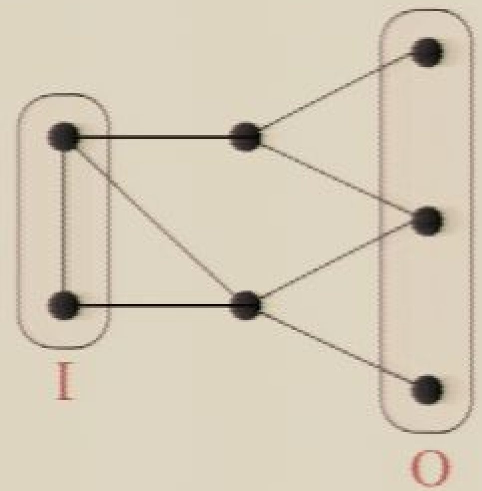

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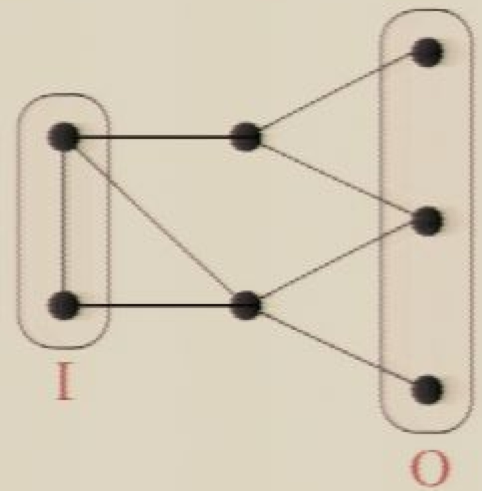

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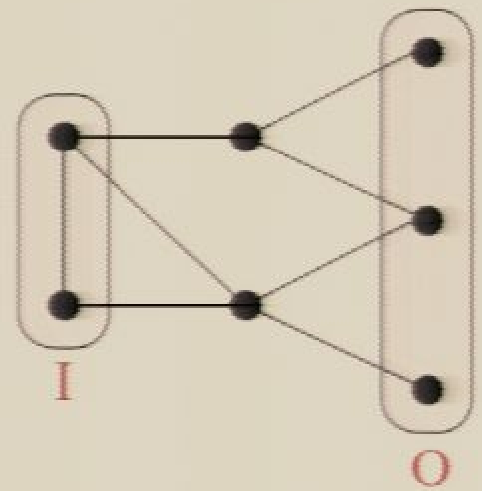

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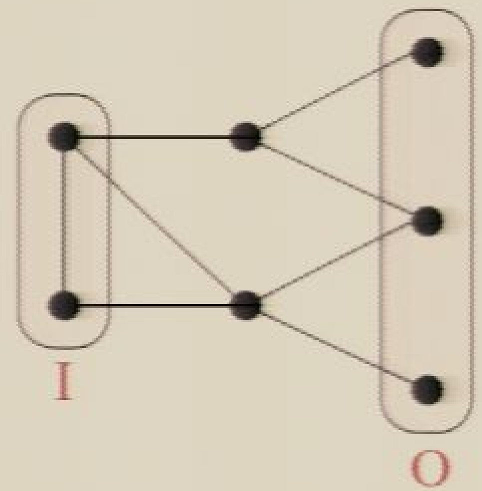

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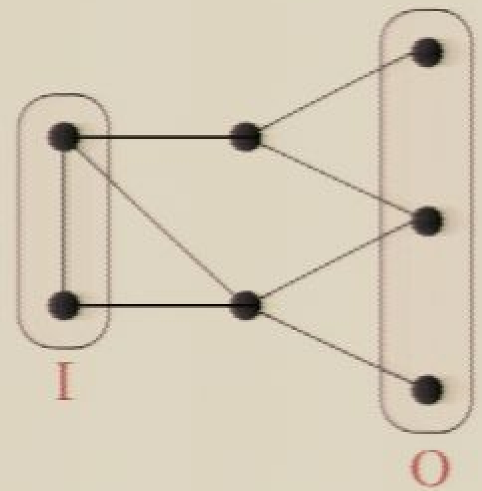

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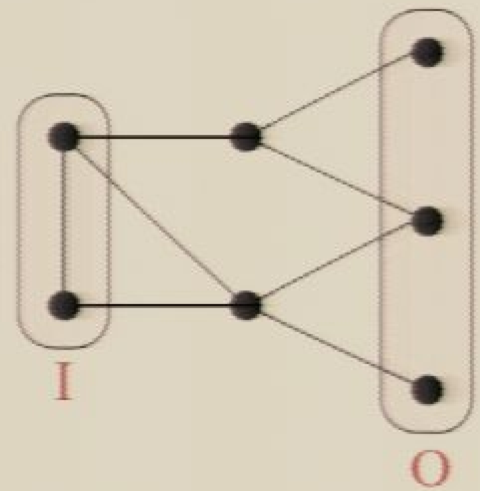

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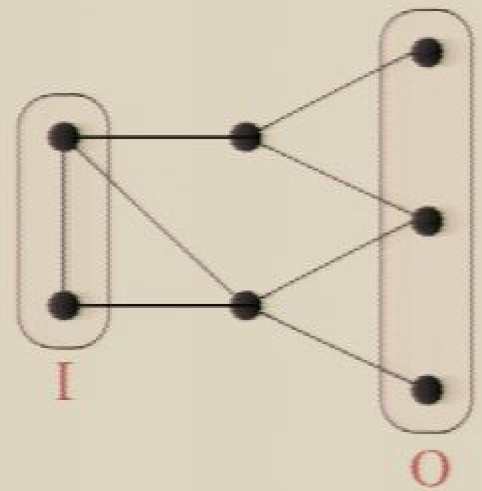

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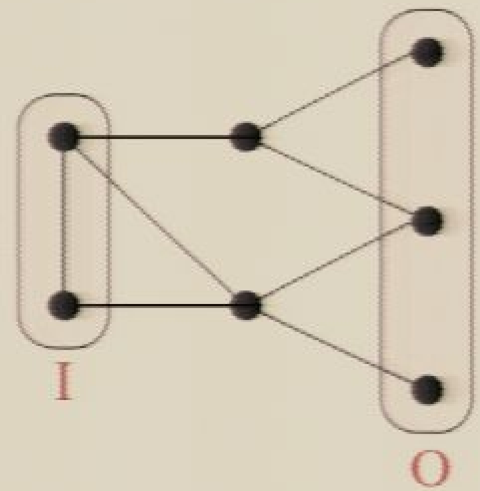

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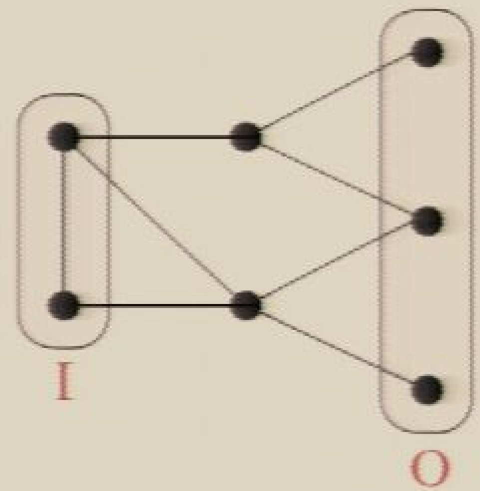

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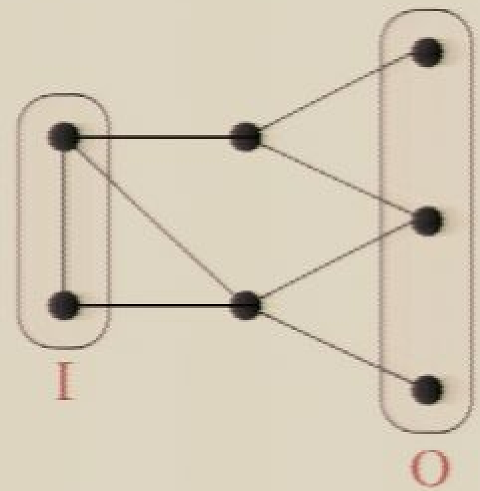

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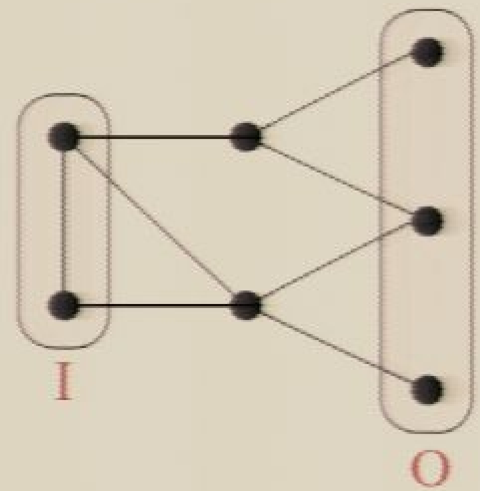

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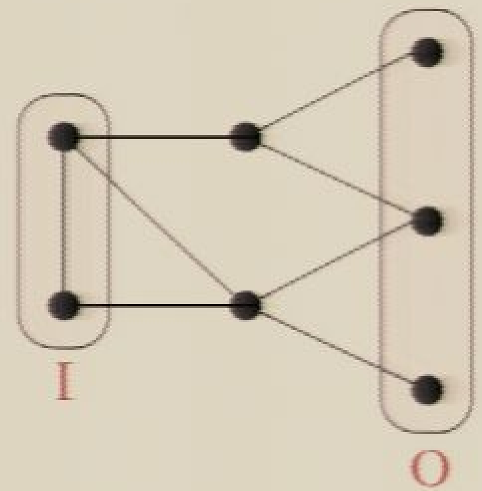

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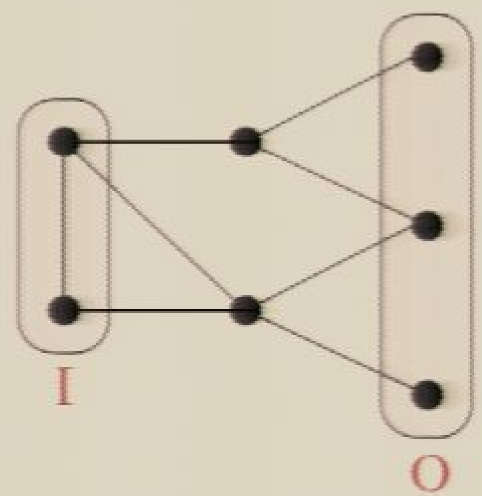

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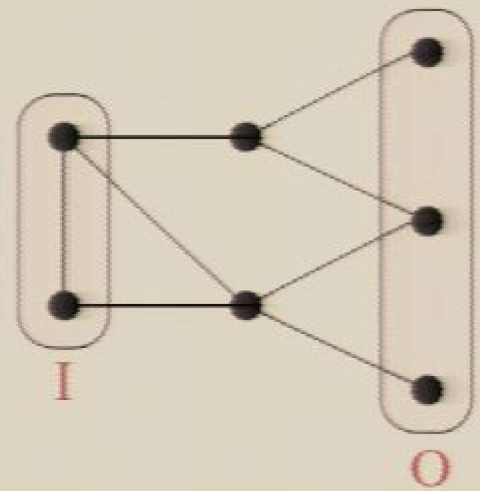

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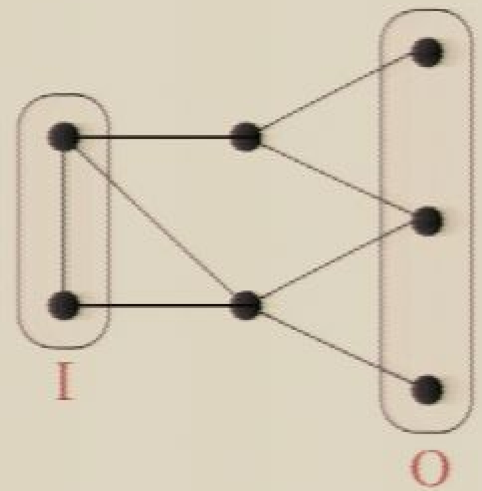

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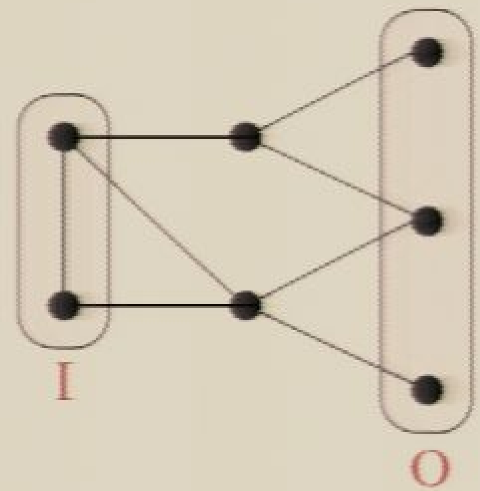

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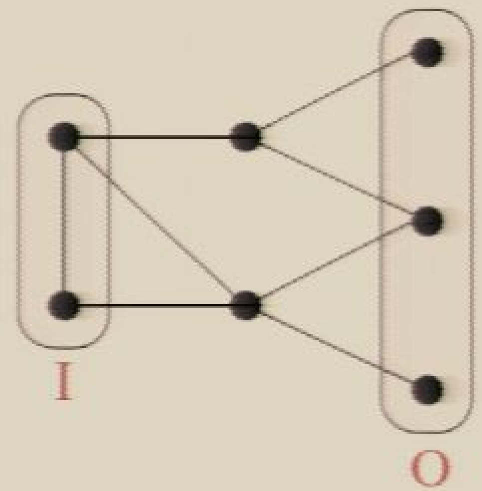

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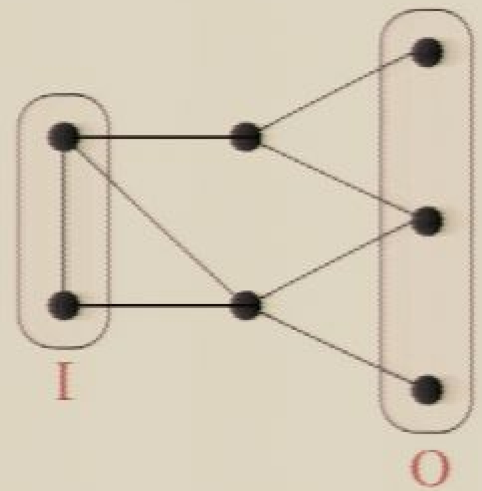

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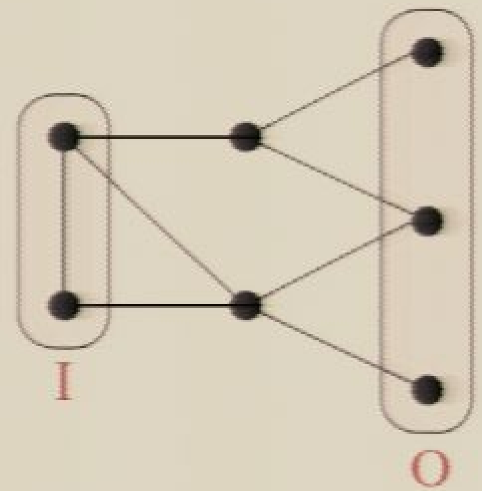

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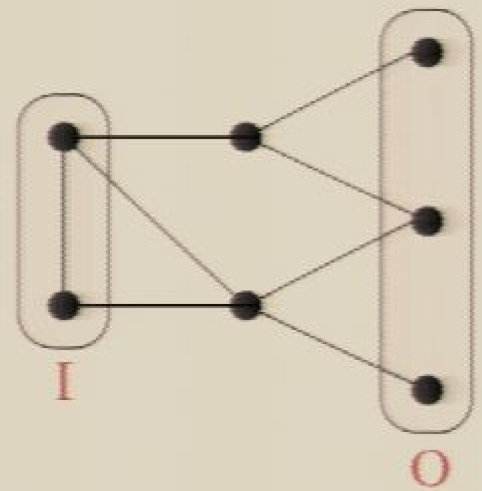

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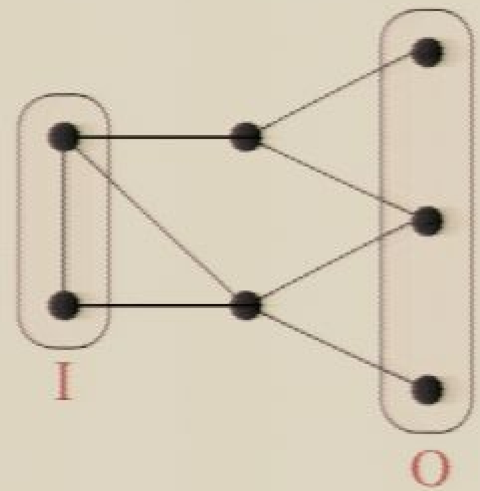

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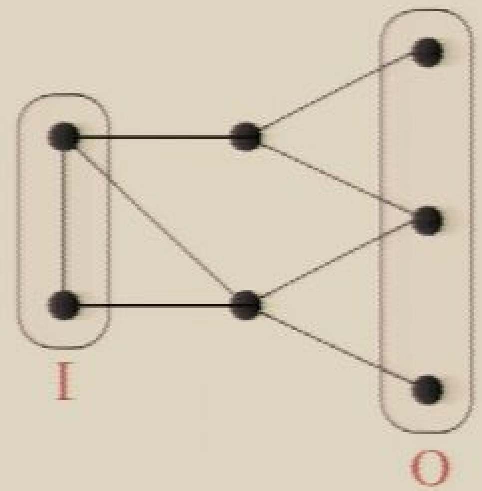

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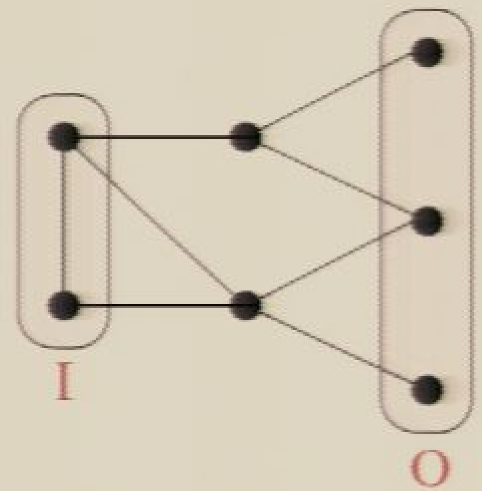

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- $f : \mathrm{O}^c \longrightarrow \mathrm{I}^c$ is a function on vertices
- $\preccurlyeq$ is a partial order on V
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which satisfy the following three conditions for all vertices:

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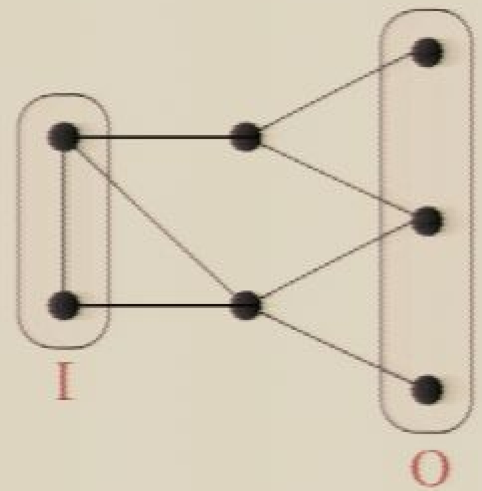

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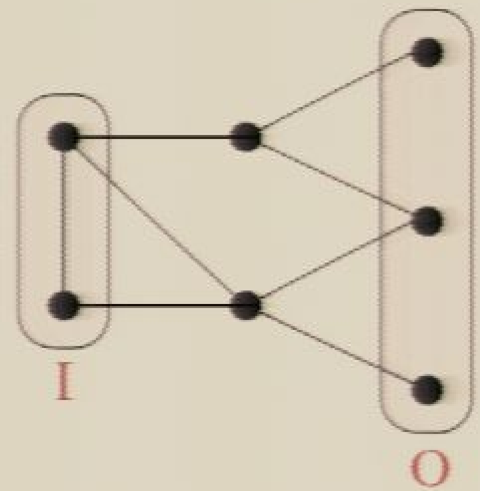

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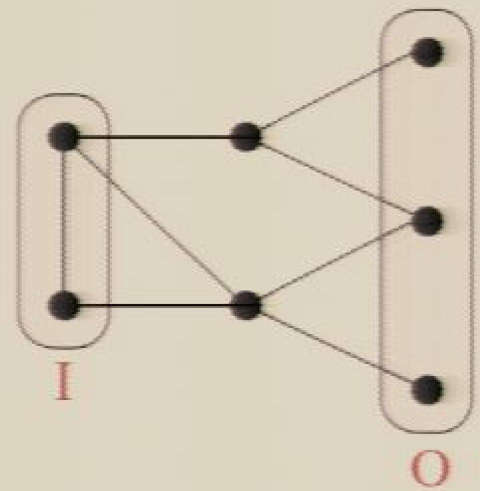

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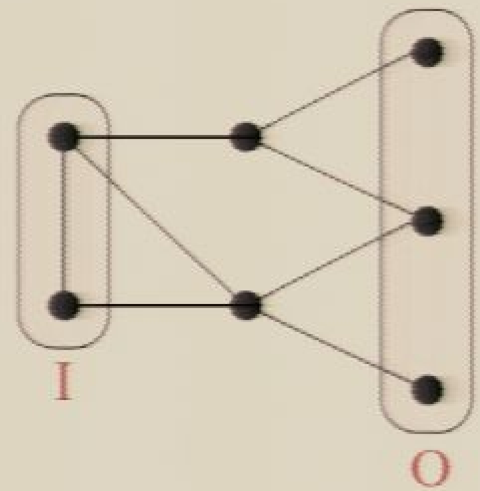

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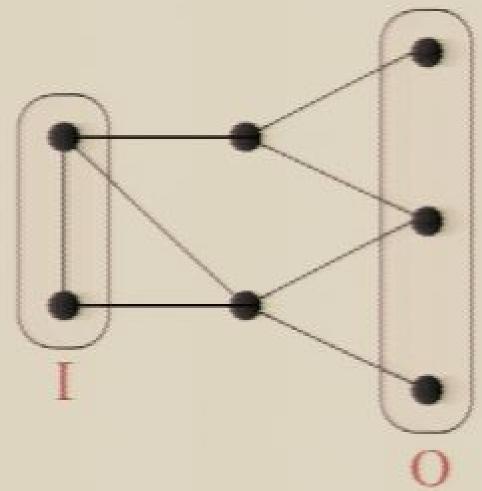

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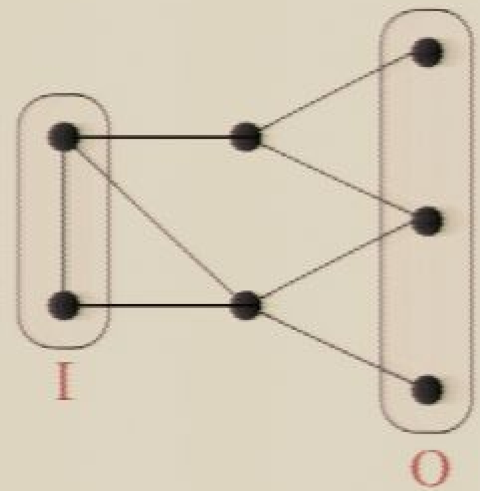

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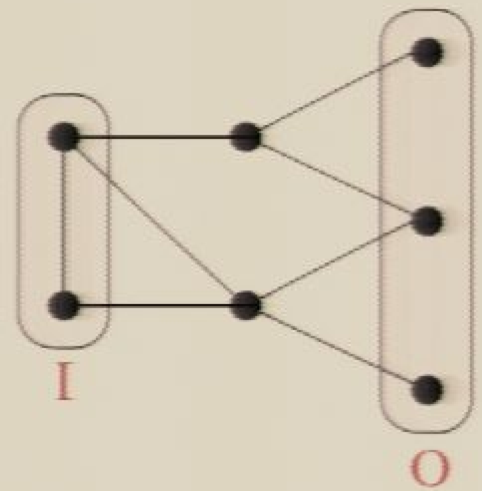

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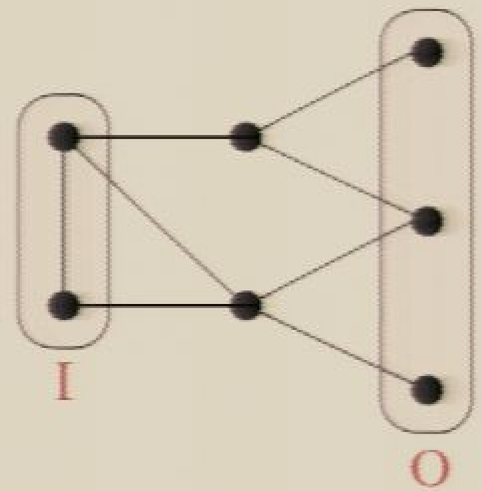

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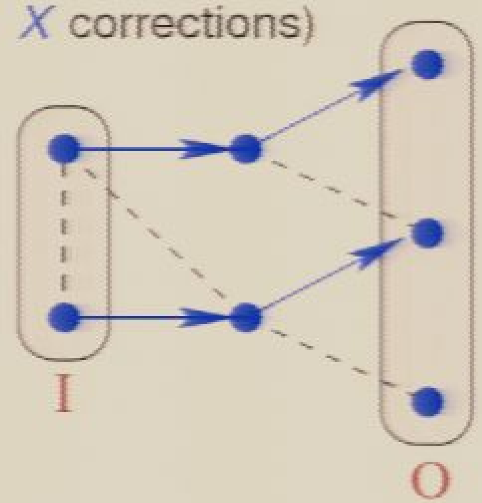

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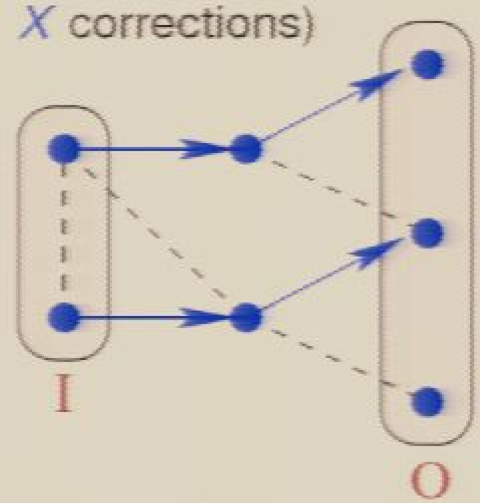

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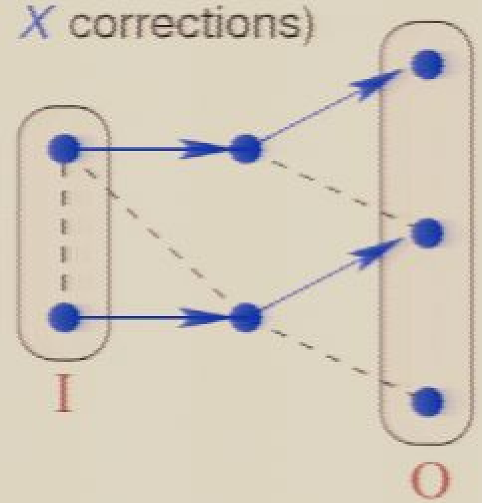

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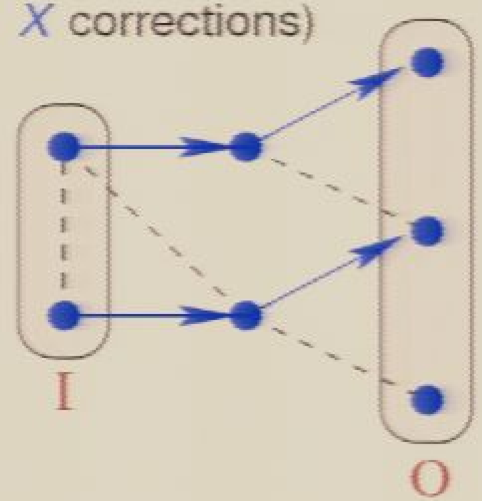

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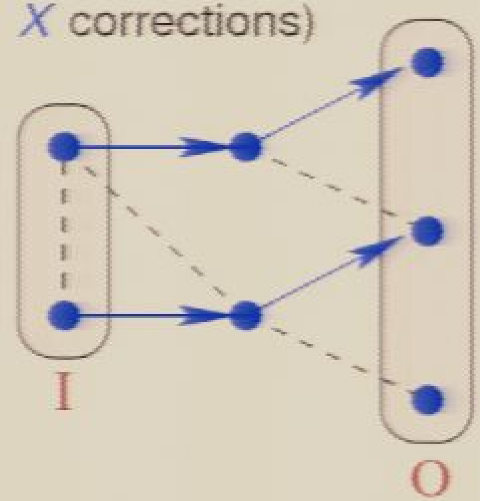

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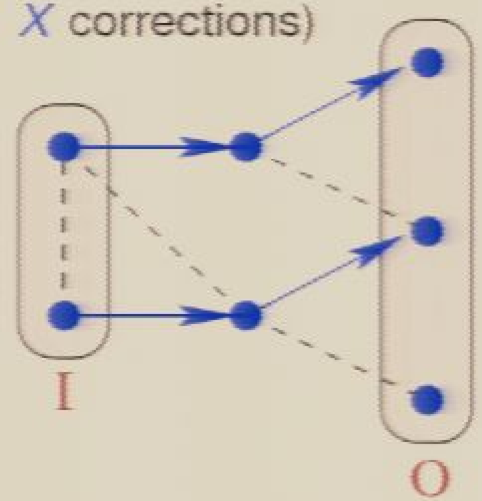

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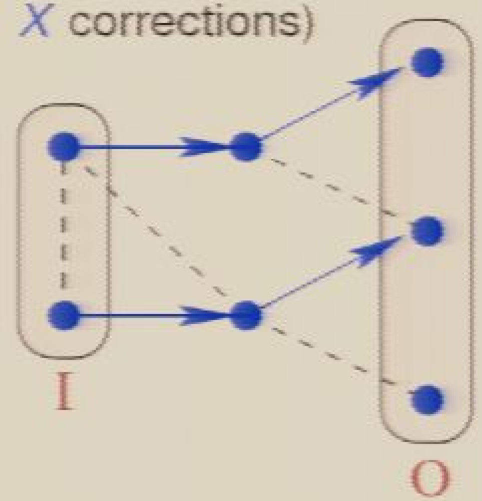

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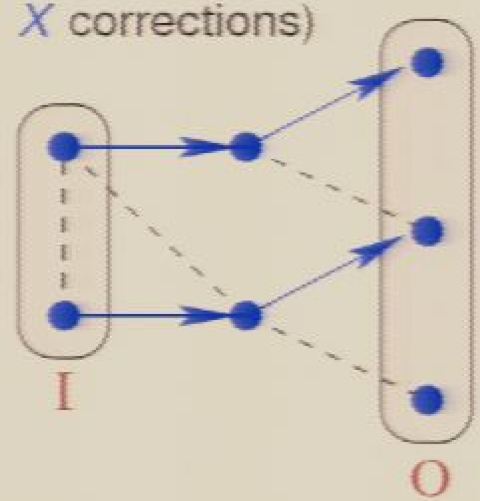

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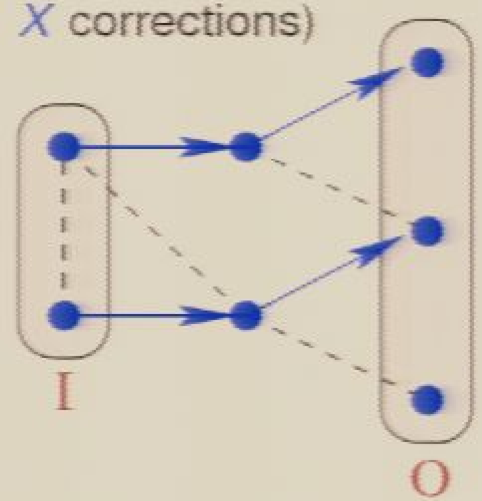

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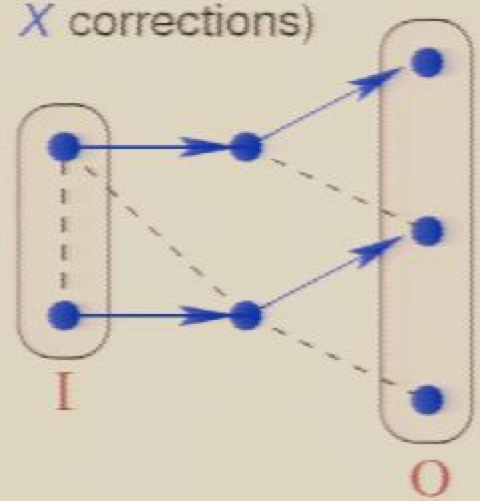

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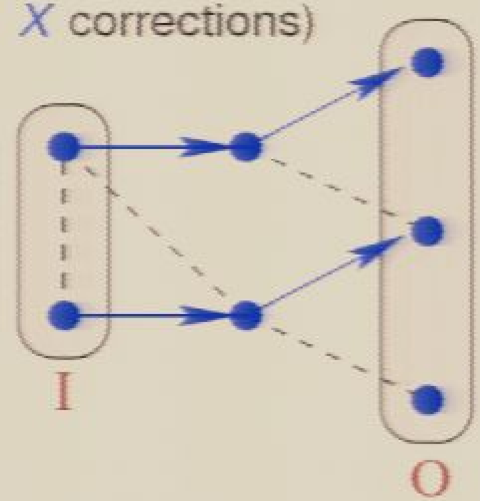

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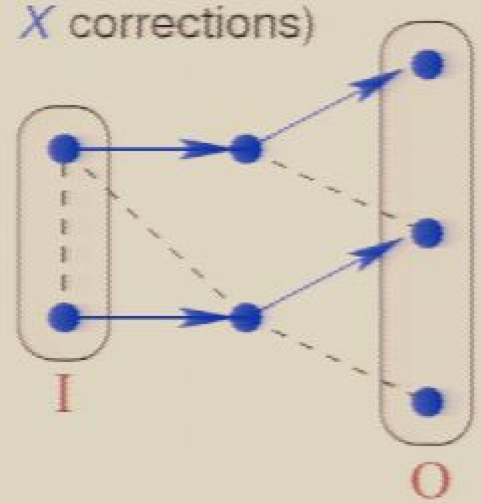

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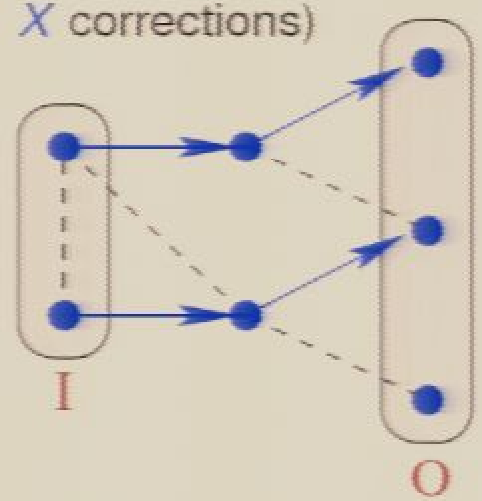

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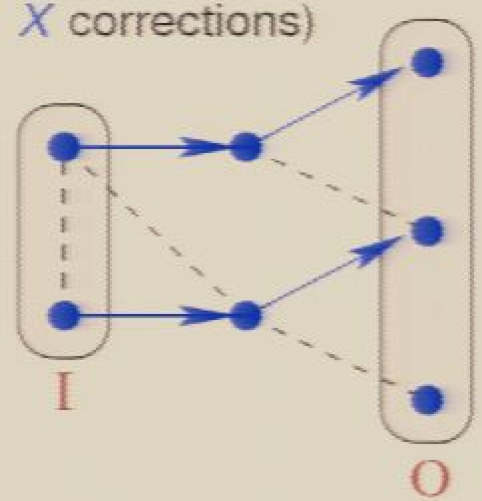

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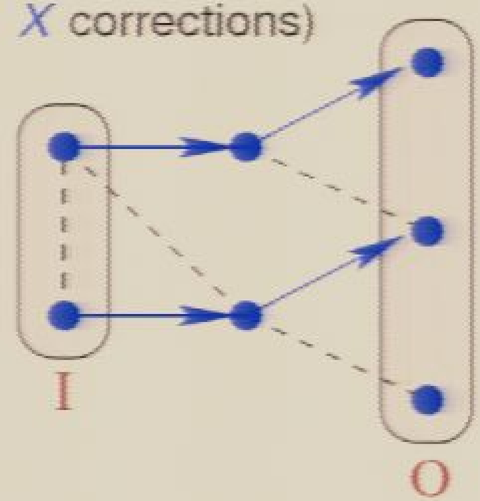

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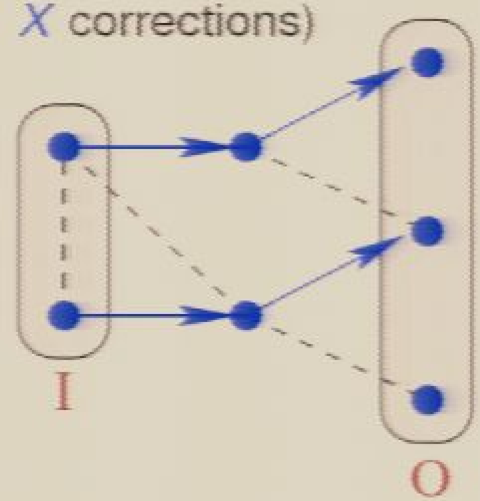

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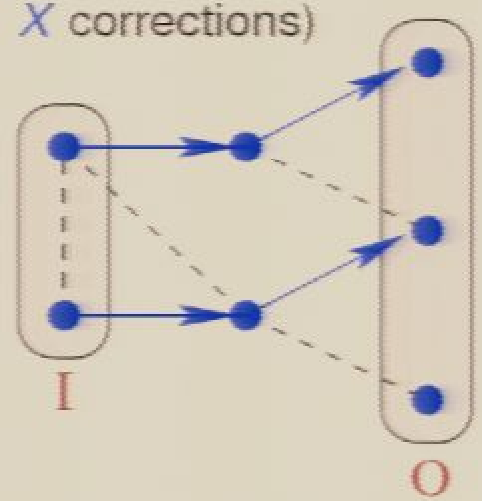

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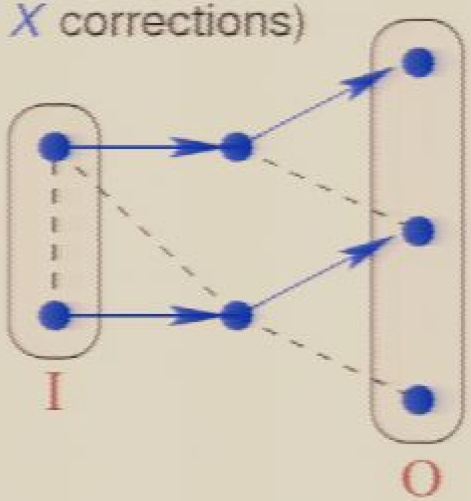

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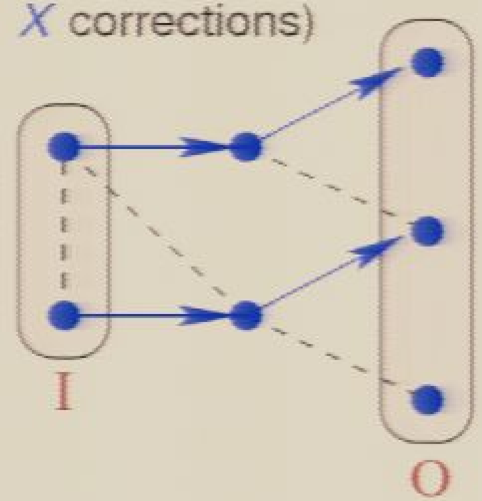

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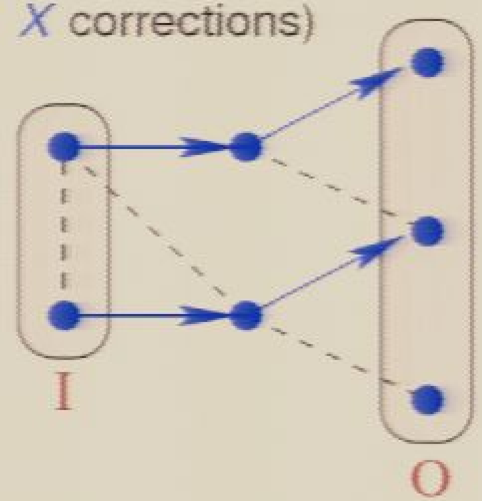

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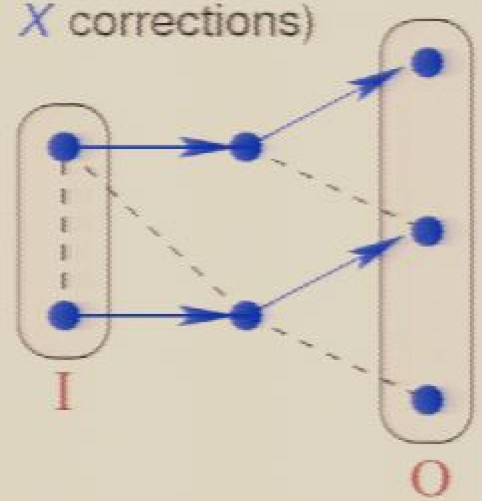

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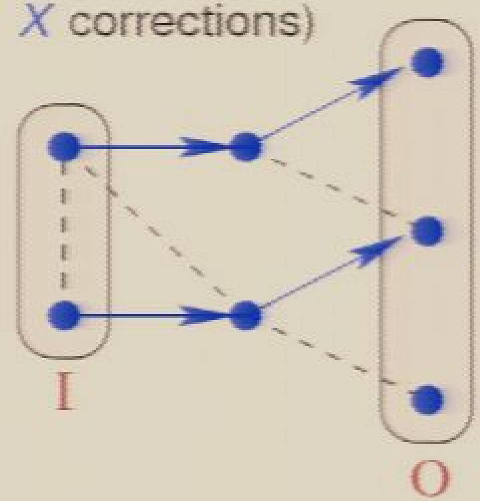

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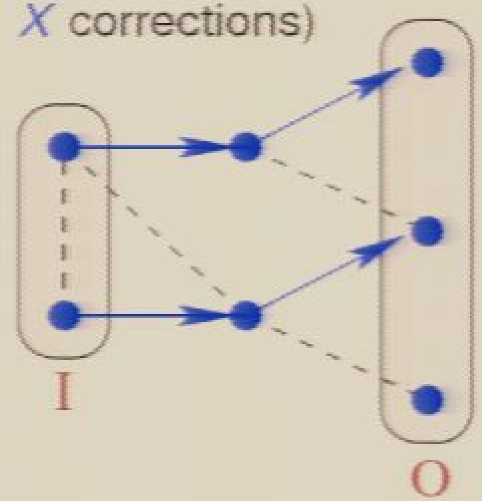

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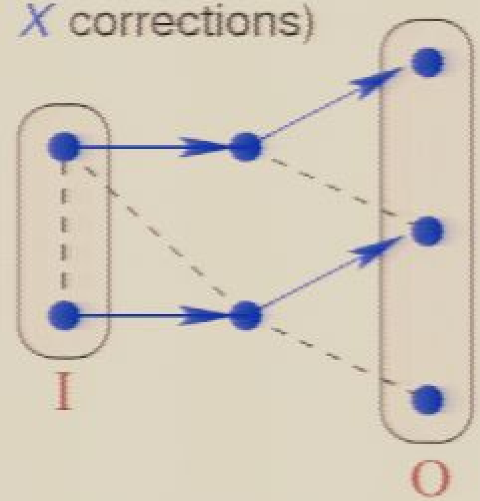

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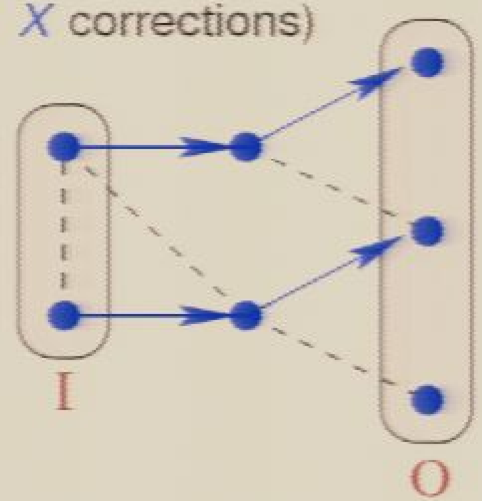

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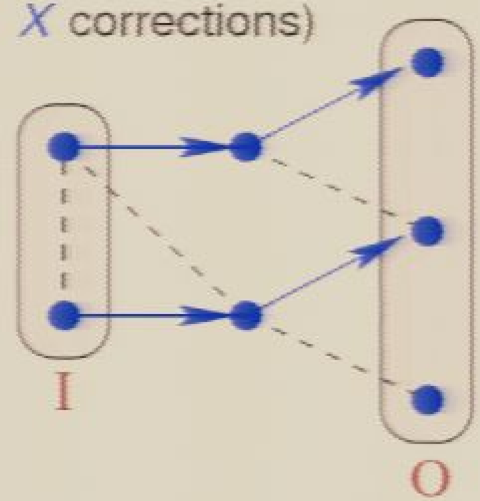

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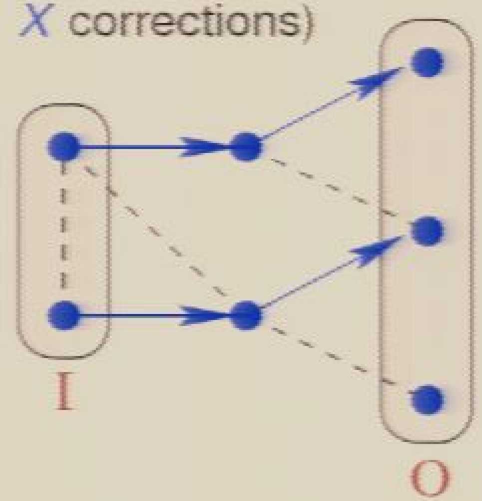

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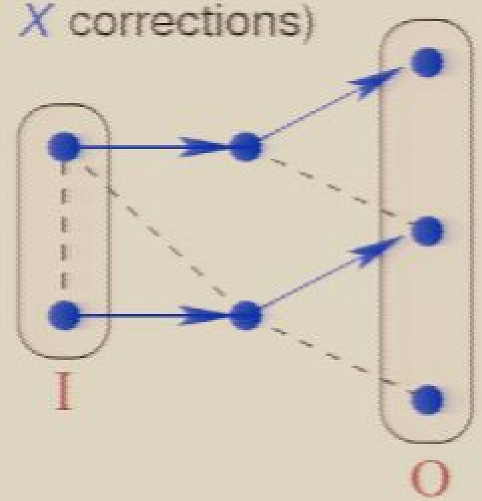

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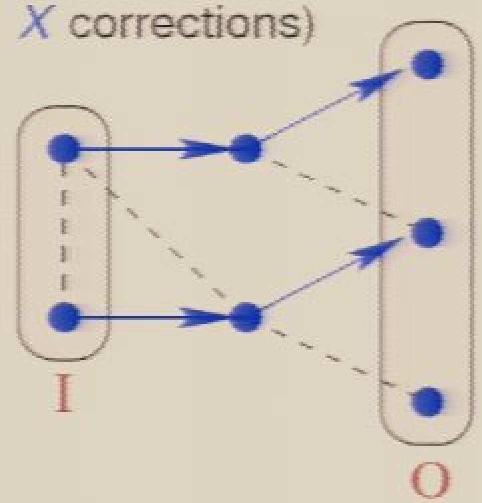

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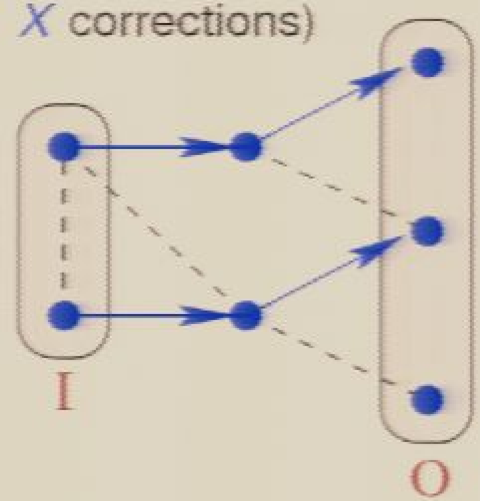

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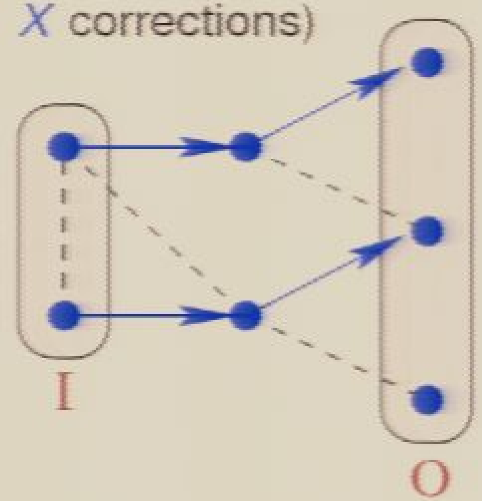

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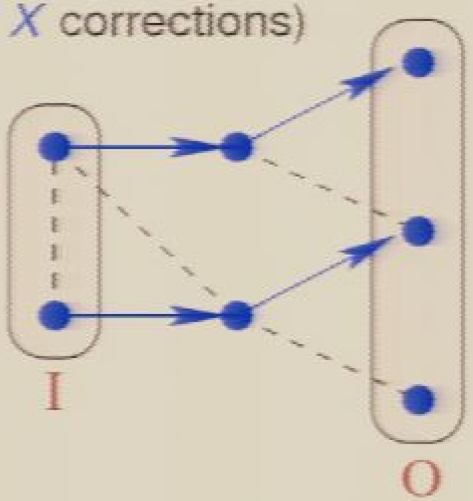

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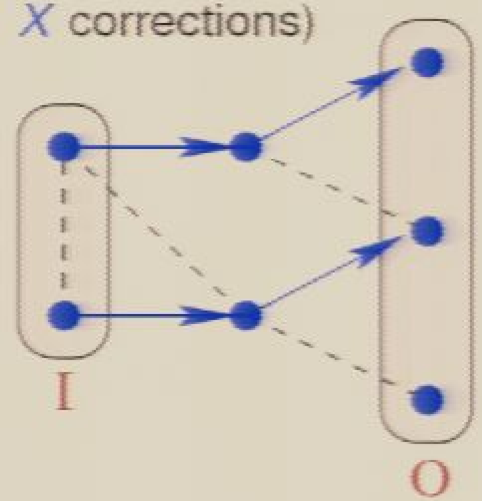

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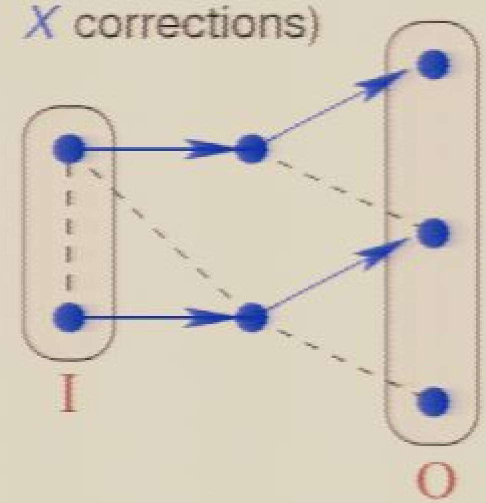

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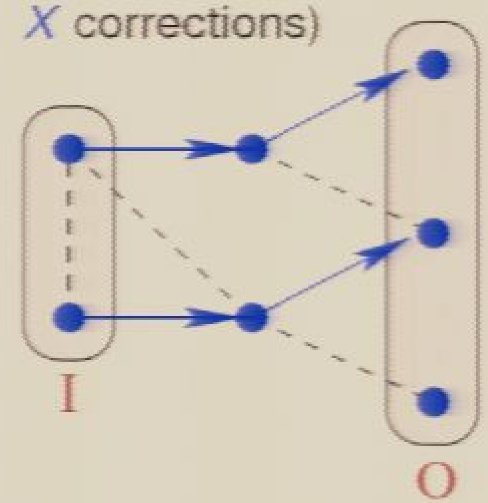

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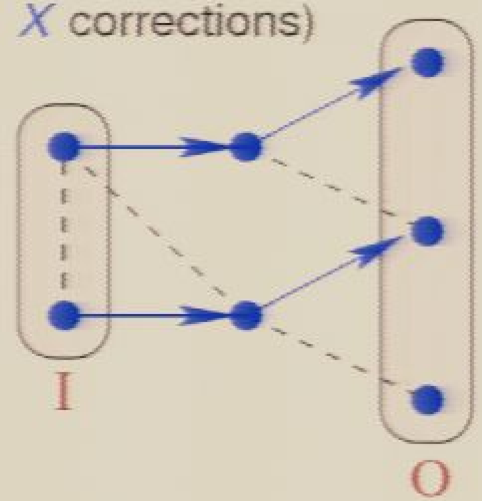

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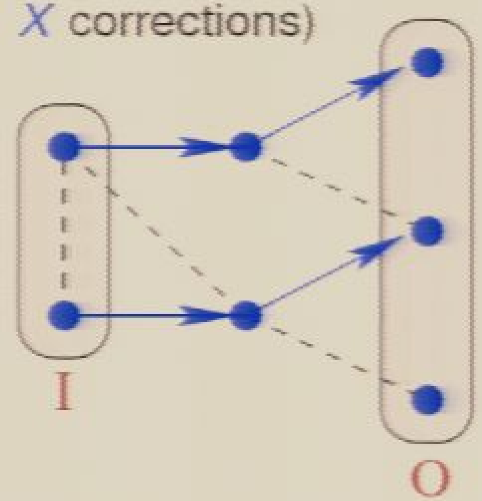

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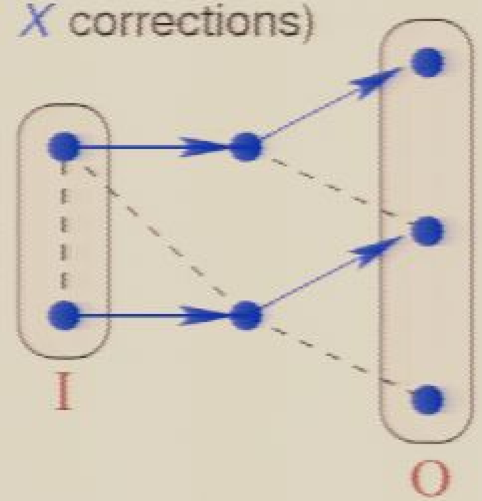

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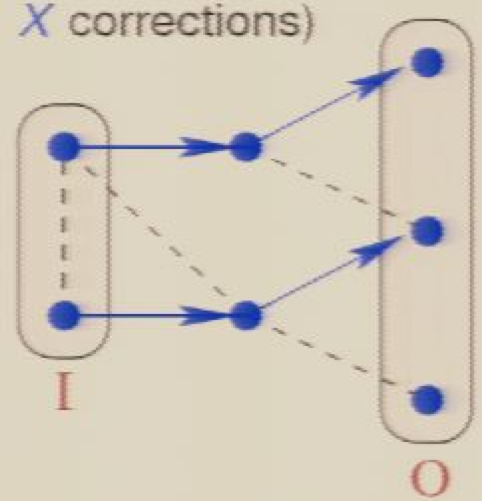

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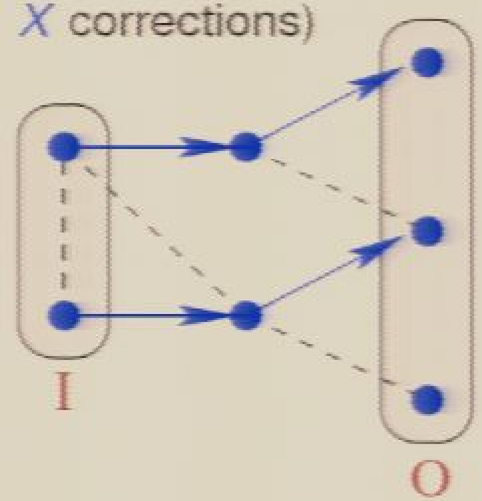

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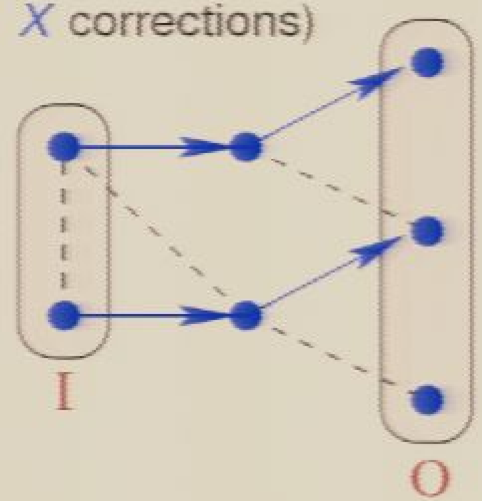

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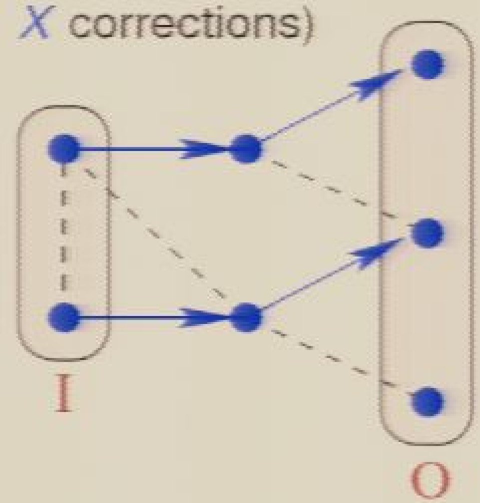

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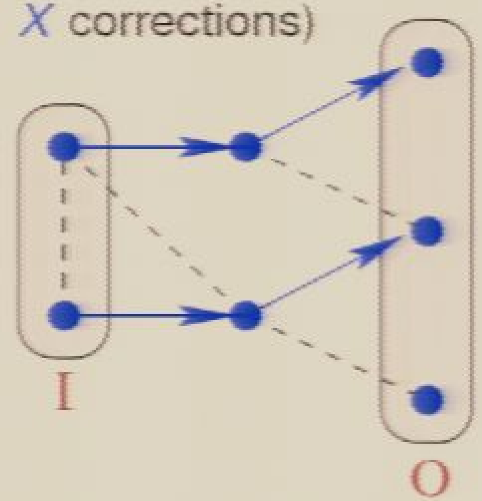

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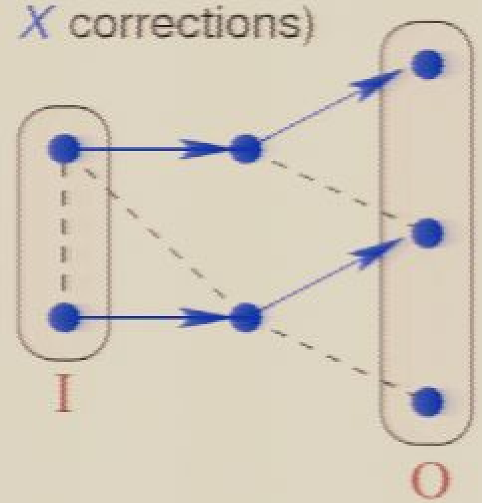

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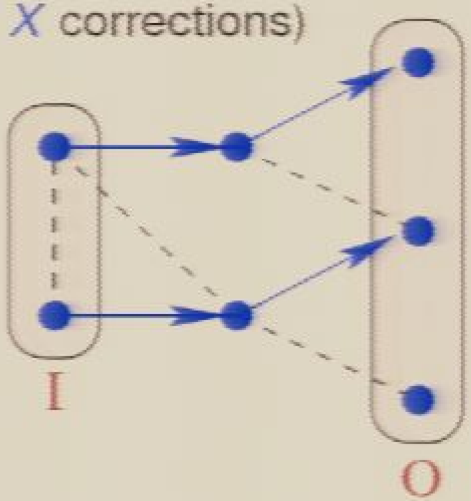

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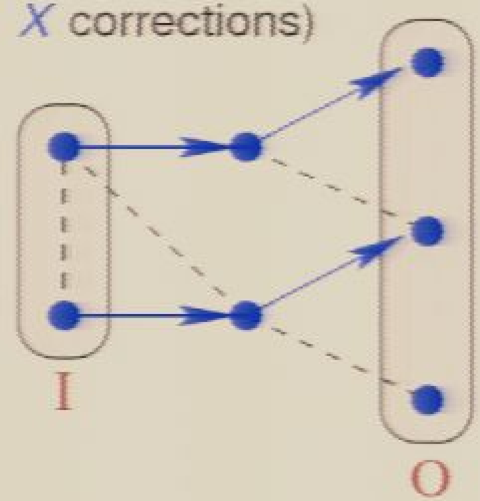

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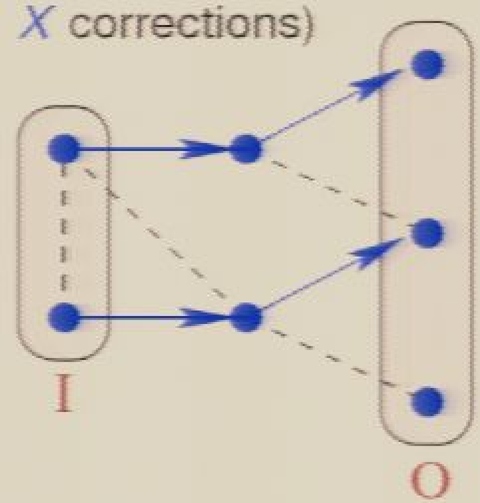

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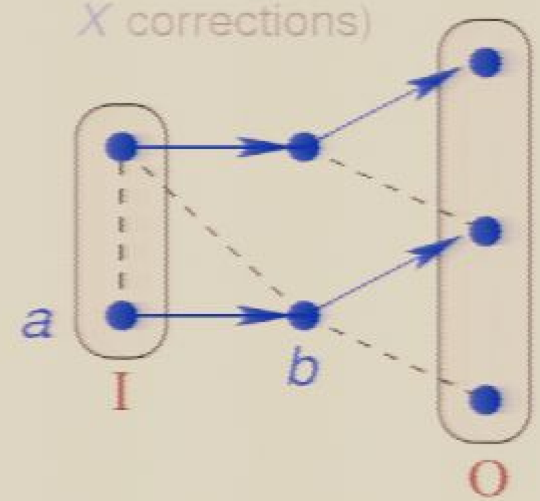

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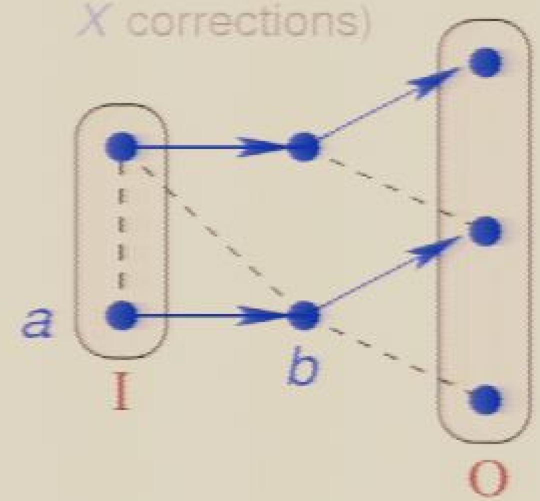

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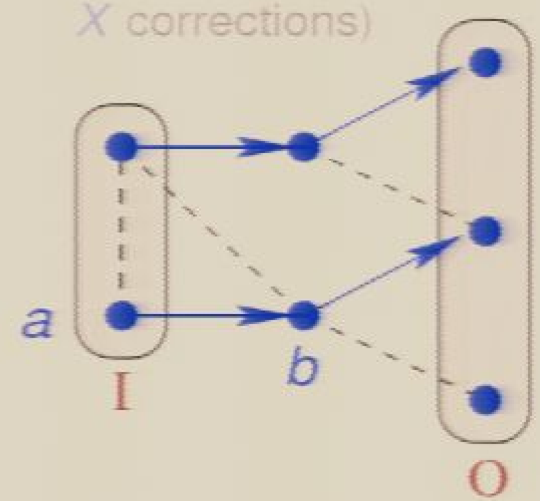

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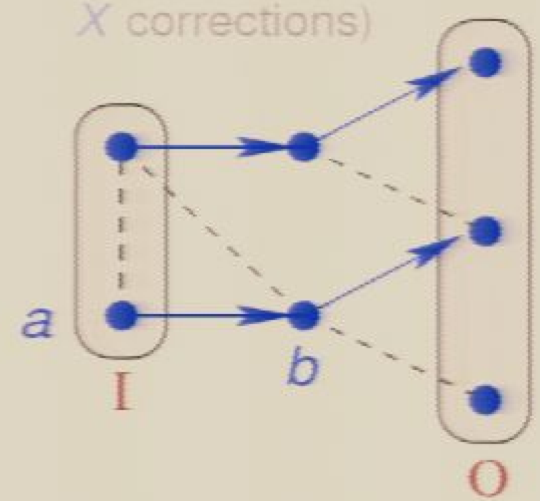

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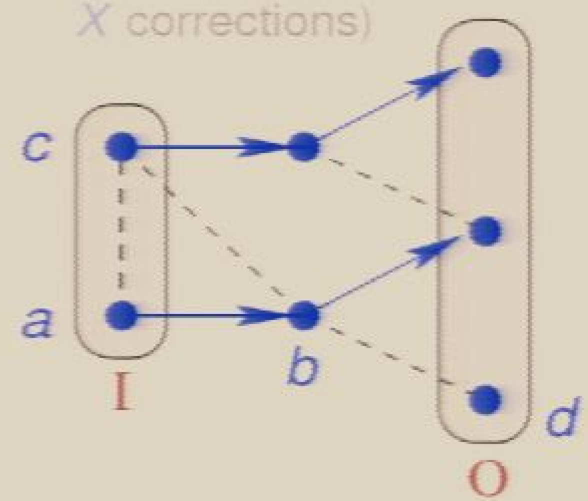

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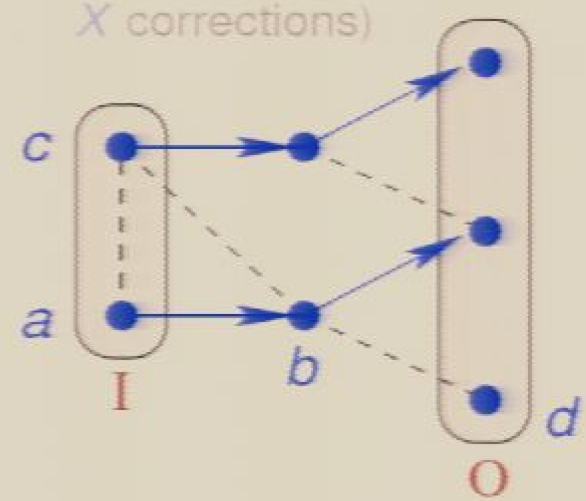

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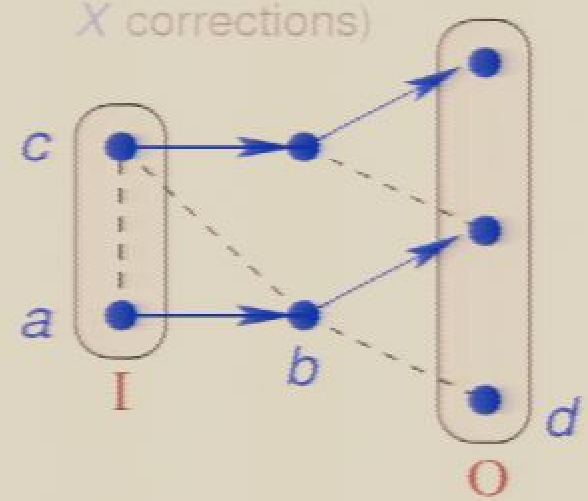

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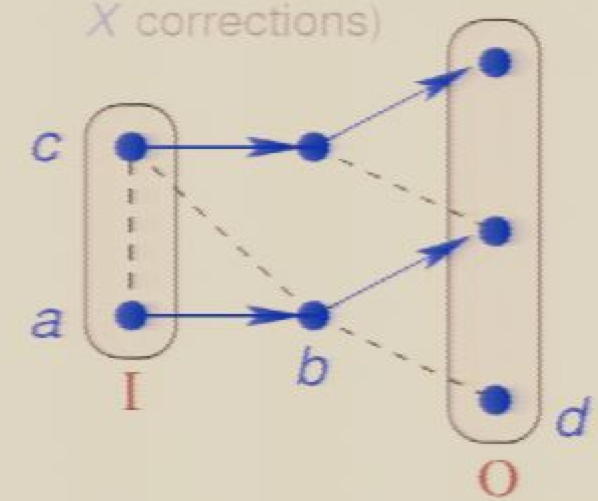

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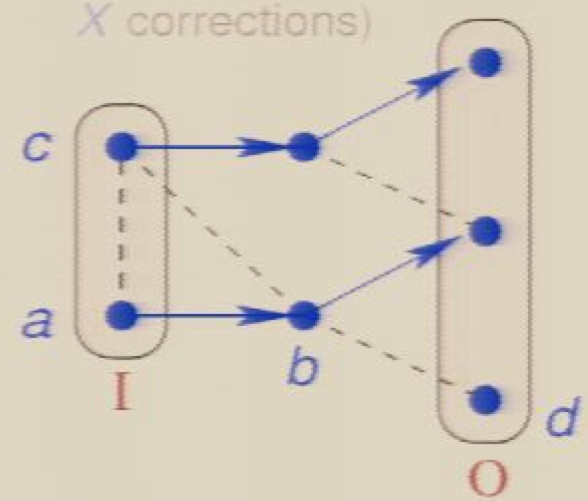

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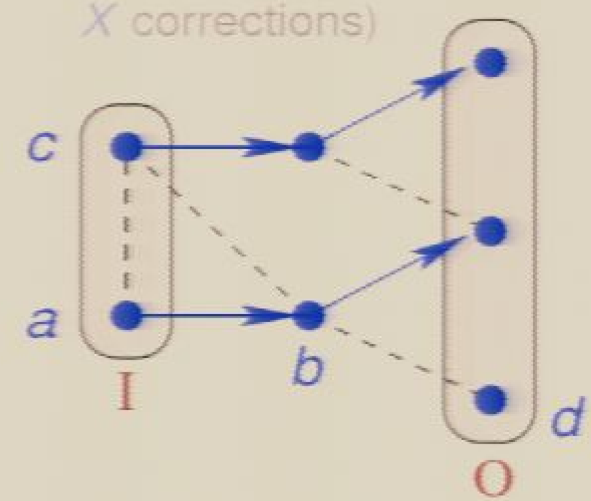

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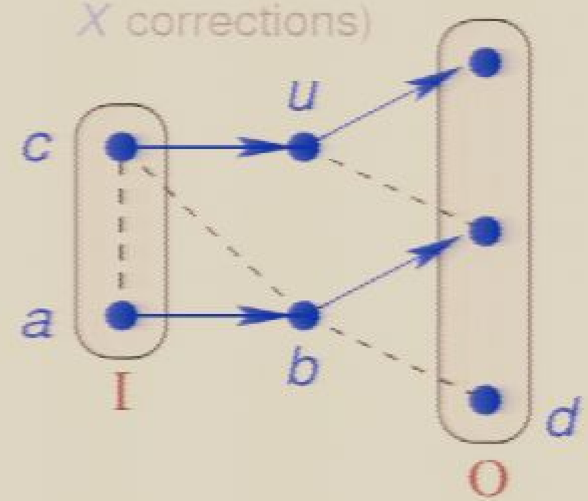

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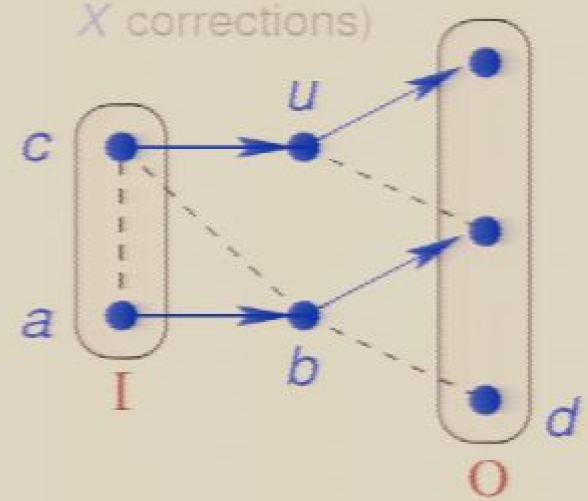

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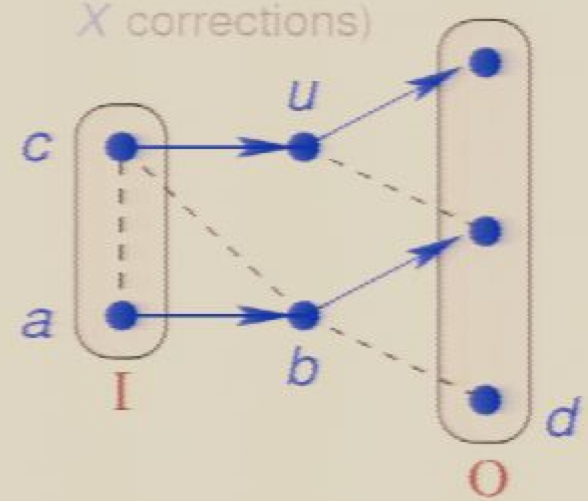

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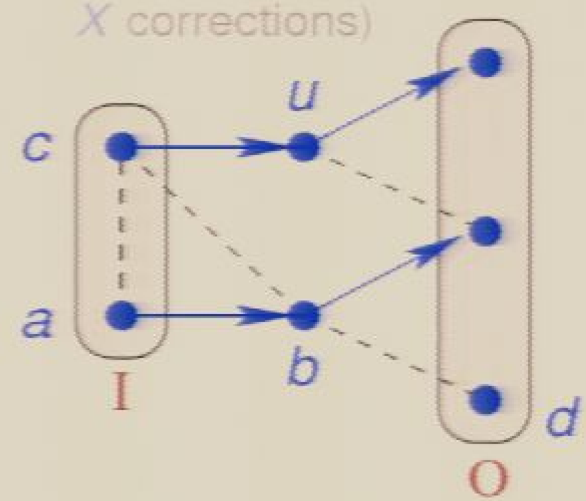

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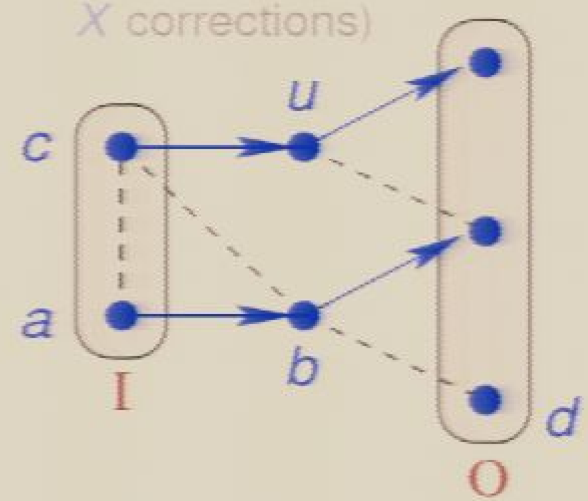

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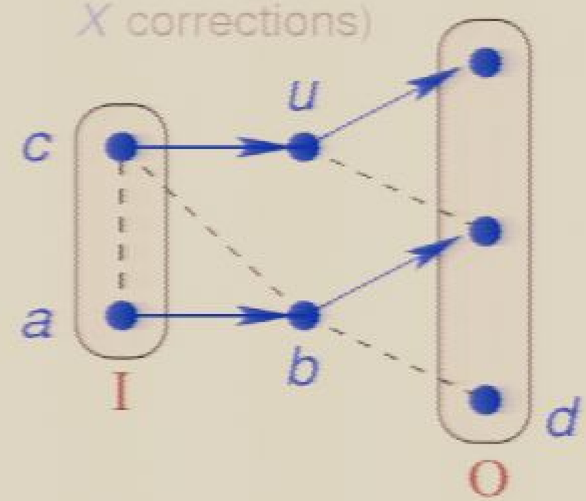

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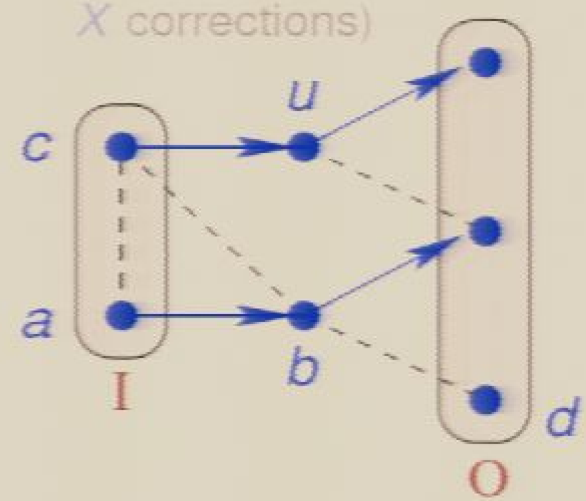

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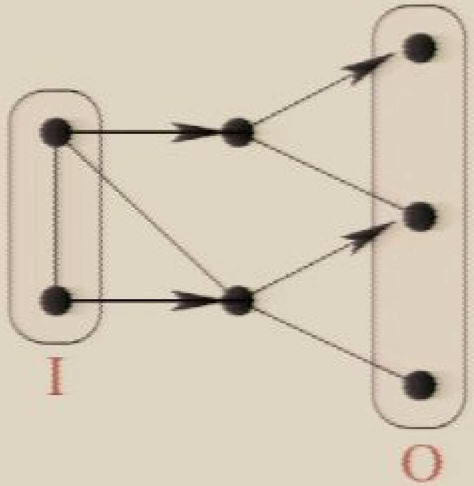

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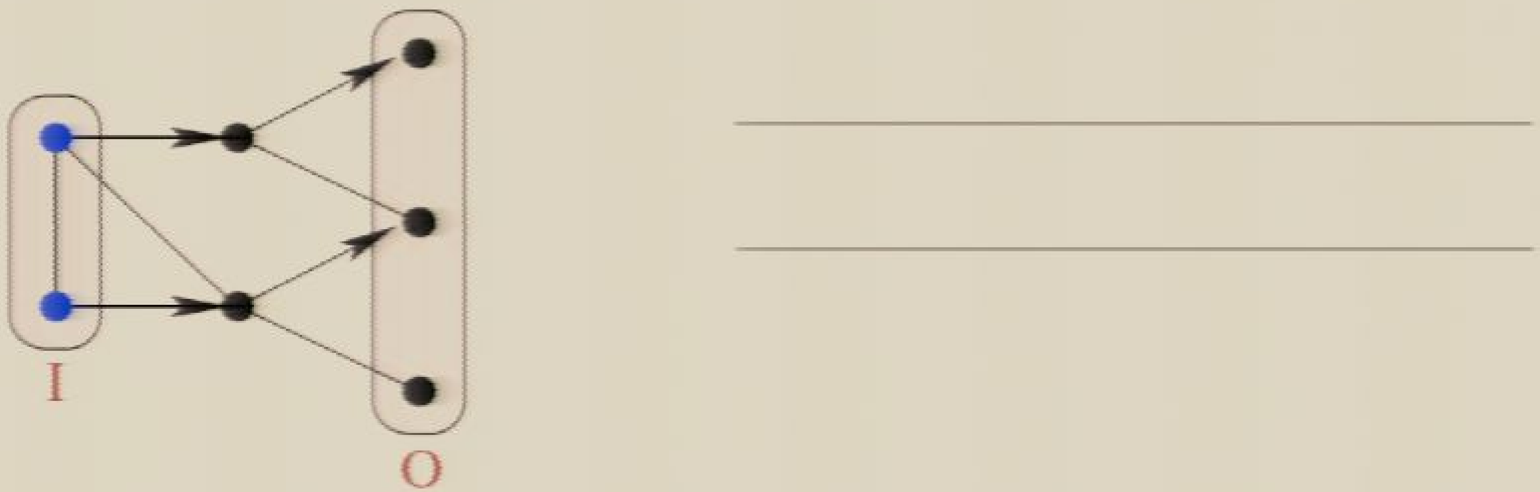

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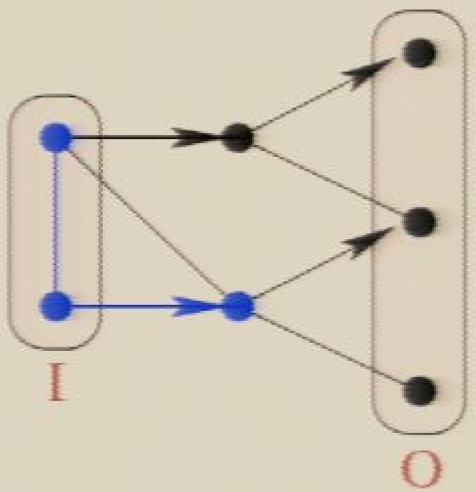

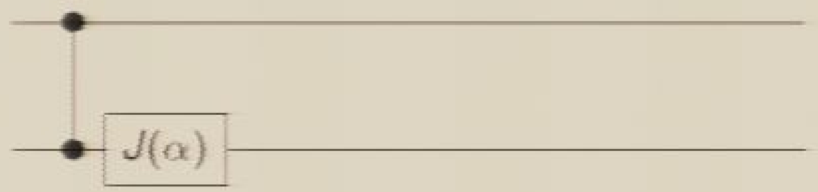

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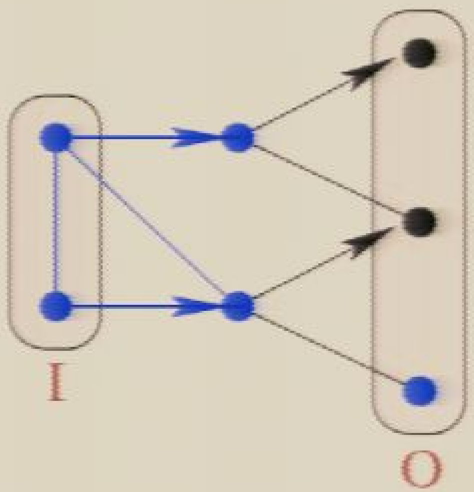

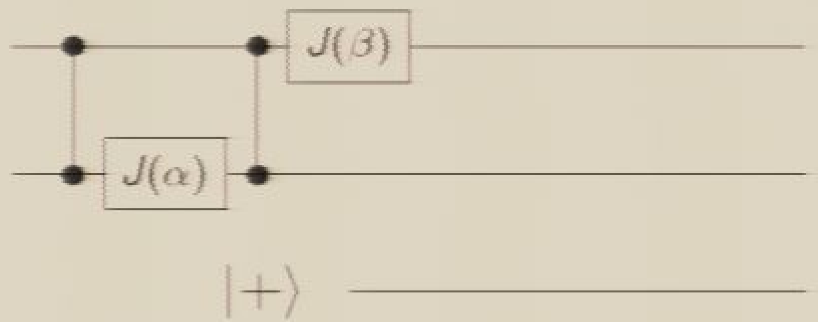

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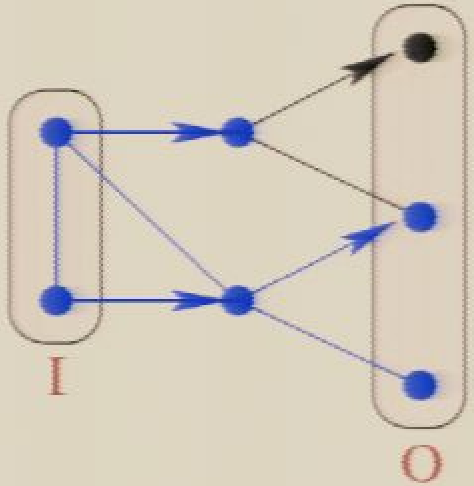

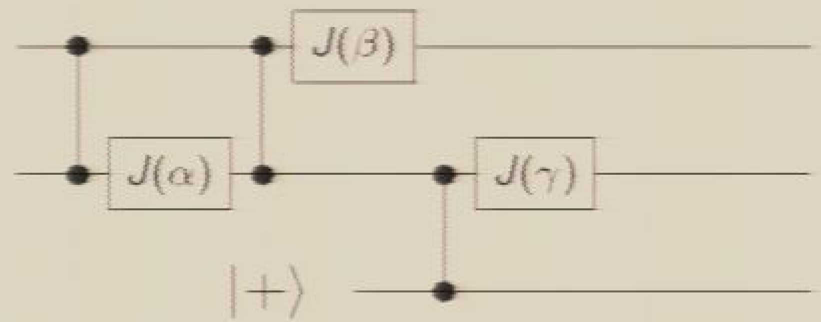

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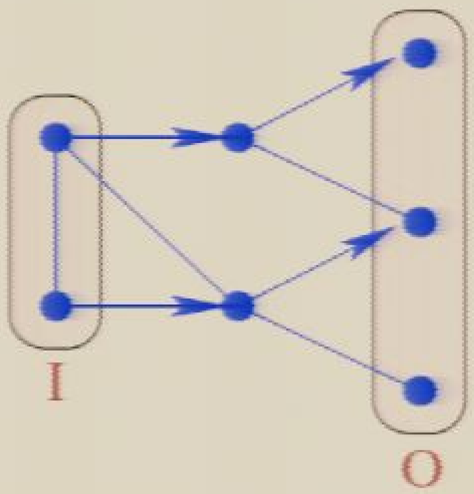

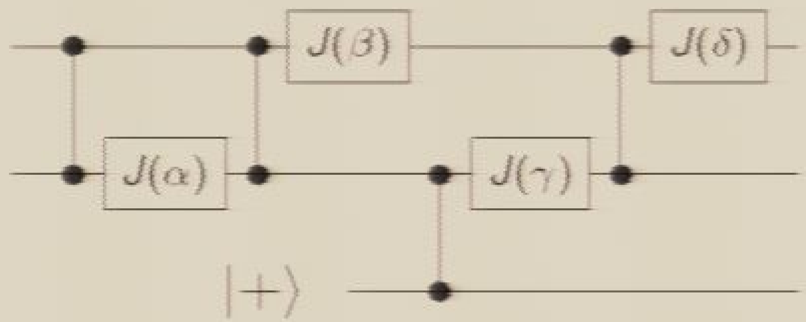

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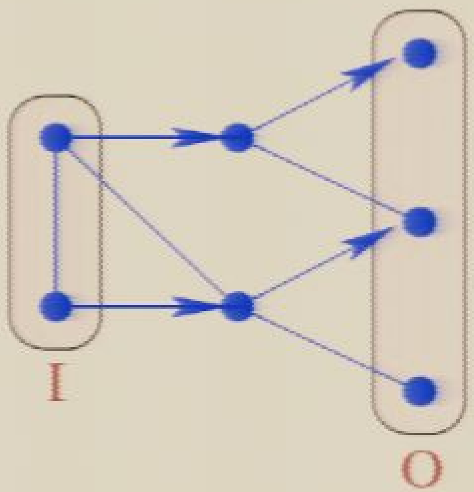

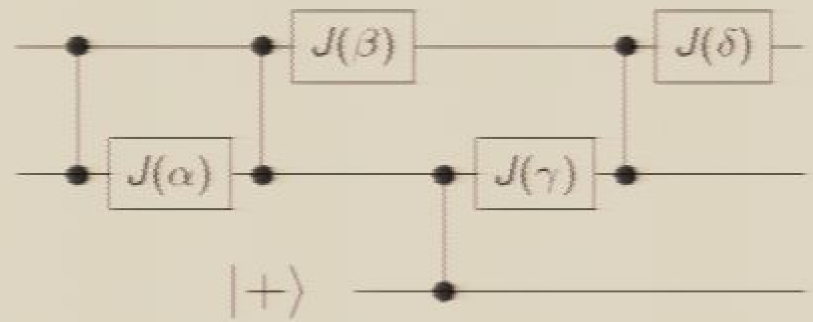

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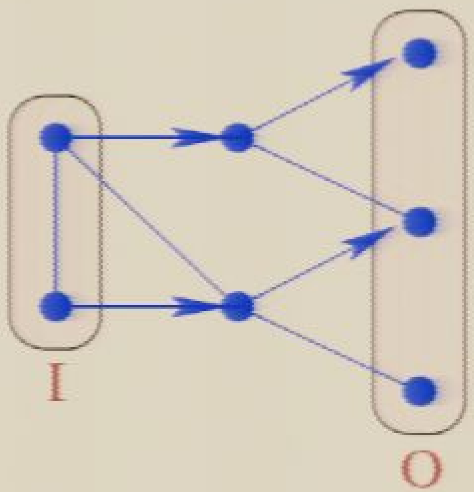

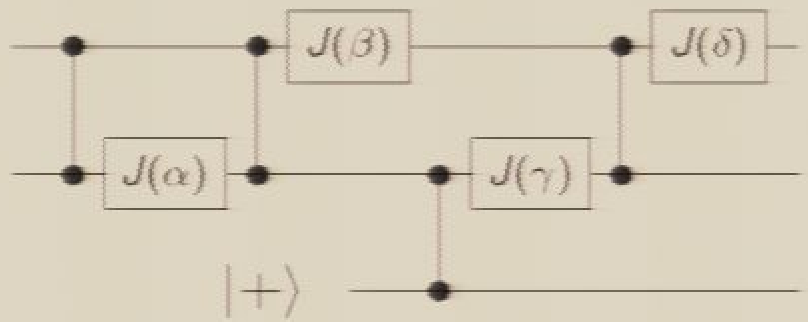

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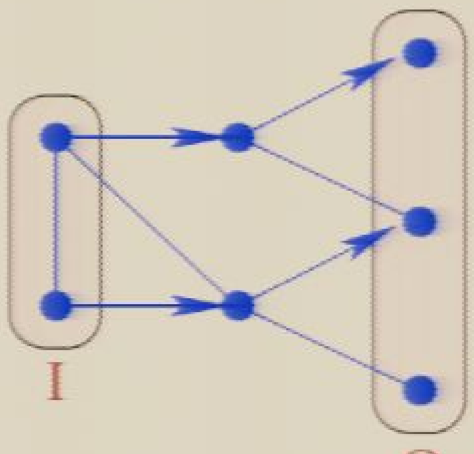

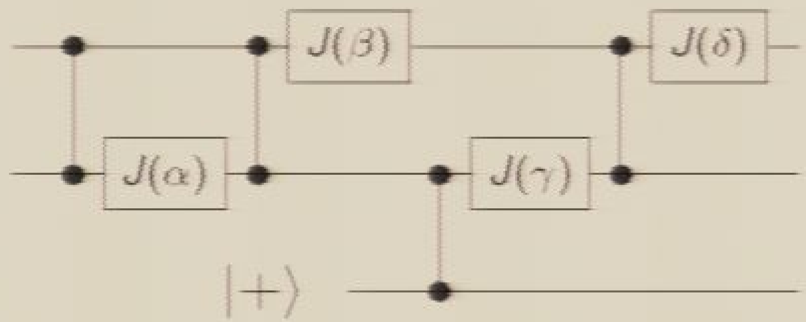

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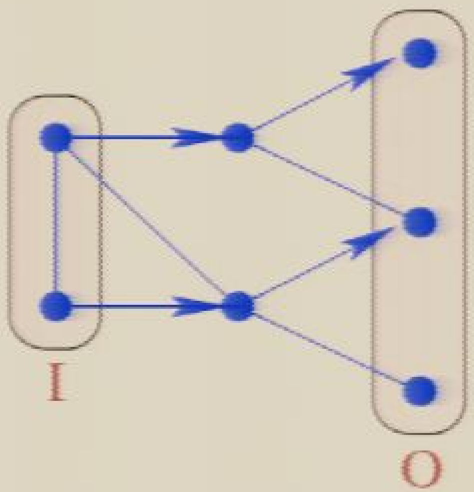

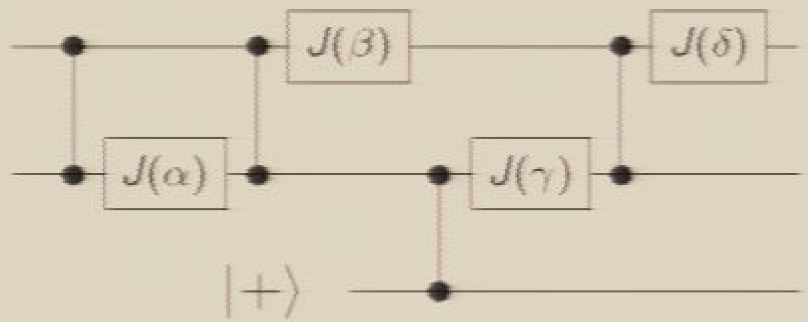

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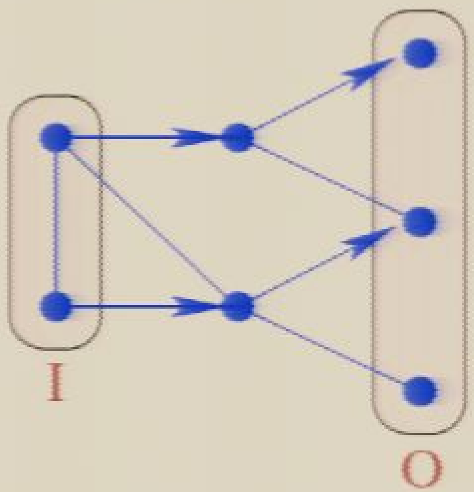

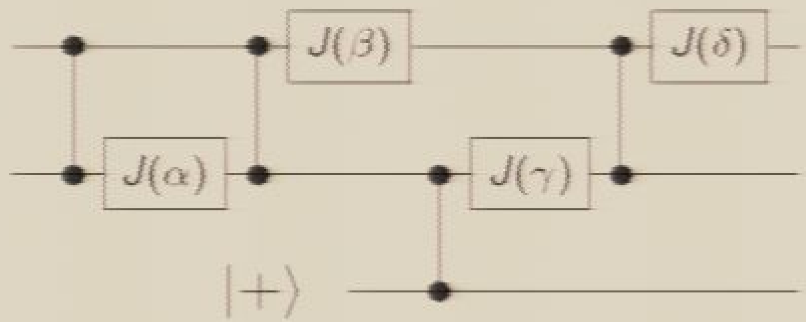

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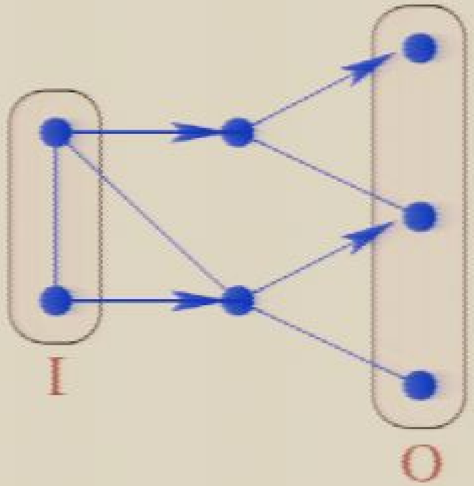

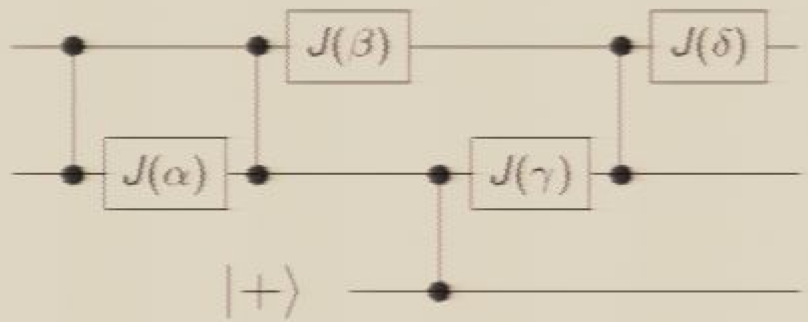

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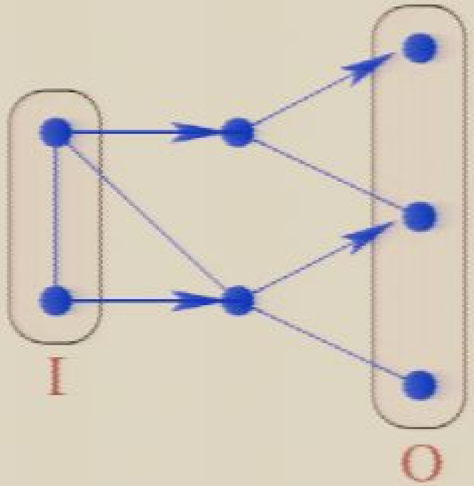

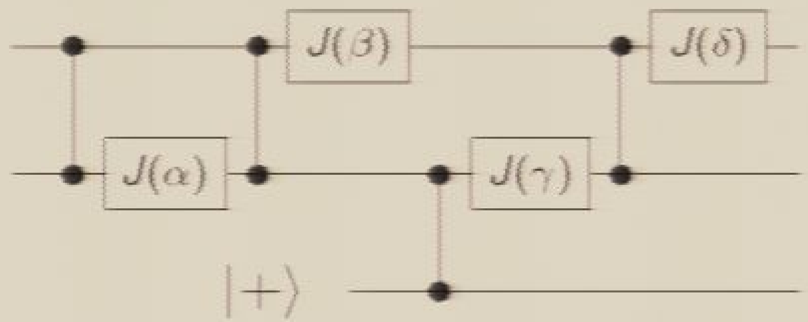

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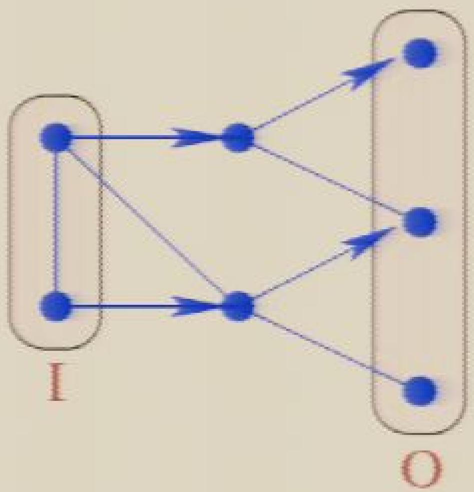

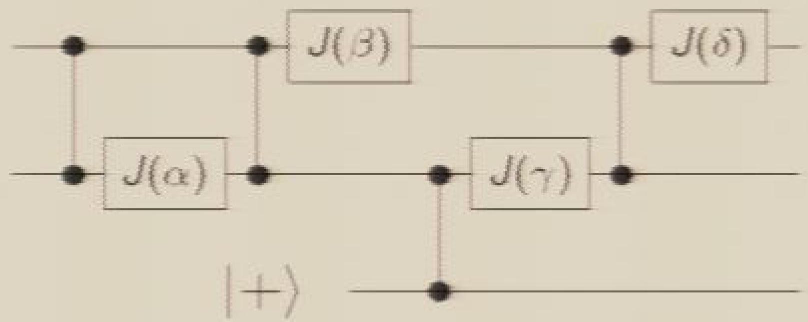

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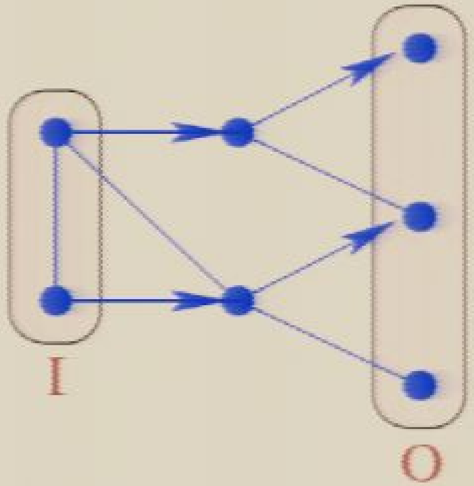

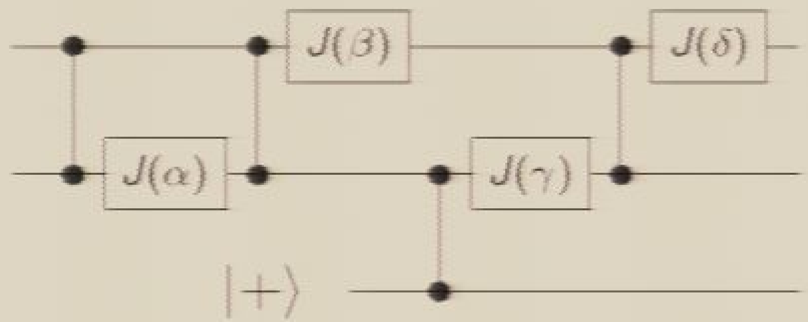

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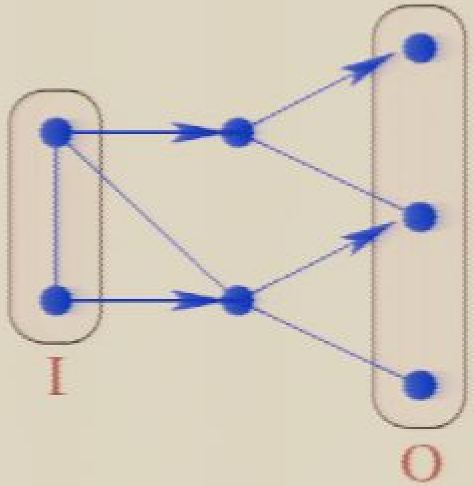

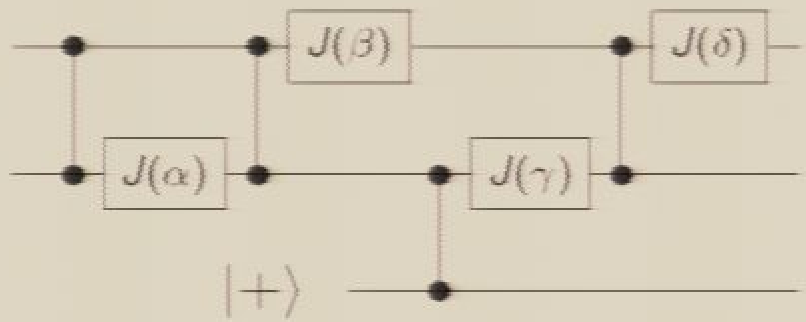

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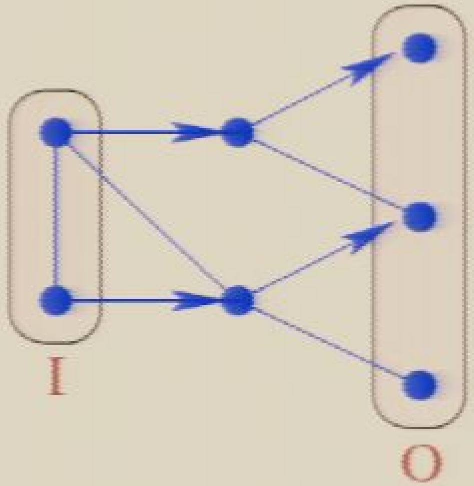

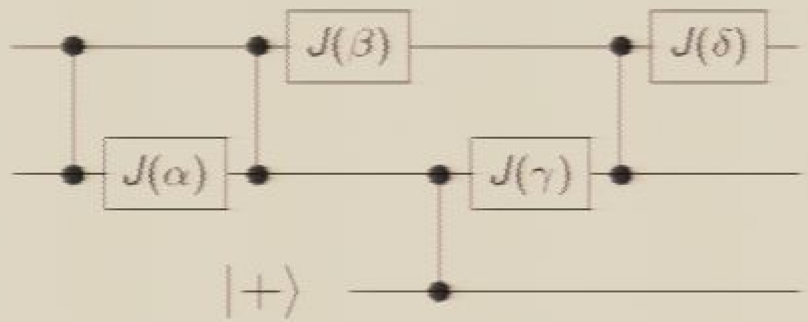

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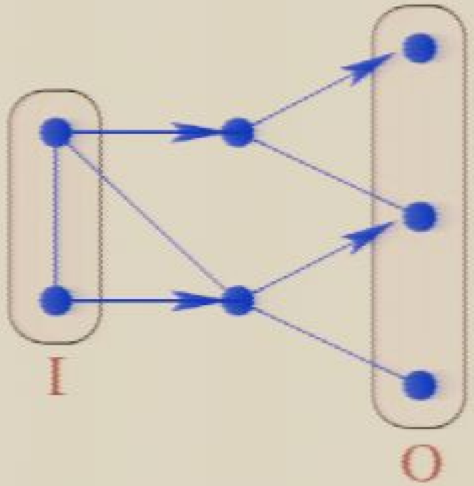

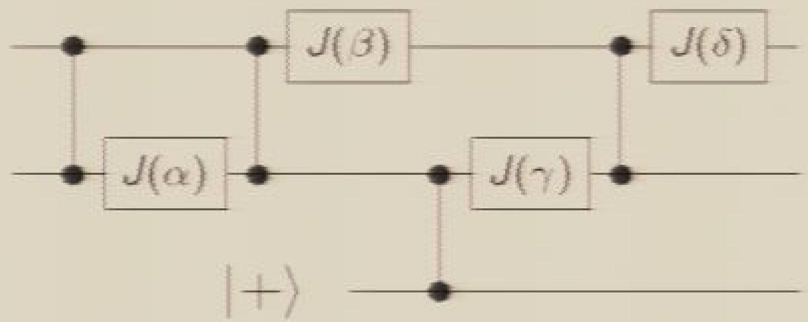

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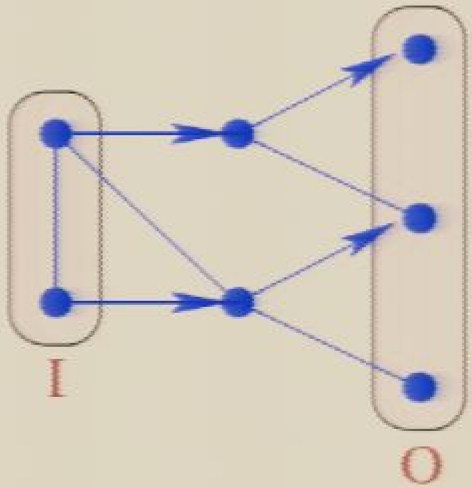

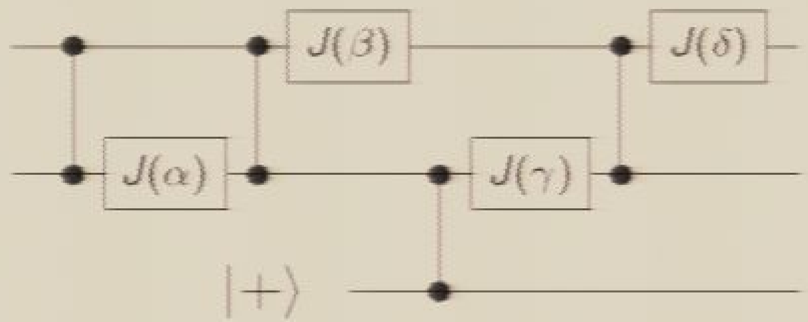

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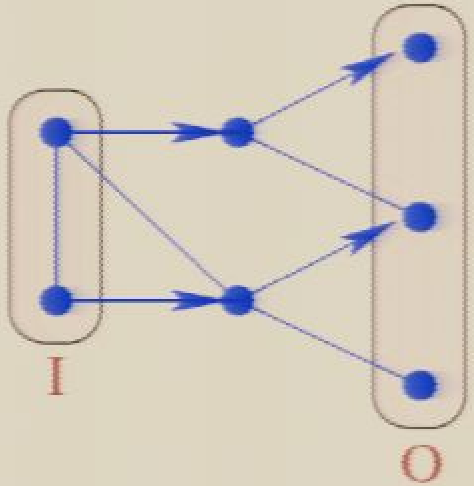

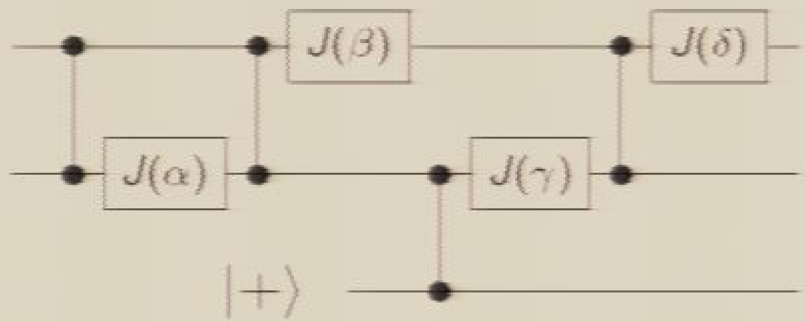

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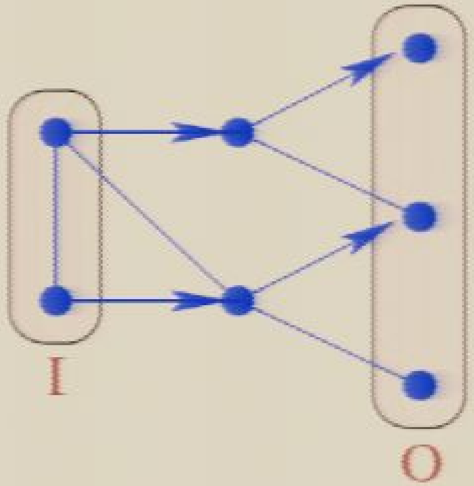

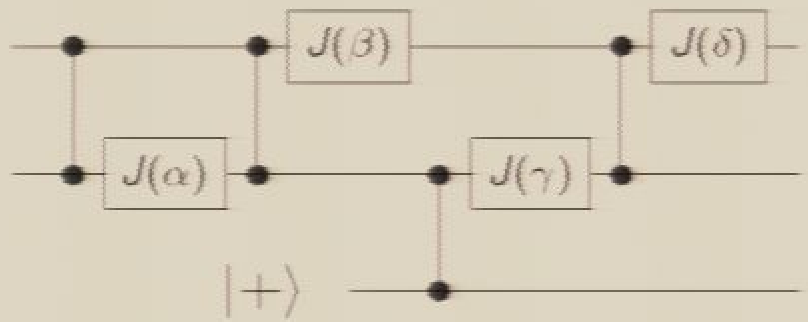

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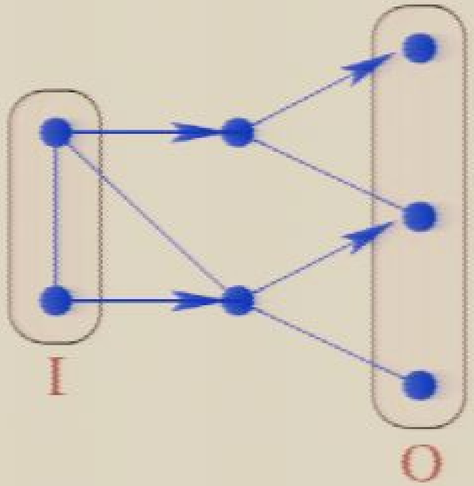

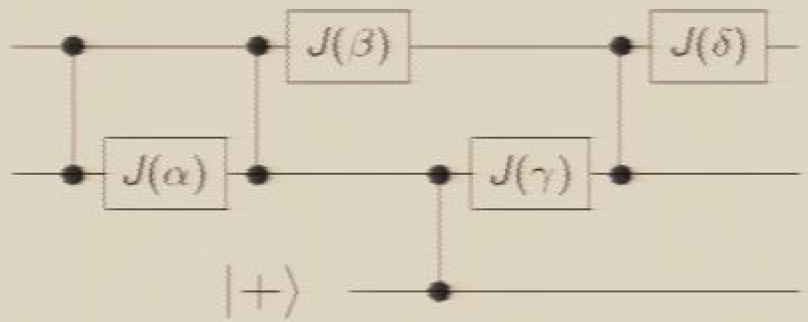

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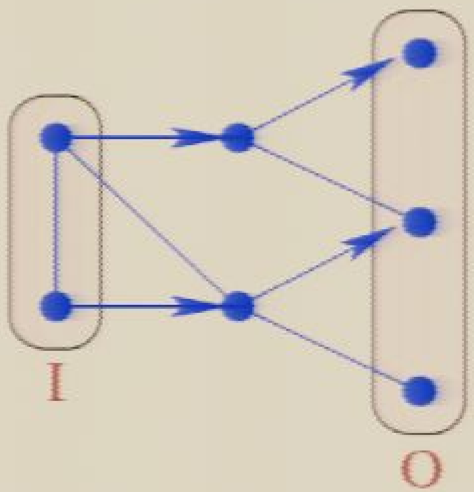

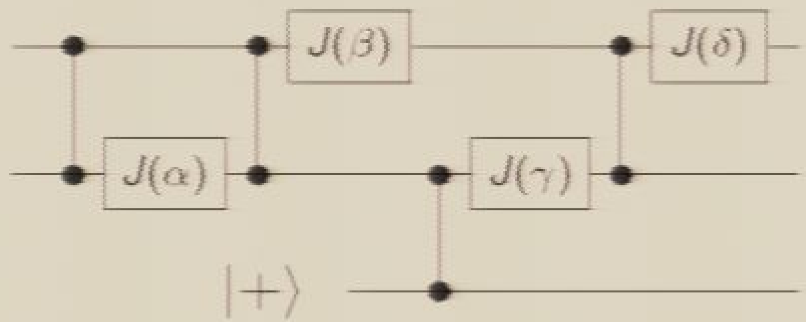

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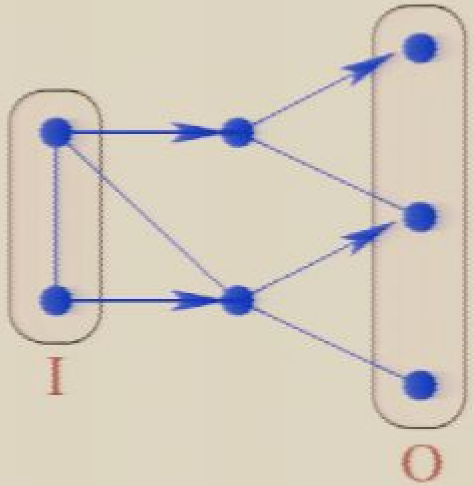

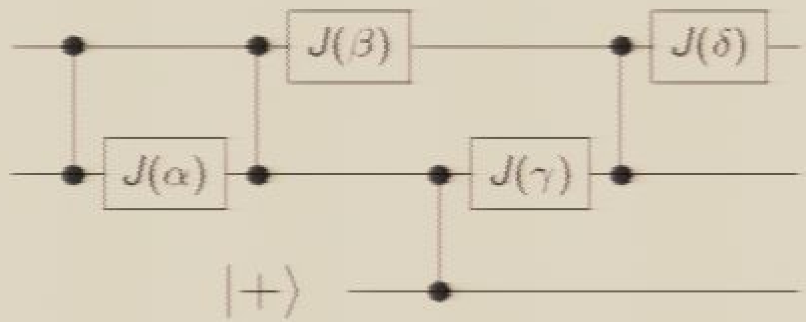

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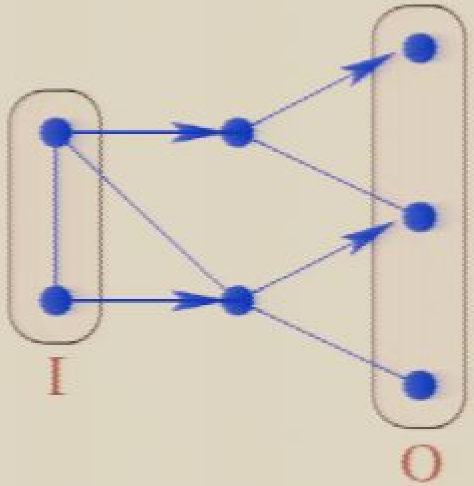

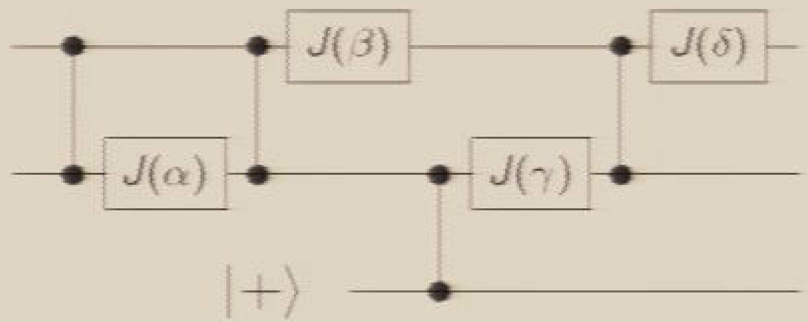

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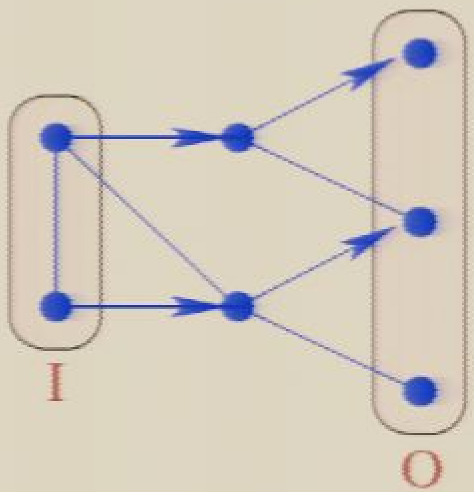

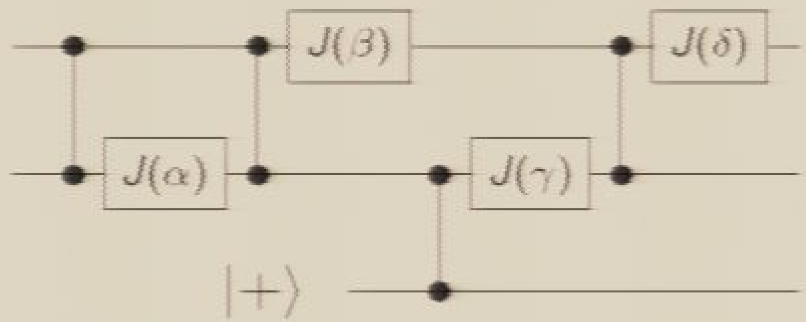

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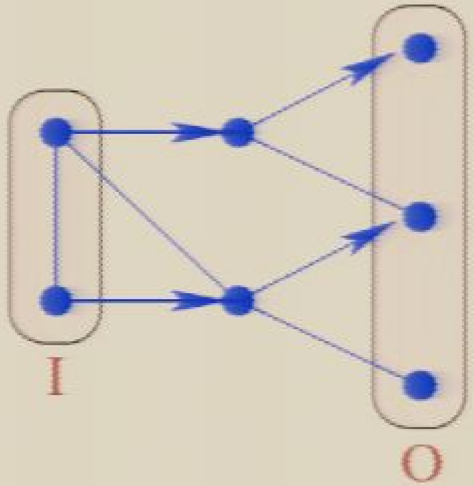

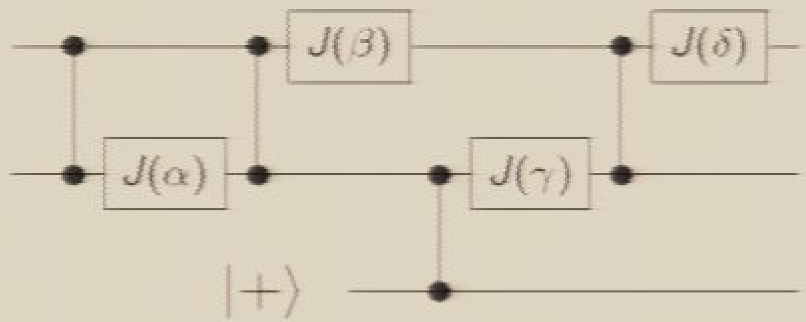

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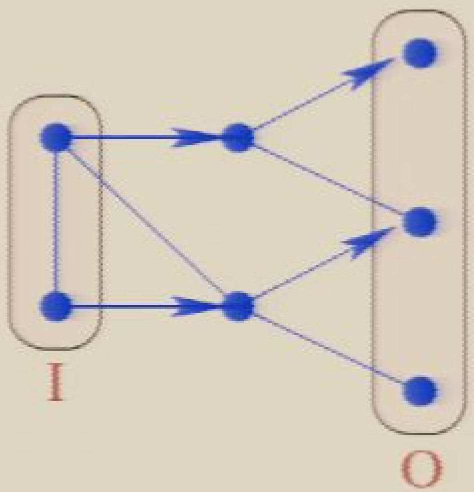

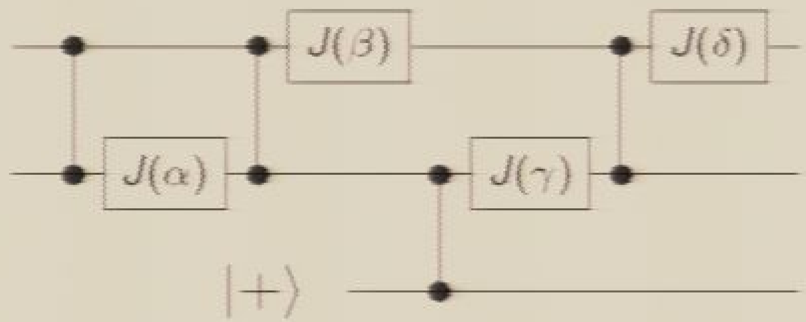

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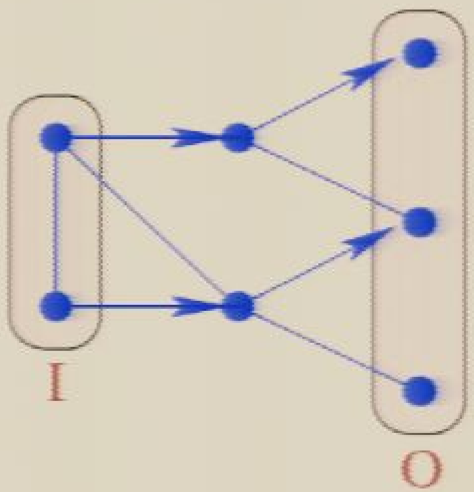

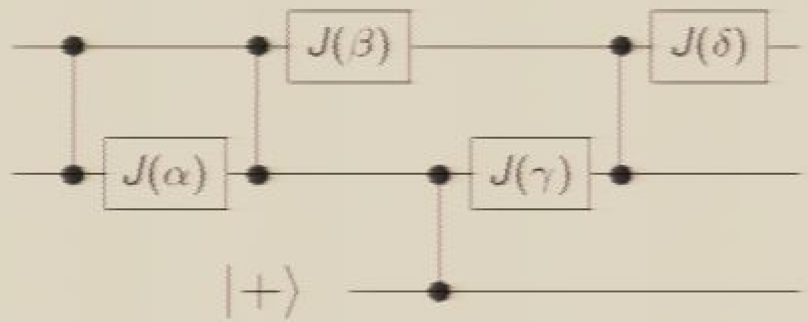

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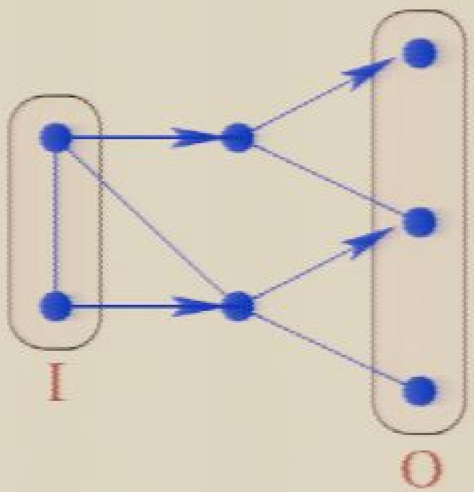

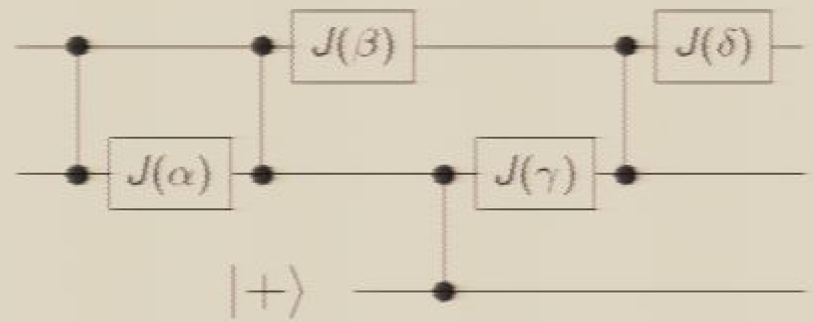

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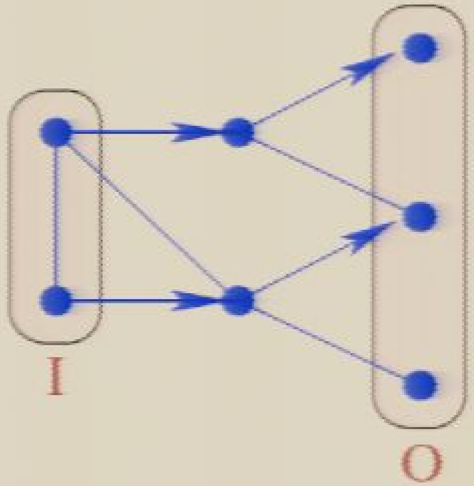

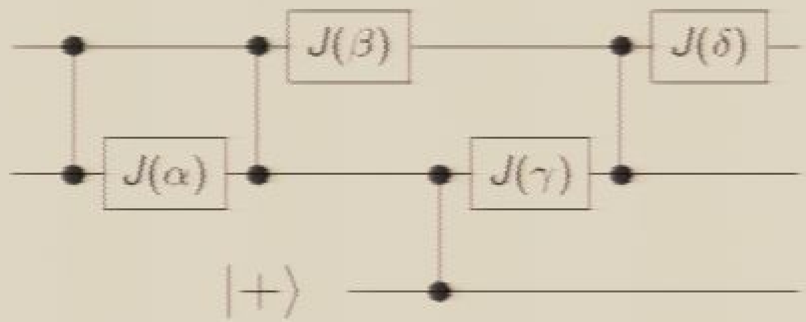

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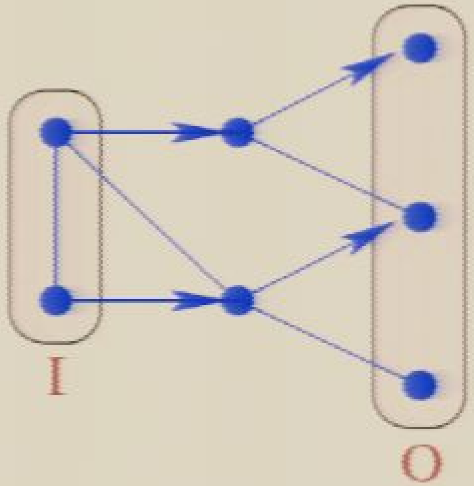

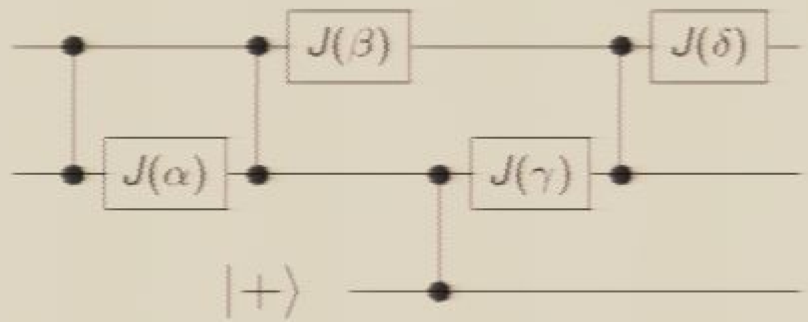

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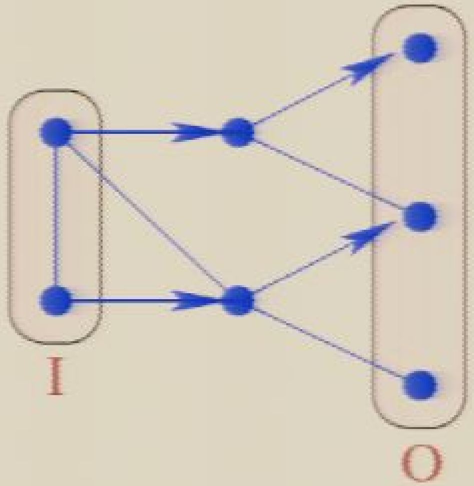

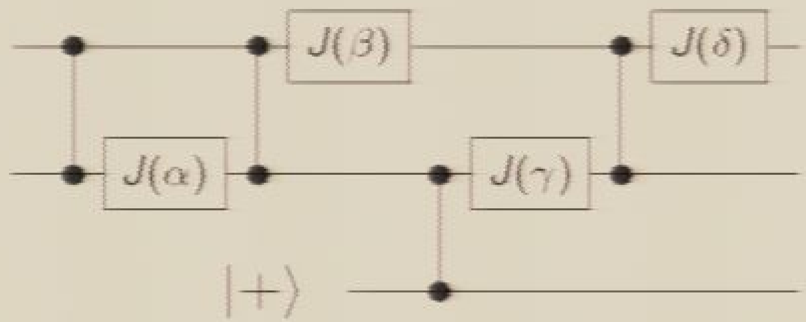

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Outline

1. Easily understood patterns
   - A somewhat different set of elementary gates
   - Unitary transformations via measurements
   - Building "measurement patterns"
   - Geometries with flows

2. Less-easily understood patterns
   - A pattern which doesn't have a flow
   - Adaptation + correction = postselection
   - Finding correction schemes
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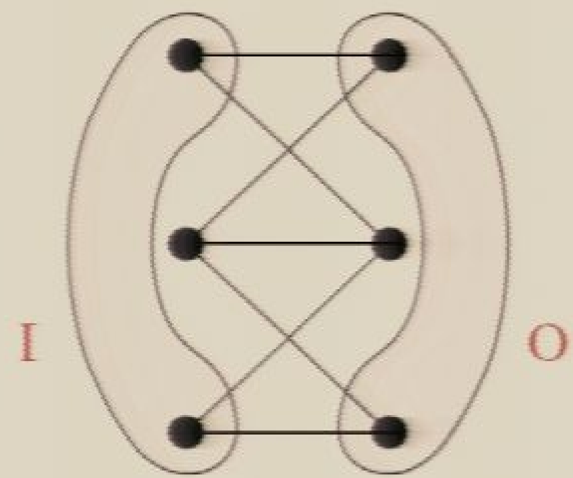

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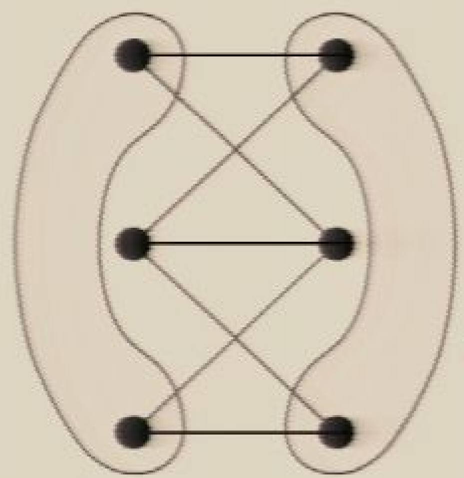

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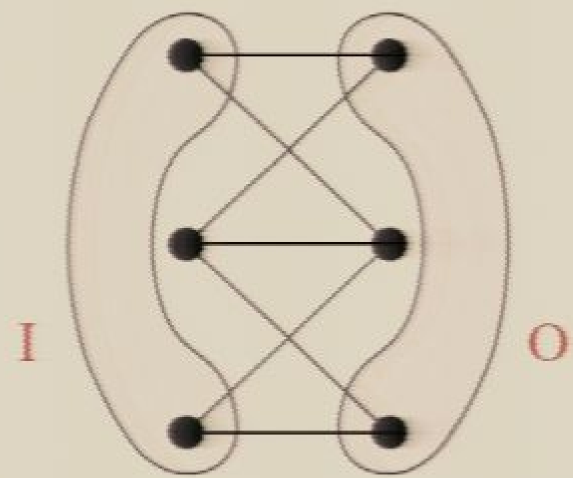

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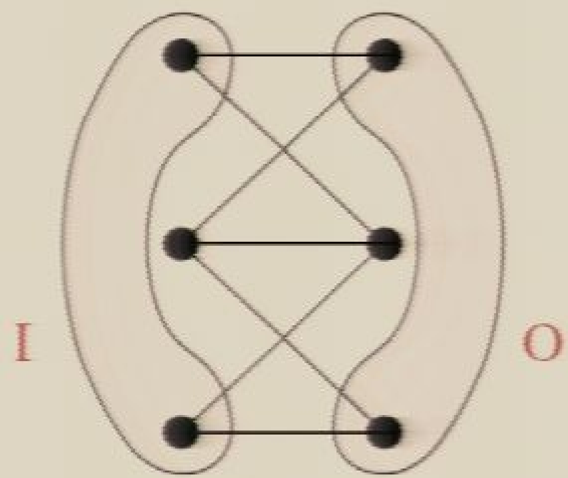

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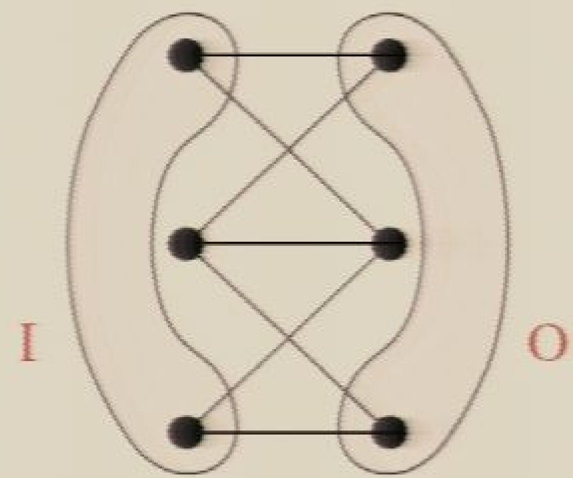

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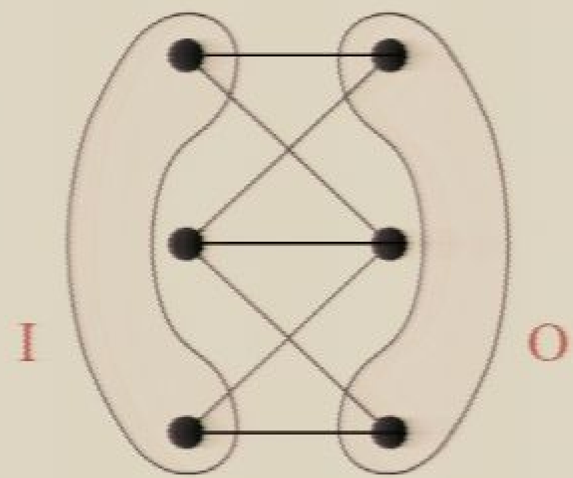

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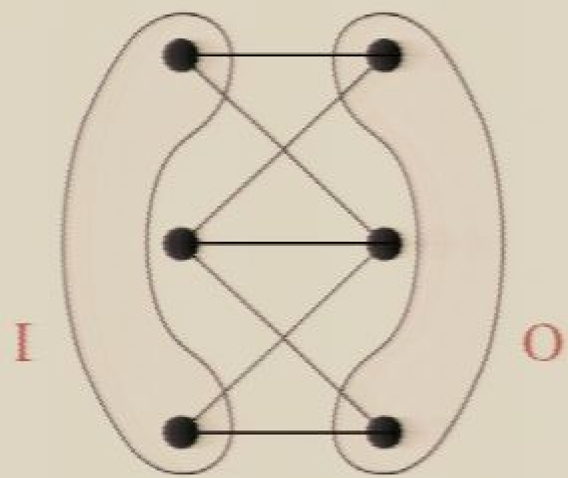

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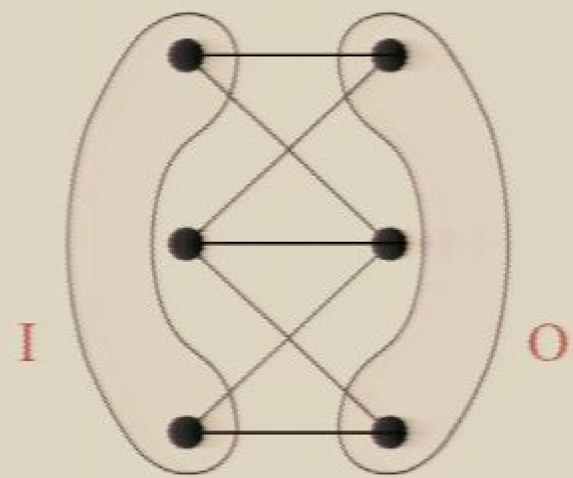

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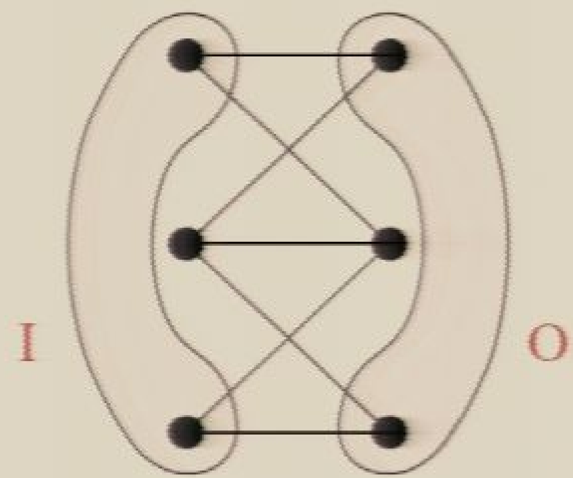

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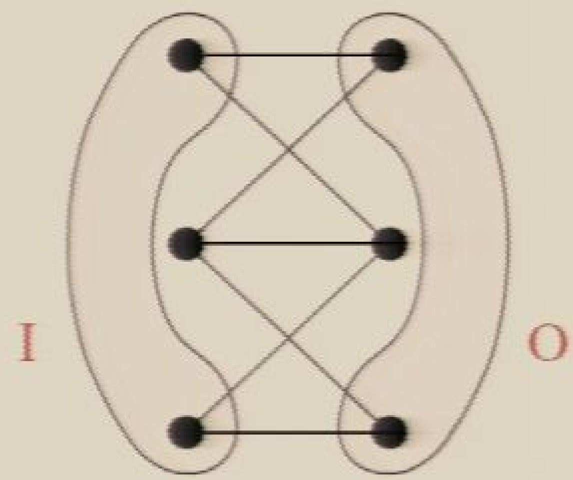

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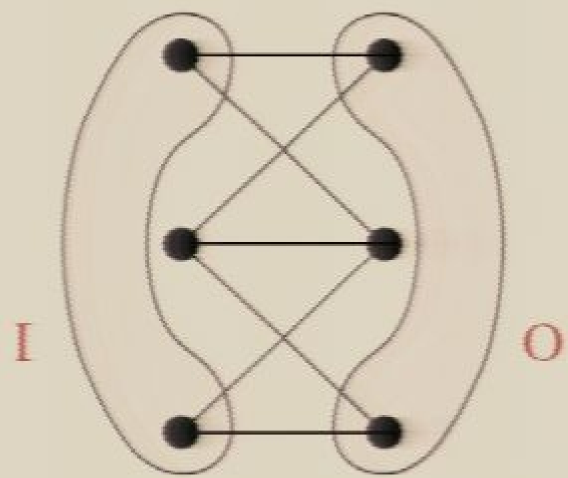

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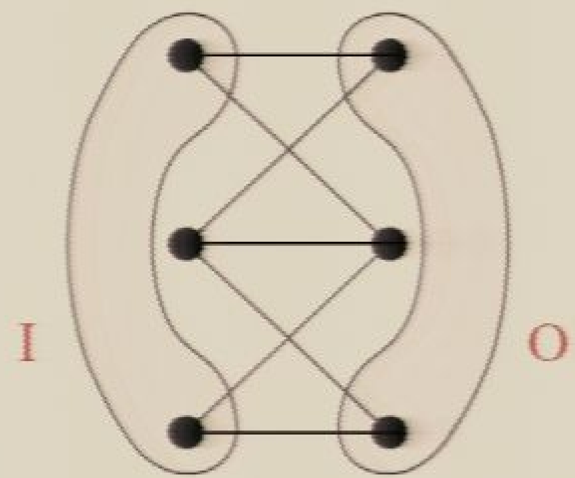

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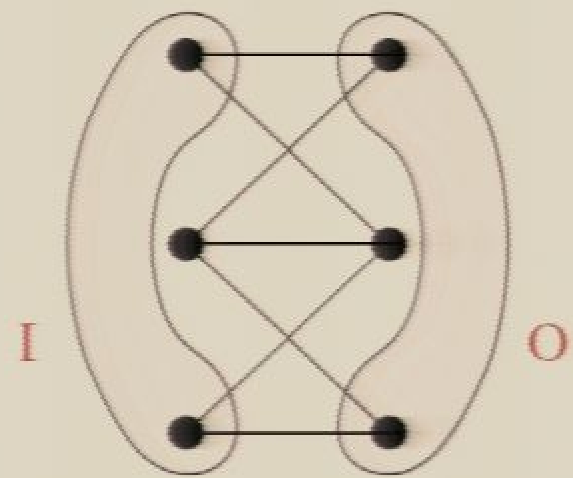

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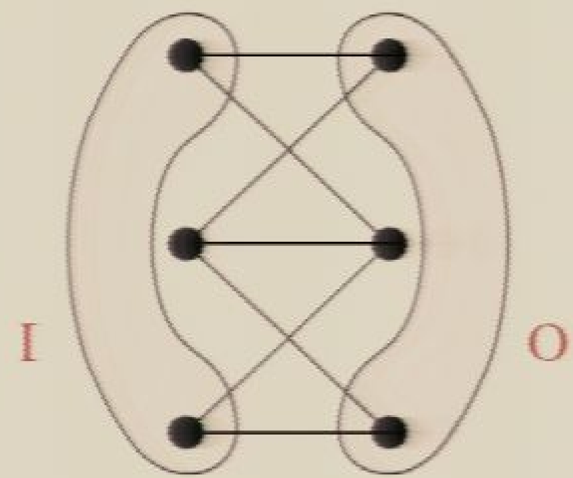

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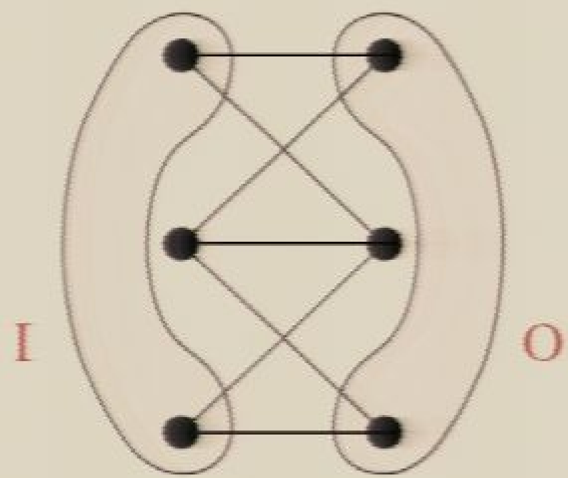

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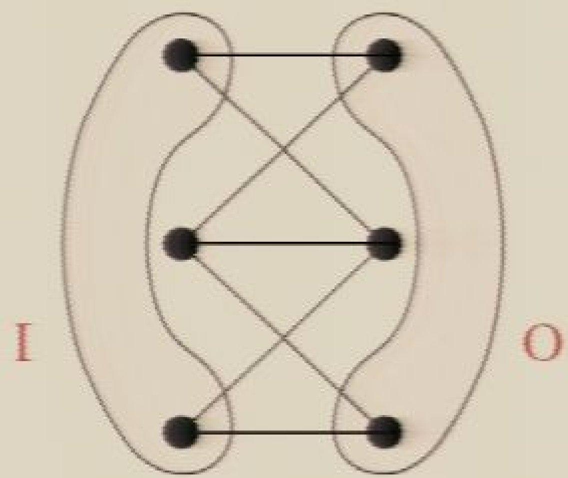

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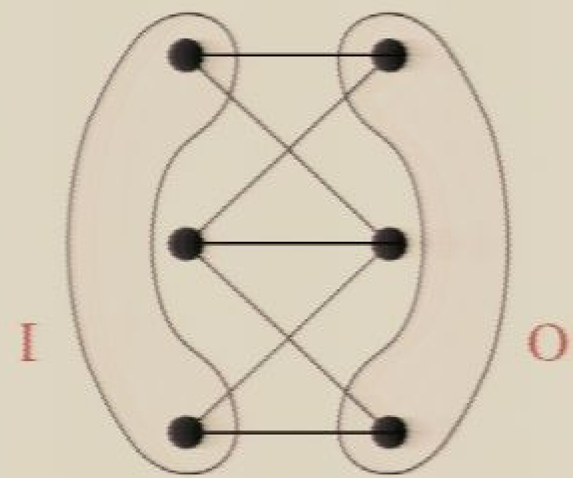

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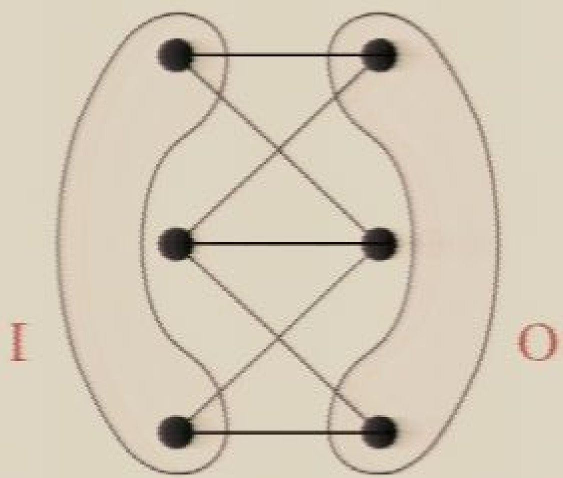

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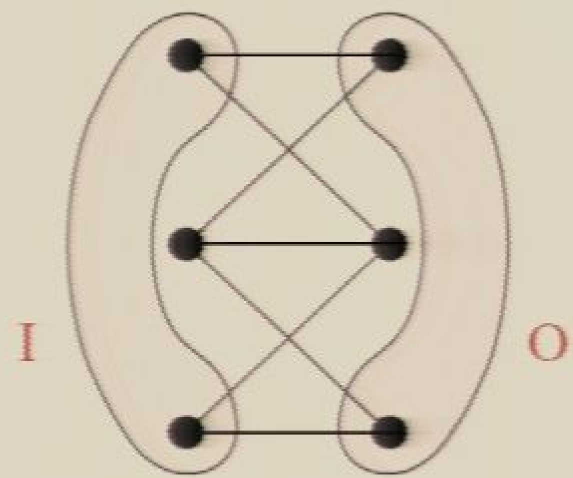

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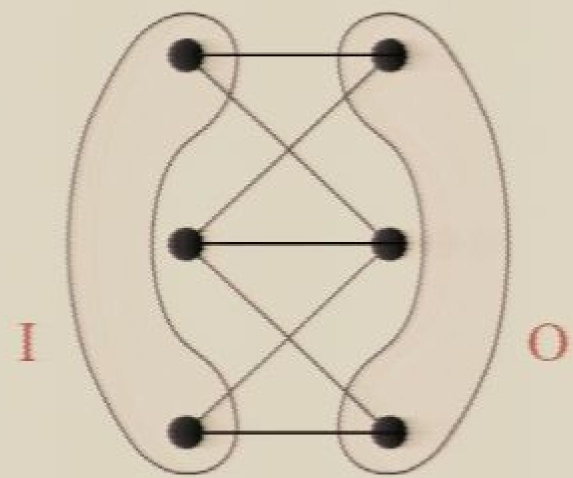

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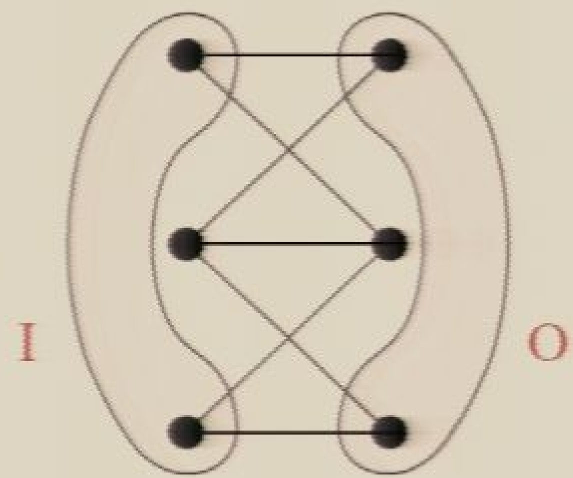

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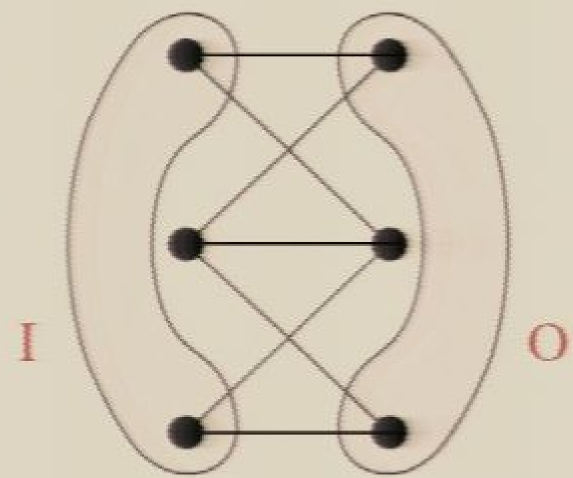

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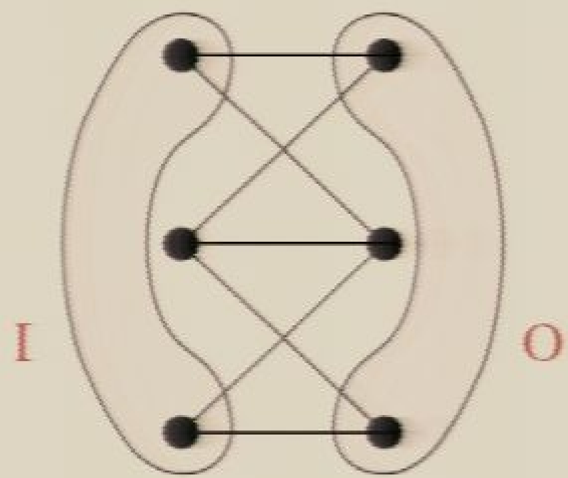

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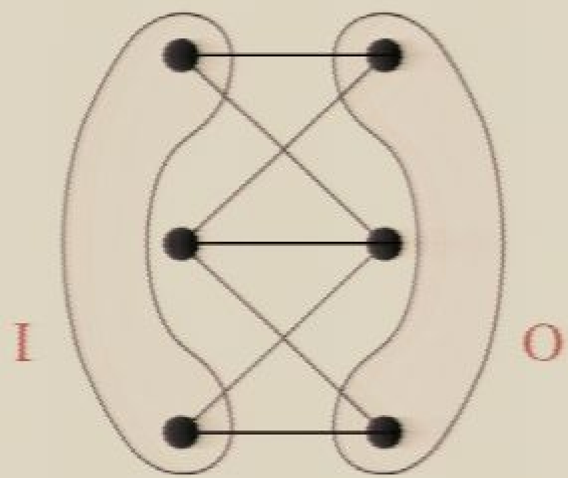

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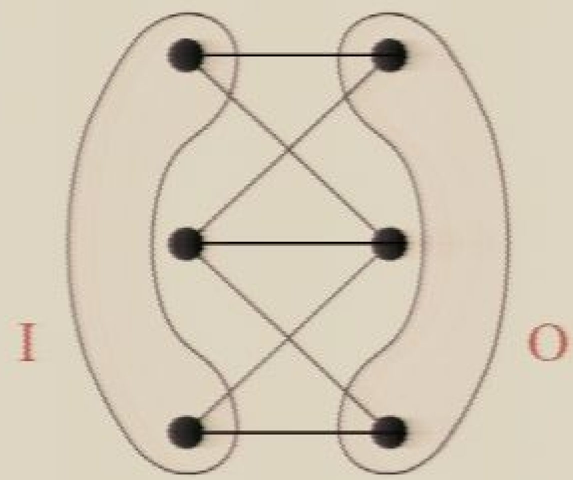

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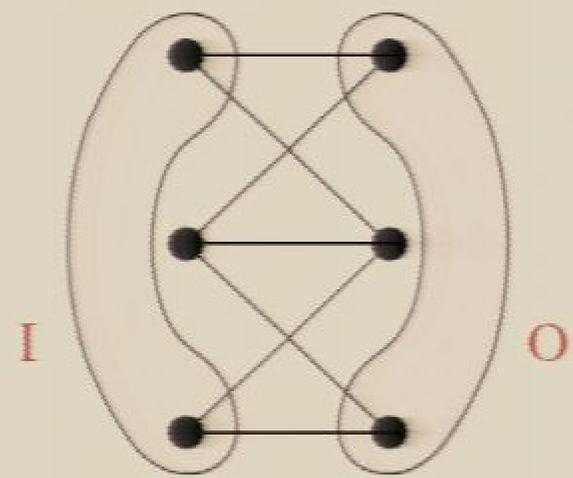

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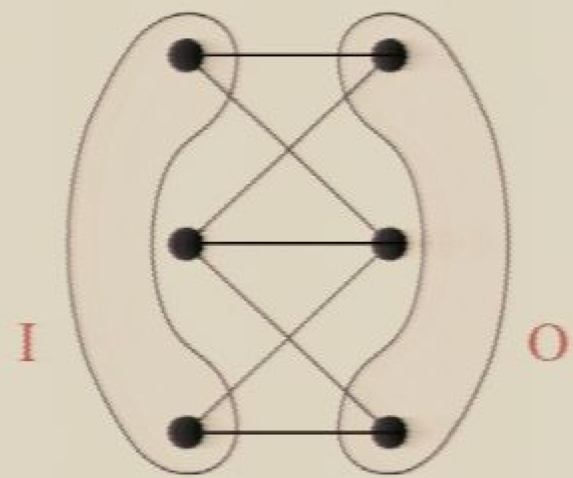

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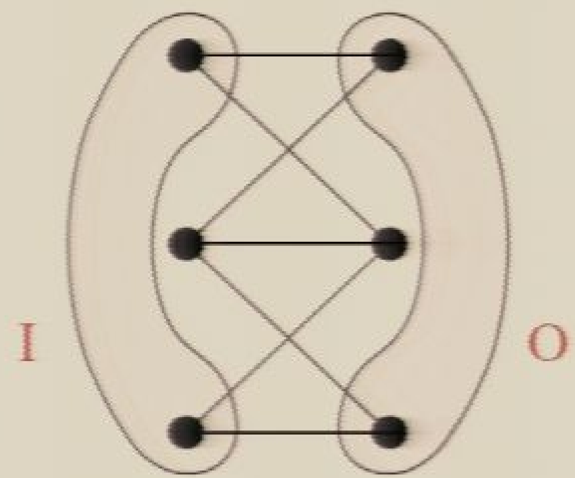

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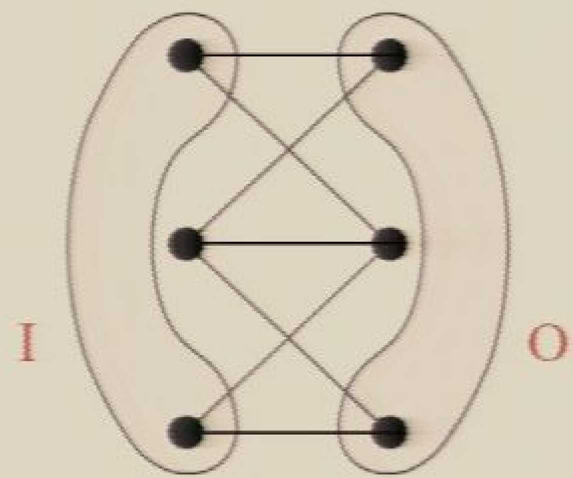

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(which is the foundation of *everything* in this talk)

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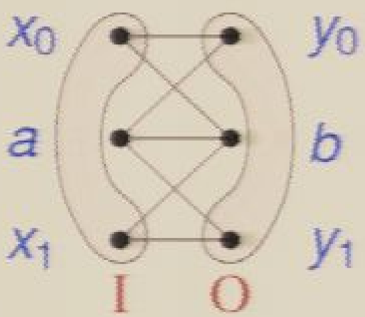

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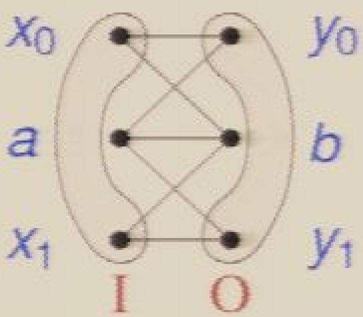

x_0	x_1	a	b	y_0	y_1
		X	Z	Z	Z
Z	Z	Z	X		
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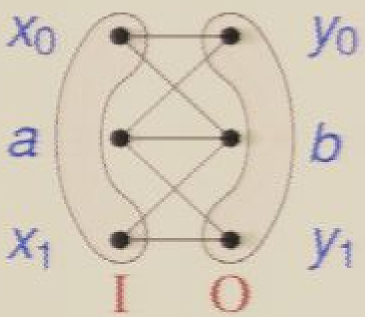

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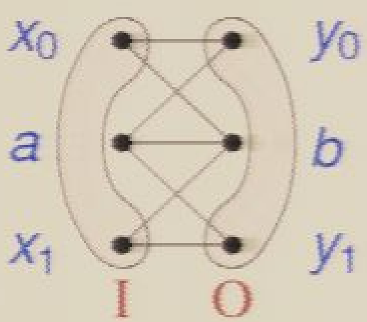

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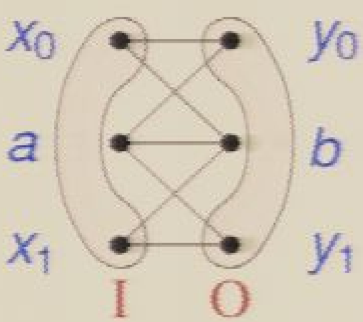

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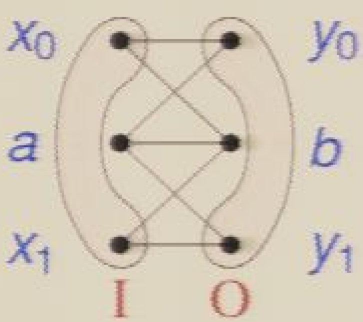

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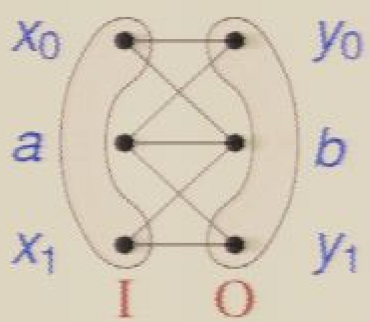

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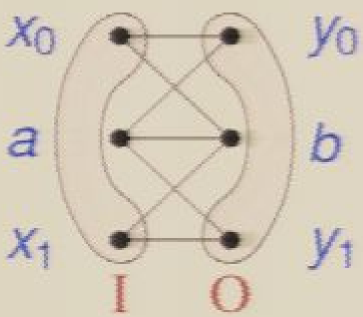

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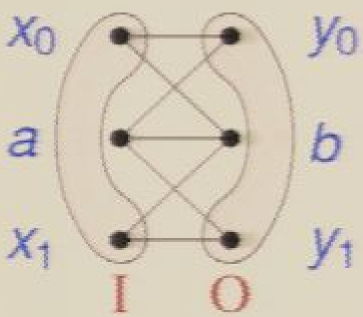

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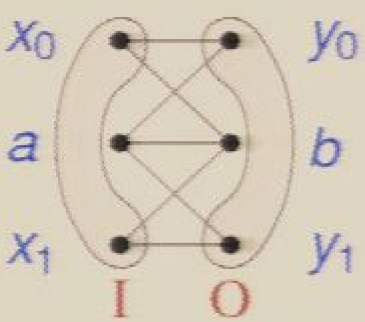

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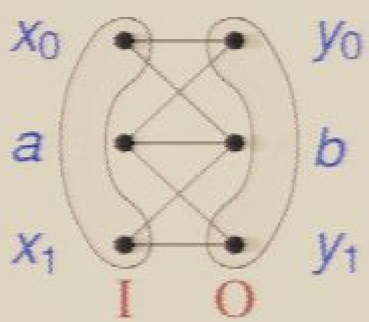

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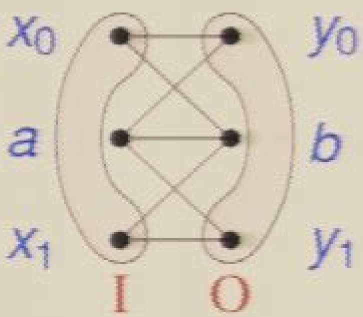

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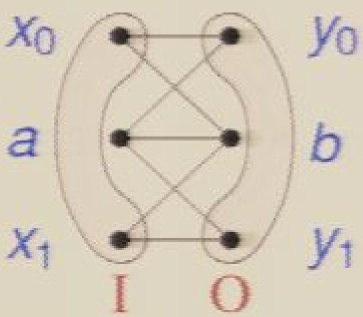

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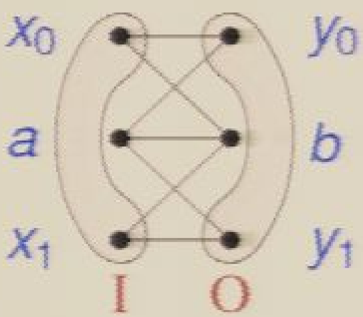

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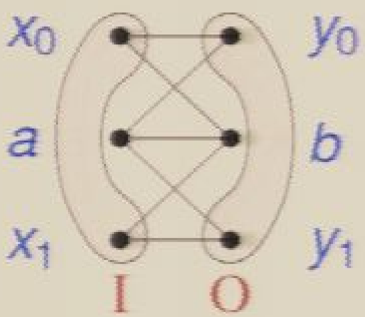

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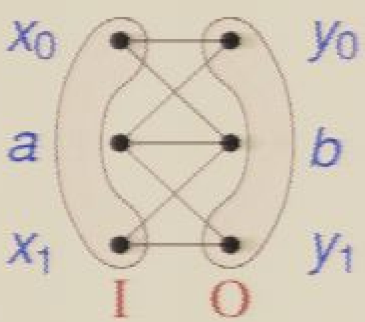

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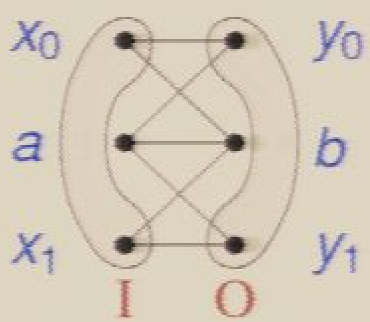

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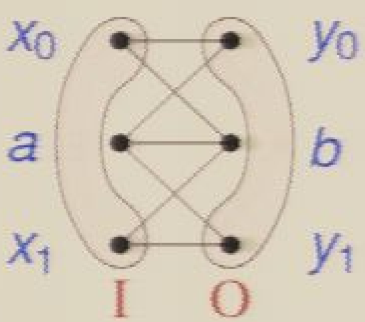

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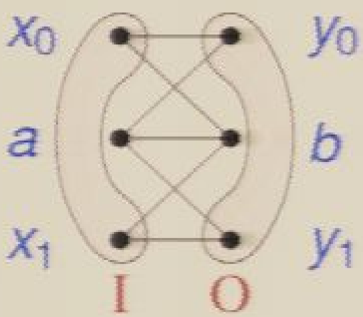

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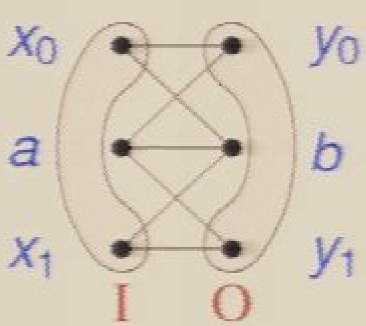

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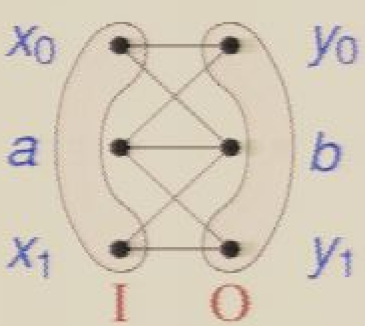

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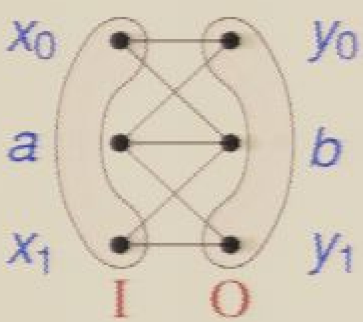

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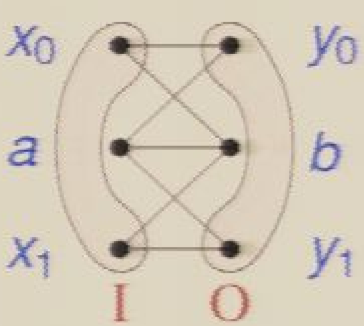

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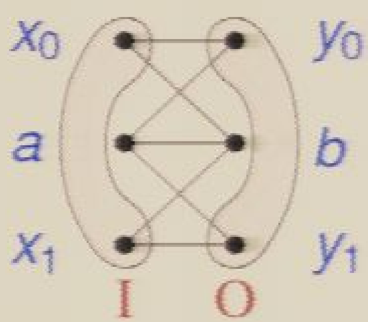

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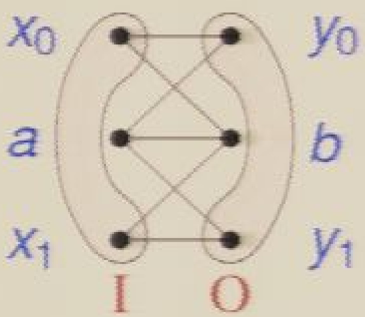

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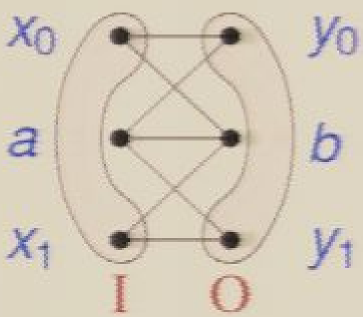

x_0	x_1	a	b	y_0	y_1
Z	Z	Z	X		
Z			X		X
	Z		X	X	
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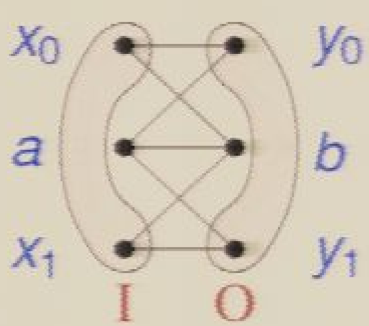

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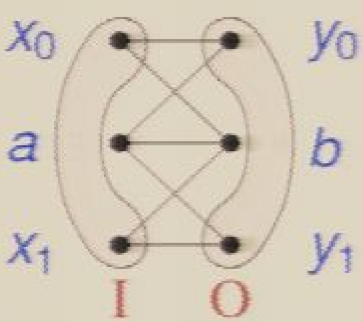

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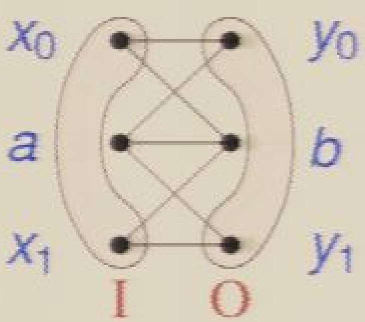

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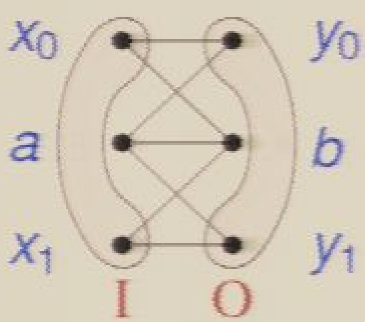

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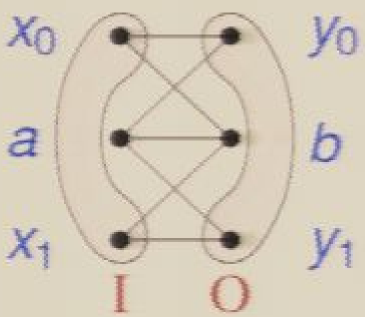

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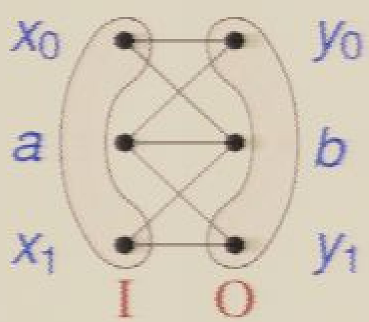

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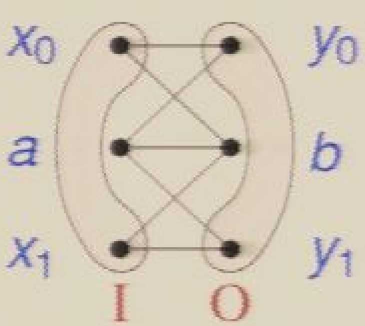

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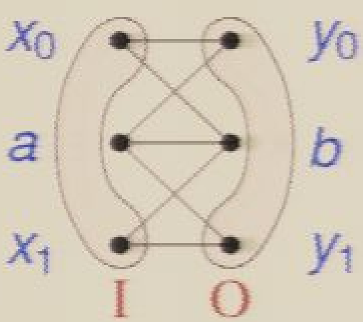

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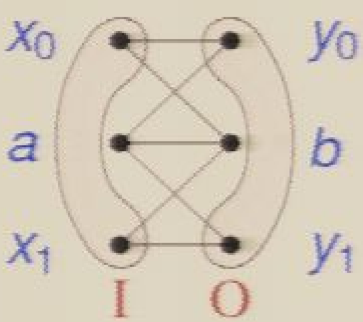

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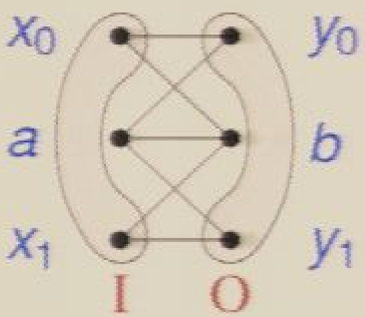

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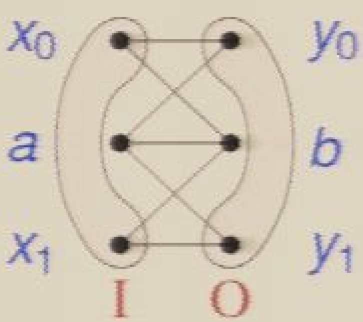

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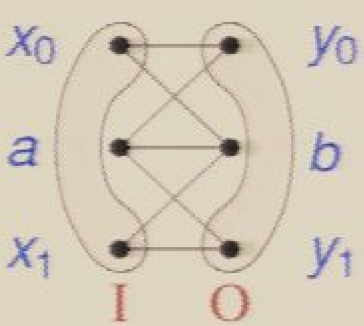

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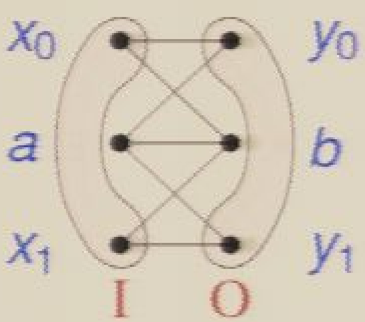

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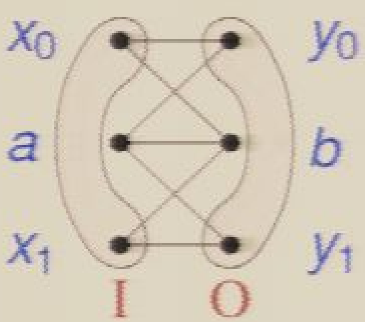

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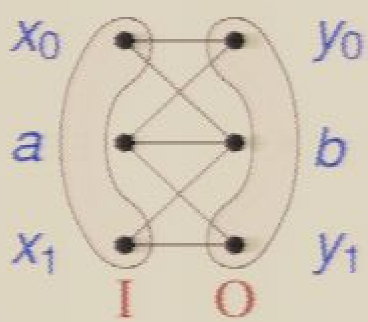

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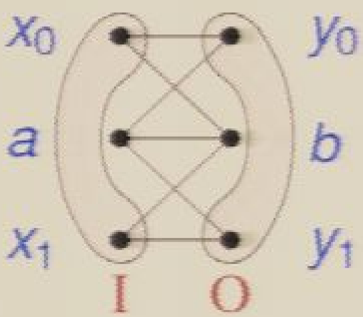

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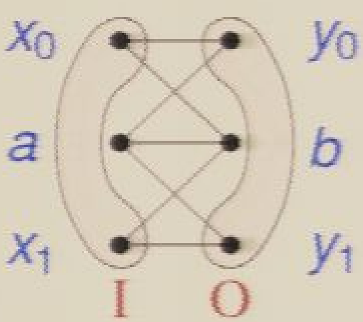

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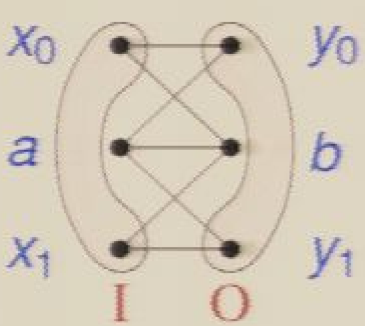

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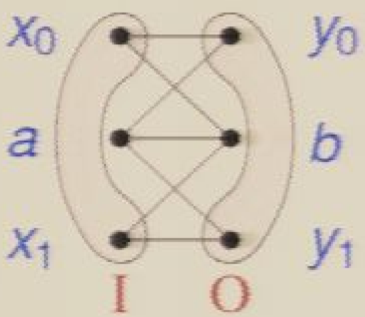

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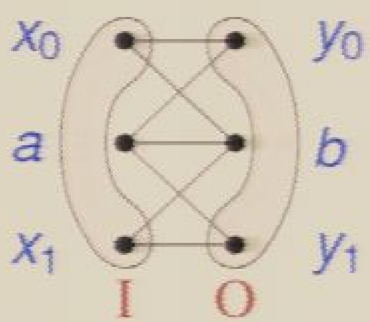

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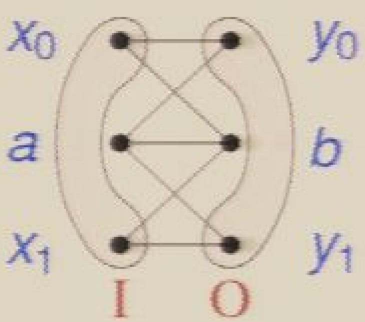

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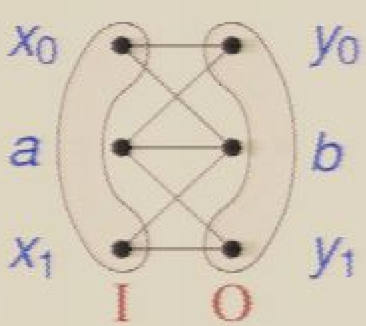

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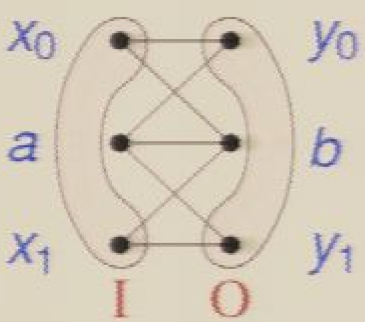

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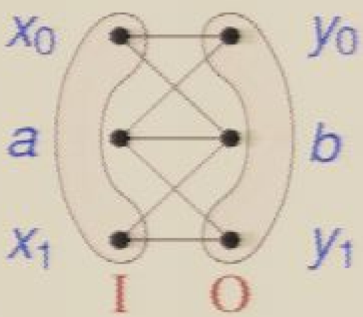

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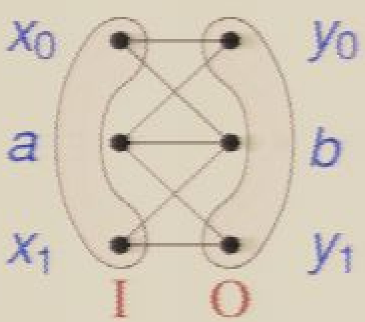

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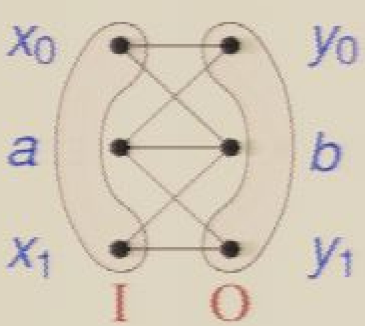

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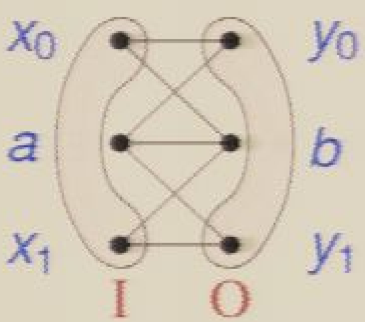

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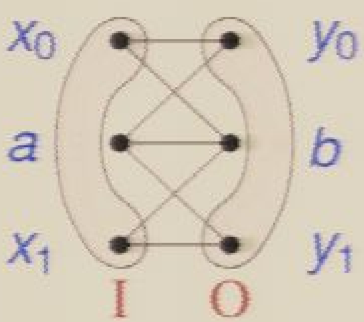

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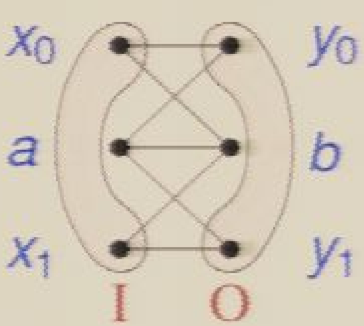

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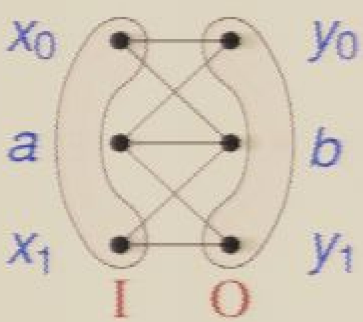

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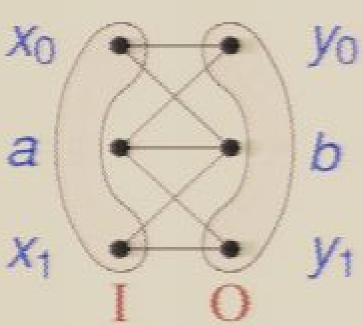

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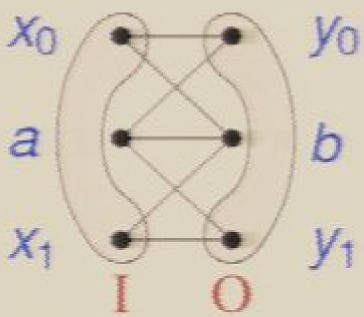

x_0	x_1	a	b	y_0	y_1
Z	Z	Z	X		
Z			X		X
	Z		X	X	
		X	Z	Z	Z

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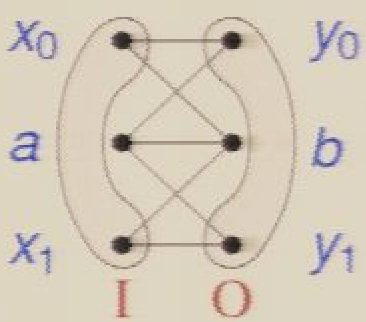

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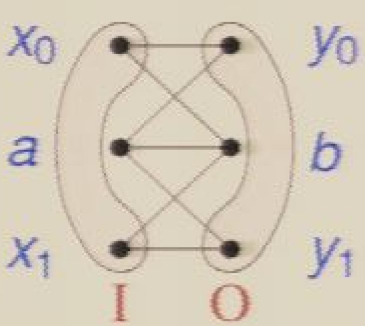

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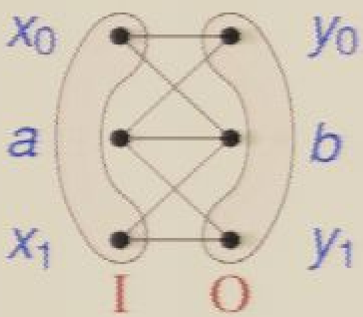

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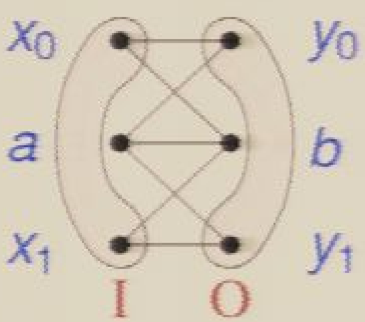

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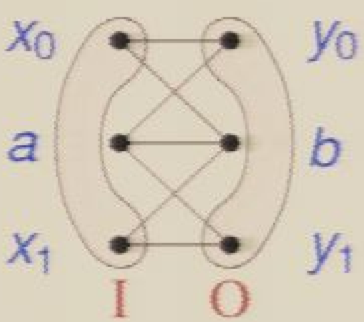

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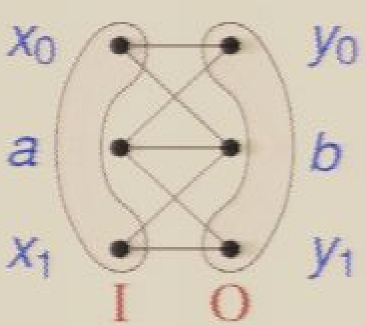

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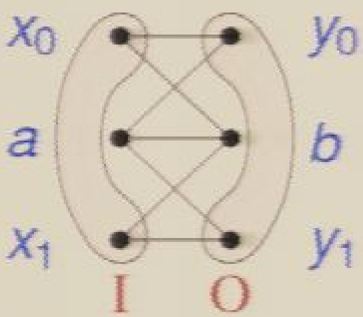

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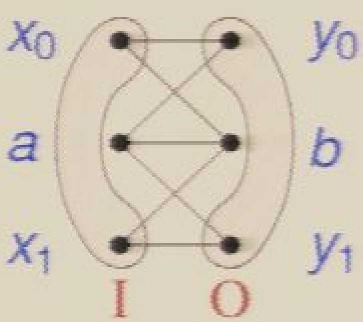

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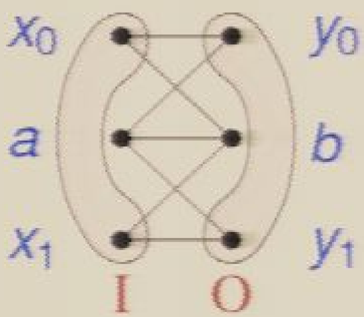

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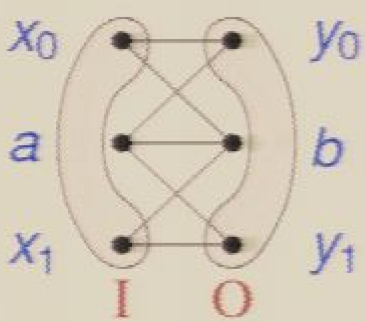

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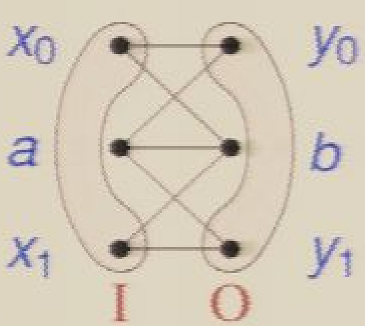

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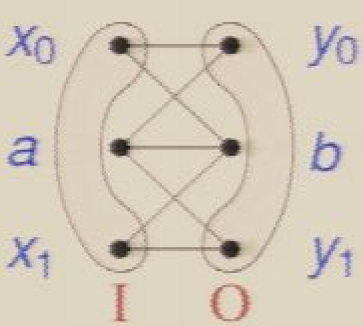

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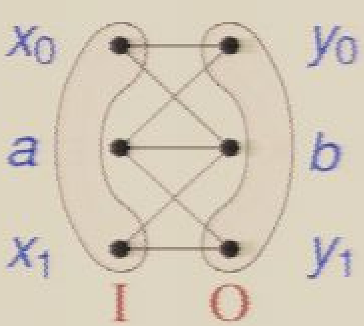

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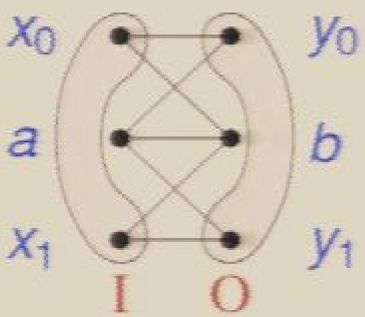

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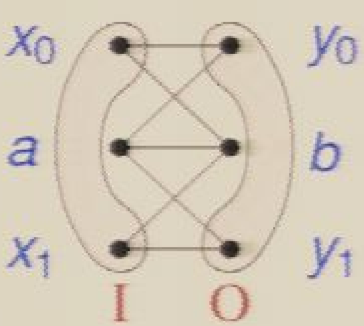

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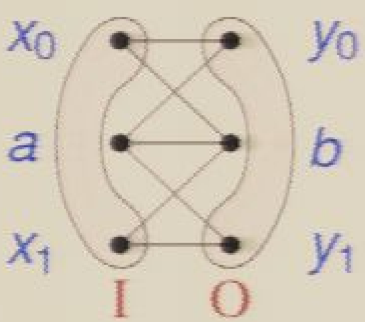

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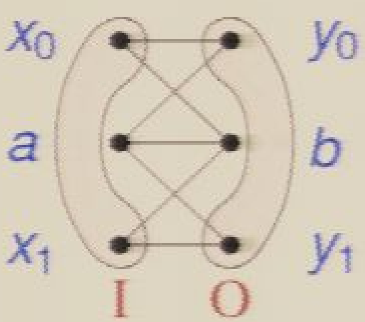

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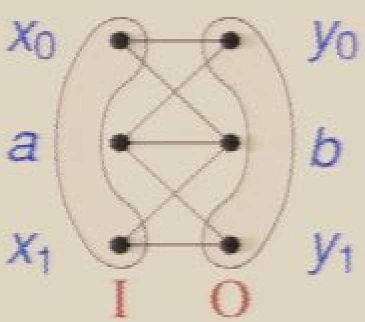

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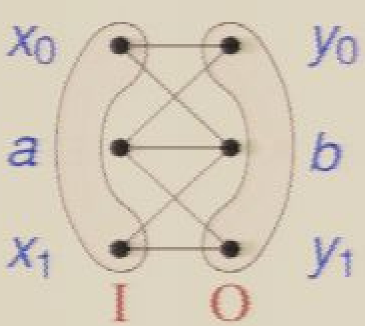

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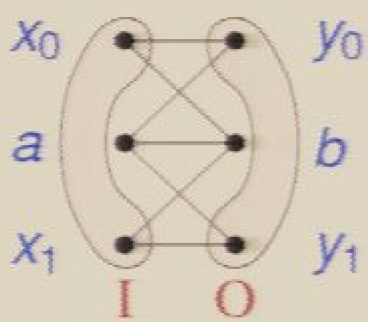

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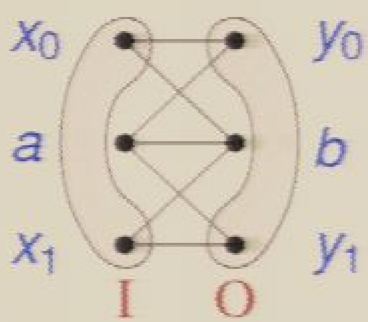

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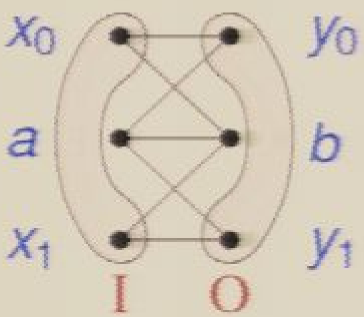

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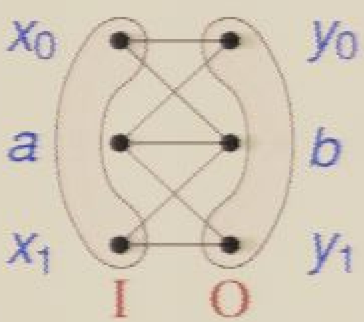

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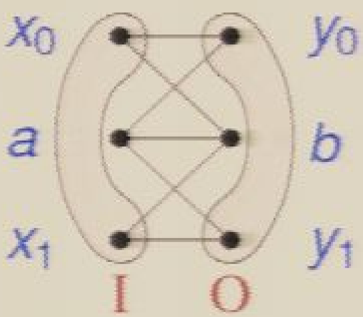

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		X			
X					
	X				
			X		

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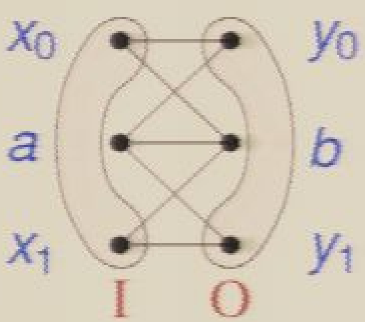

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		X			
X					
	X				
			X		

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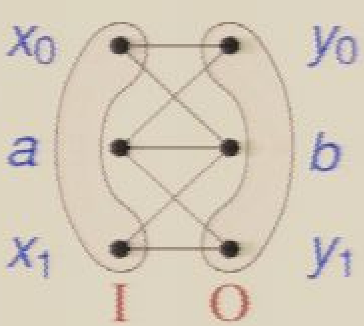

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X					
	X				
			X		

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Finding correction schemes

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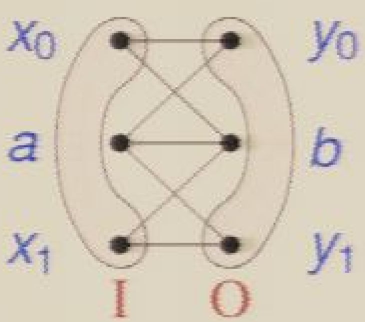
(which is the foundation of *everything* in this talk)



x_0	x_1	a	b	y_0	y_1
		X		$\mathbb{1}$	$\mathbb{1}$
X				$\mathbb{1}$	$\mathbb{1}$
	X			$\mathbb{1}$	$\mathbb{1}$
			X	$\mathbb{1}$	$\mathbb{1}$

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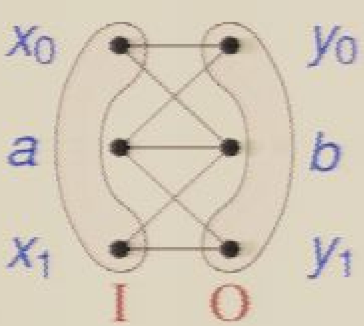

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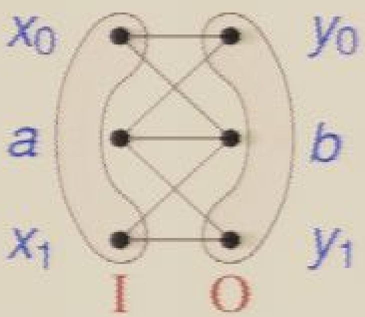

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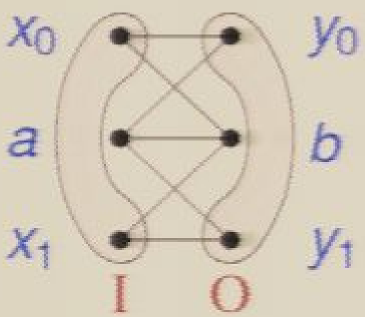

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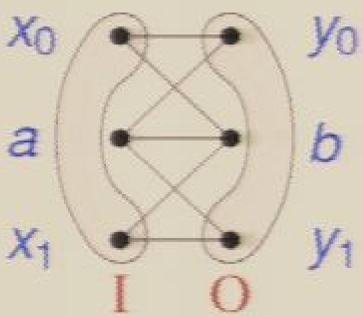

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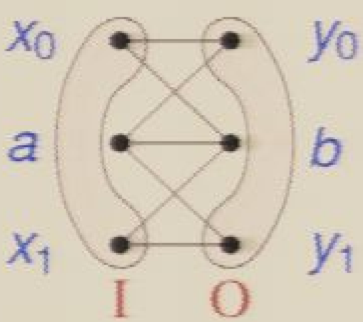

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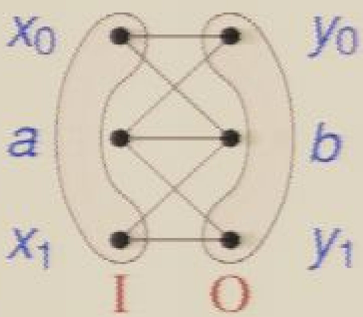

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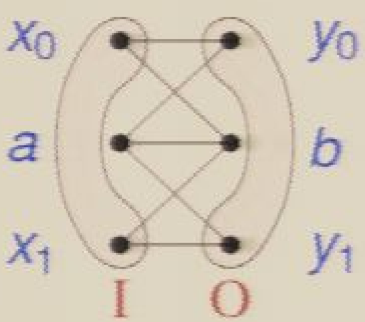

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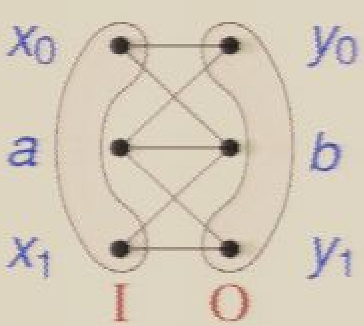

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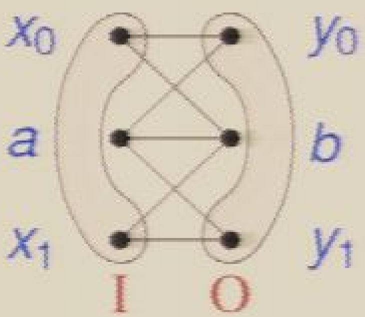

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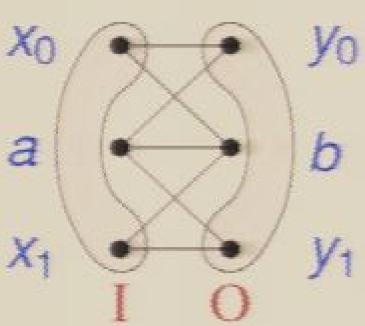

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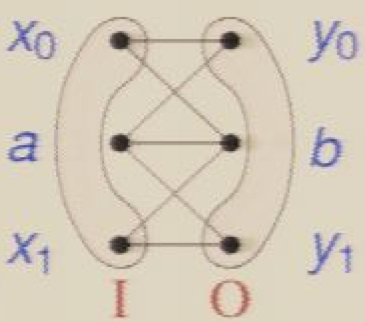

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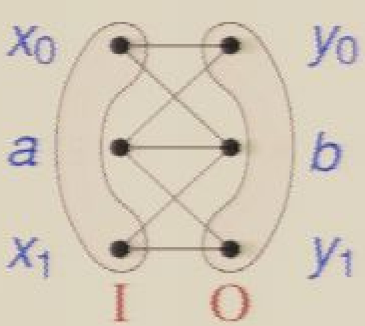

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a set of measurement angles θ_v :

- When does this represent a unitary matrix?
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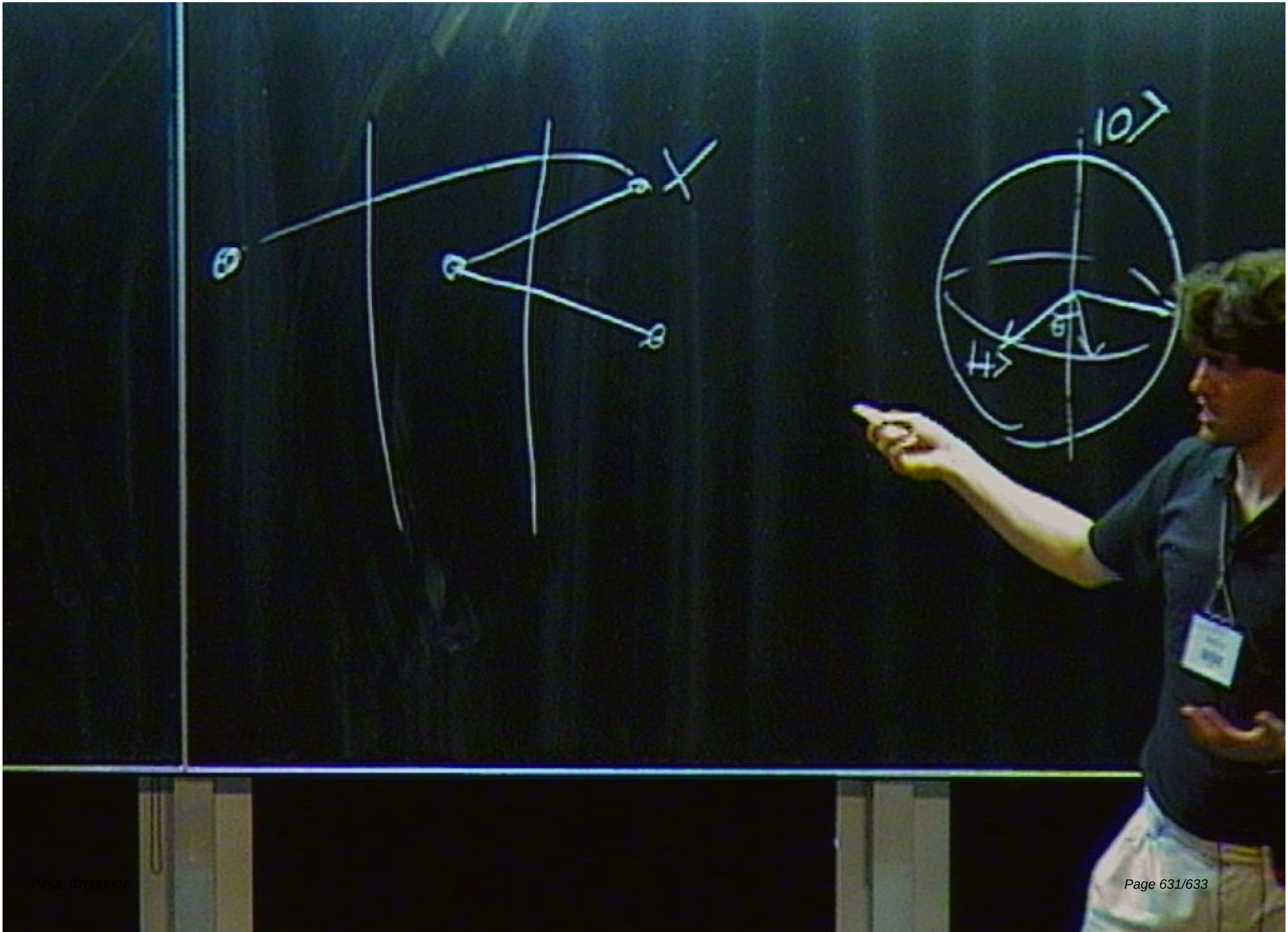
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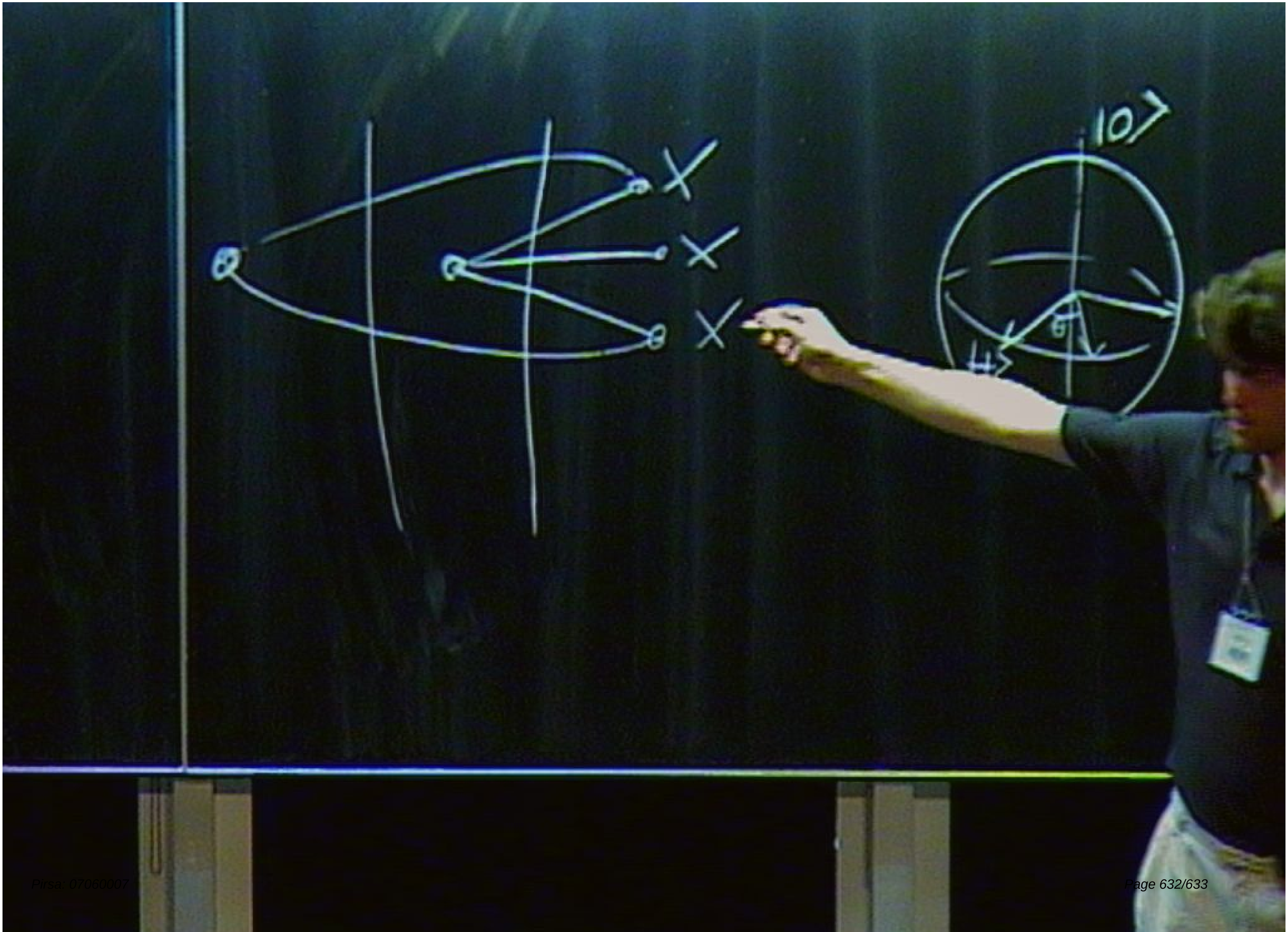
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Adaptation + correction = postselection

The purpose of the *adaptive* measurements/corrections:
evolve the state as if $|+_\theta\rangle$ were always the measurement result

$$U \propto \left[\bigotimes_{v\in O^c} \langle +_{\theta_v}|\right]\left[\prod_{uv\in E(G)} \wedge Z_{u,v}\right]\left[\bigotimes_{v\in I^c} |+\rangle\right]$$

$$= \left[\bigotimes_{v\in O^c} \langle +|\right]\underbrace{\left[\bigotimes_{v\in O^c} P(-\theta_v)\right]\left[\prod_{uv\in E(G)} \wedge Z_{u,v}\right]}_{\text{a diagonal unitary (\textit{phase map})}}\left[\bigotimes_{v\in I^c} |+\rangle\right]$$