

Title: Braid-like Chiral States in Quantum gravity

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Abstract: There has been a dream that matter and gravity can be unified in a fundamental theory of quantum gravity. One of the main philosophies to realize this dream is that matter may be emergent degrees of freedom of a quantum theory of gravity. We study the propagation and interactions of braid-like chiral states in models of quantum gravity in which the states are (framed) four-valent spin networks embedded in a topological three manifold and the evolution moves are given by the dual Pachner moves. There are results for both the framed and unframed case. We study simple braids made up of two nodes which share three edges, which are possibly braided and twisted. We find three classes of such braids, those which both interact and propagate, those that only propagate, and the majority that do neither. These braids may serve as fundamental matter content.

# Braid-like Chiral States in Quantum Gravity

Yidun Wan

Perimeter Institute and Univ. of Waterloo, Waterloo, ON, Canada

PI QG Seminar, 2008.1.31

"Propagation and Interaction of Chiral States in Quantum Gravity", L. Smolin, Y. Wan,  
arXiv:07101548, accepted by **Nucl. Phys. B**.

"On Braid Excitations in Quantum Gravity", Y. Wan, arXiv:07101312, under review in *Class. Quant. Grav.*

# OUTLINE

- 1 Motivations
- 2 Introduction
  - Embedded (framed) 4-valent spin-networks
  - Notation
  - 3-strand braids
- 3 Operations
  - Equivalence Moves
  - Reducibility of Braids
  - Evolution Moves
- 4 Braid Interaction
- 5 Braid Propagation
- 6 Some Discussion on Braid Interaction/Propagation
- 7 Conclusions and Future Works

# Motivations

## Road to Unification

- The lame beauty of Loop Quantum Gravity: Where is matter?
- Two main philosophies of unifying gravity with matter:
  - Coupling matter fields with quantum gravity;
  - Emergent matter in quantum gravity (the one we take).
- Sundance's ribbonized Preon model sheds light on LQG with matter.
- Particle-like excitations of quantum gravitational fields in LQG exist on embedded 3-valent spin-networks (SB, FM, LS).
- However,
  - 3-valent case suffers from serious limitations.
  - and 4-valent spinnets have true correspondance with 3-space.
- Then what about the embedded 4-valent spin-networks?

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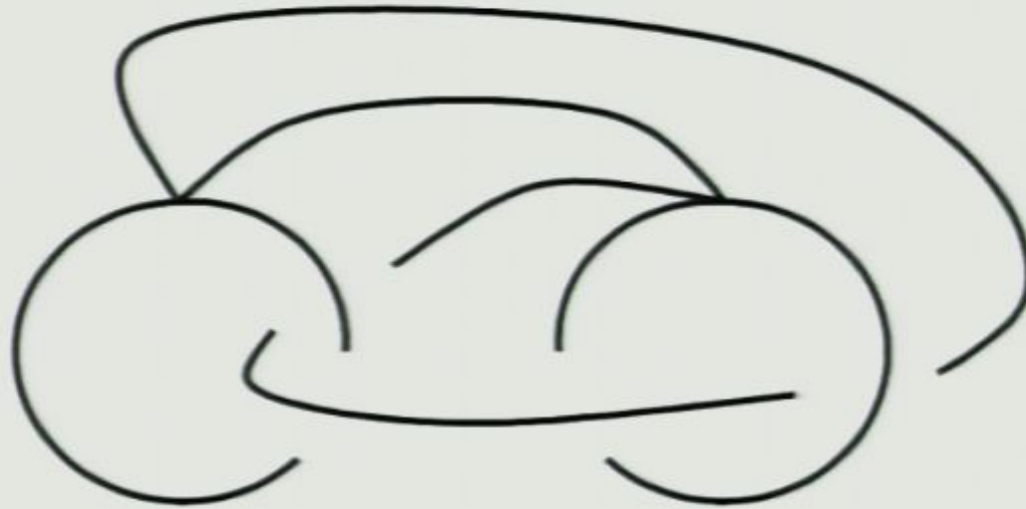
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- How do we notate this kind of graphs?



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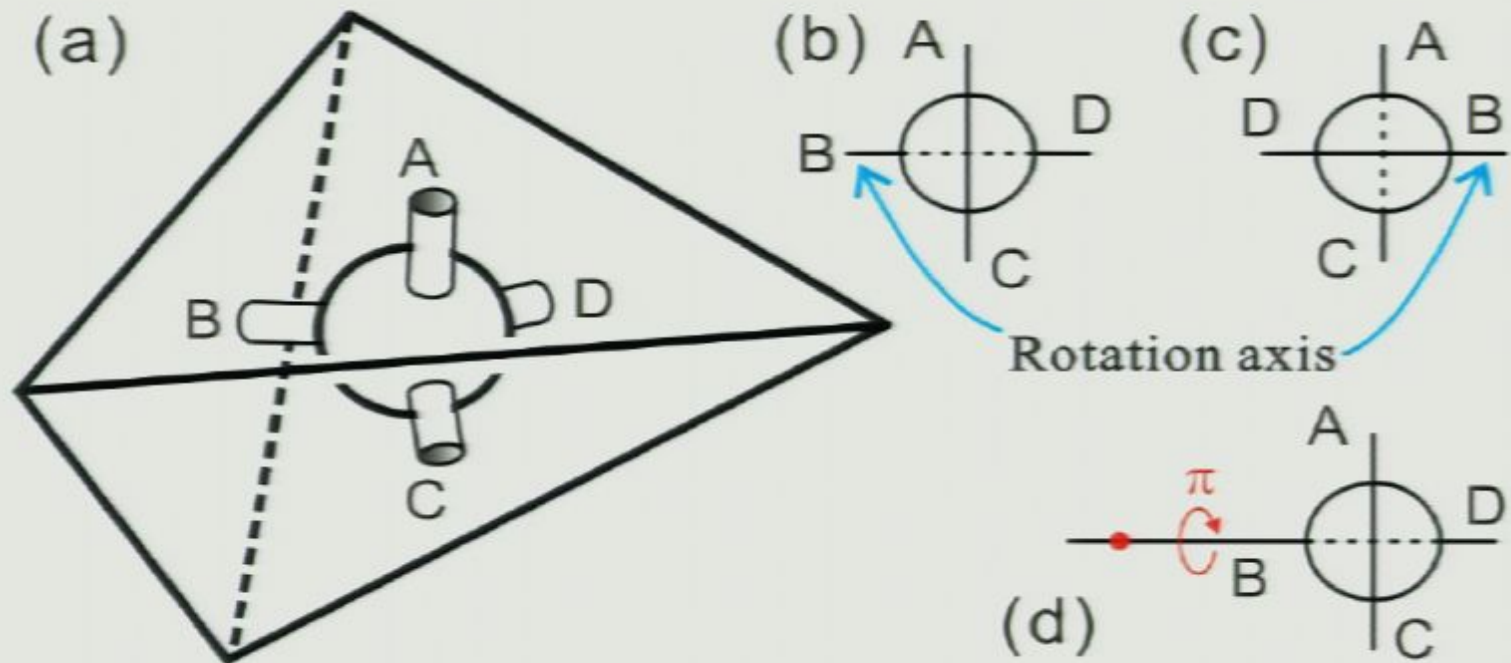
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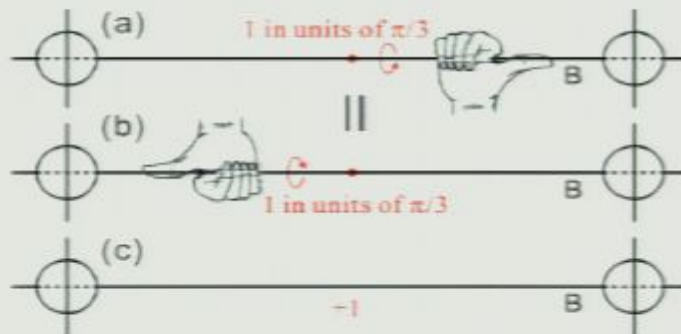
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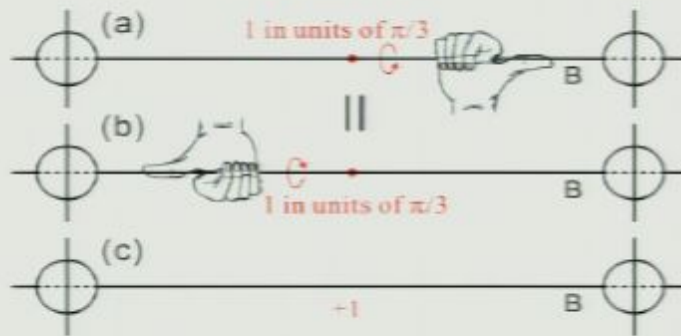
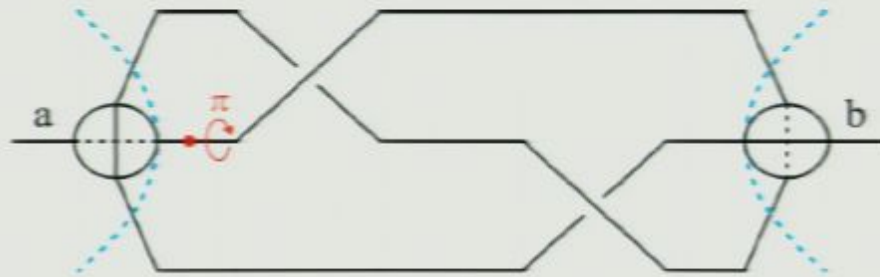
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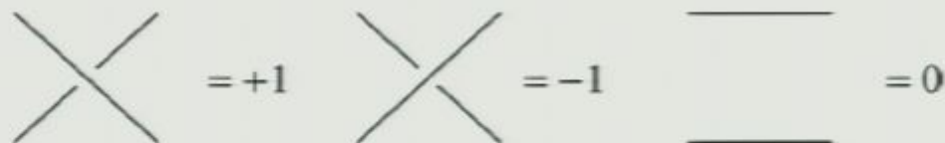
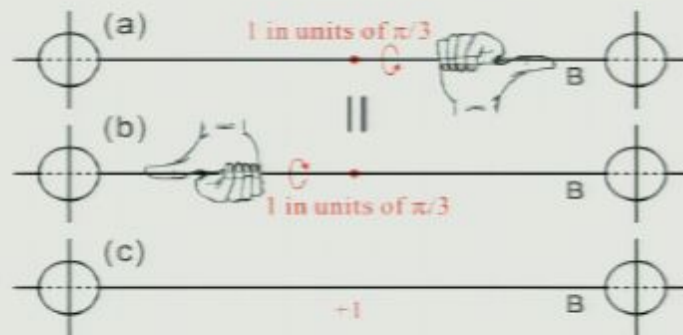
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# $\frac{\pi}{3}$ -Rotations: generators of rotations

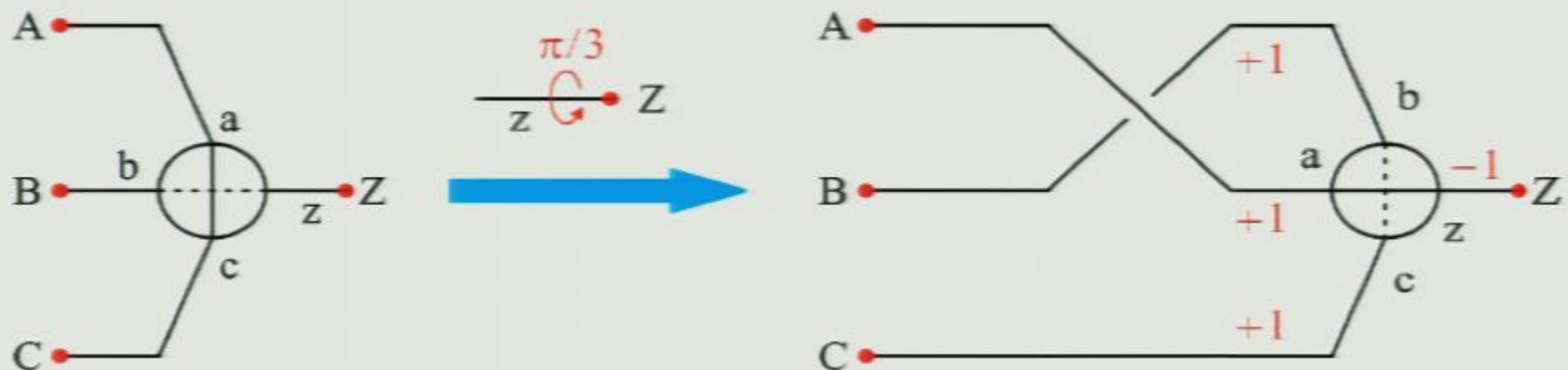
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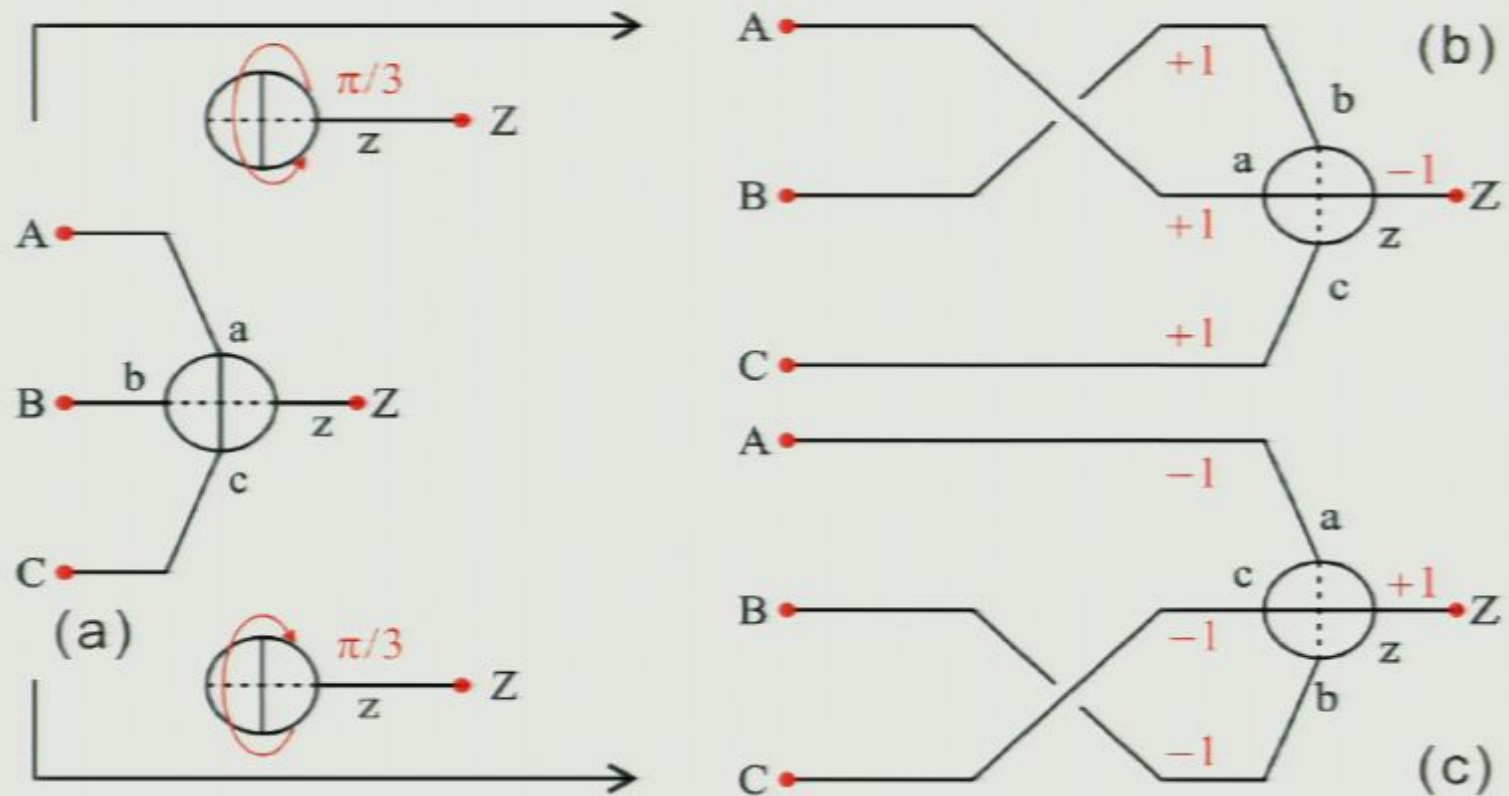
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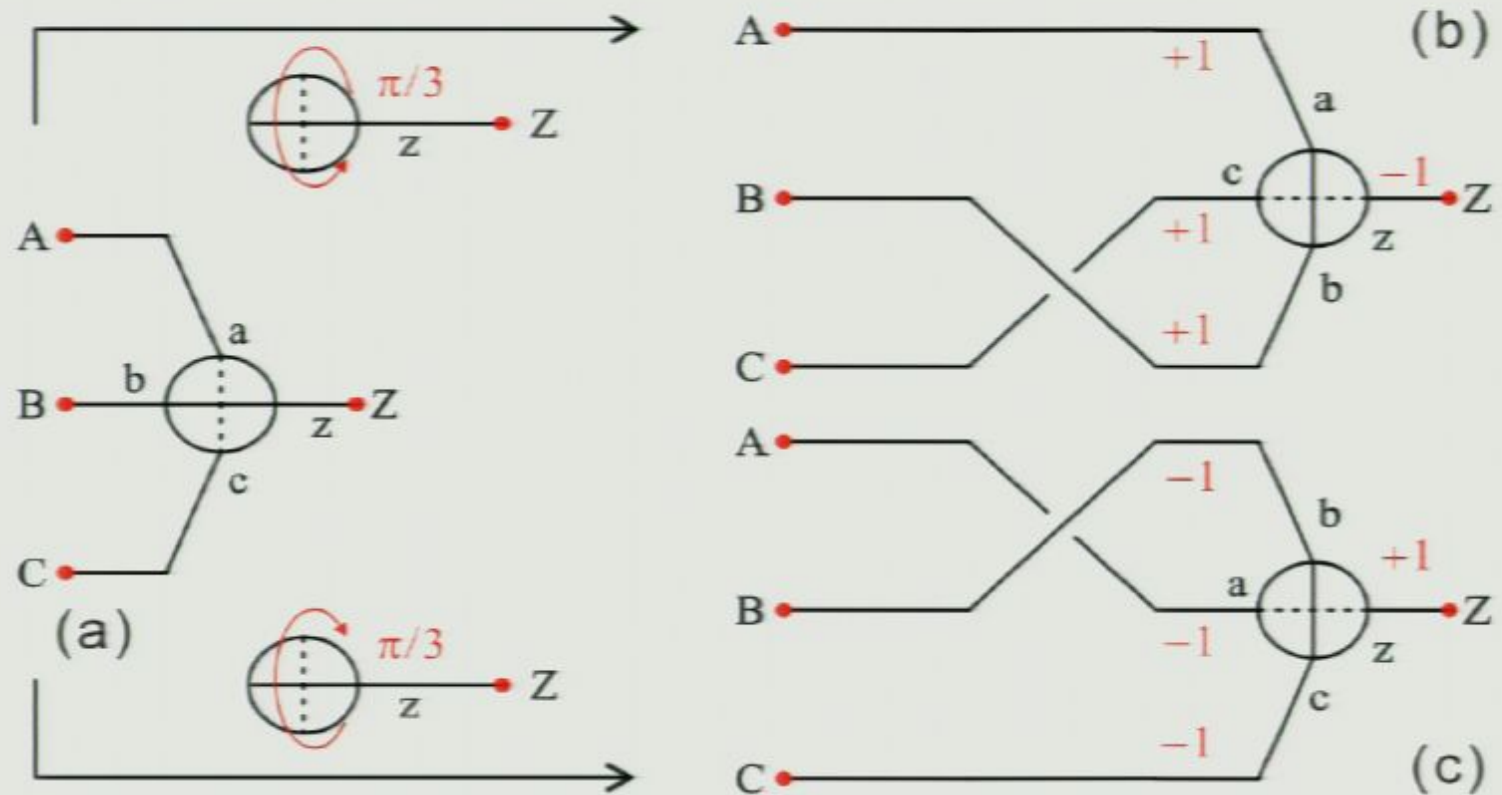




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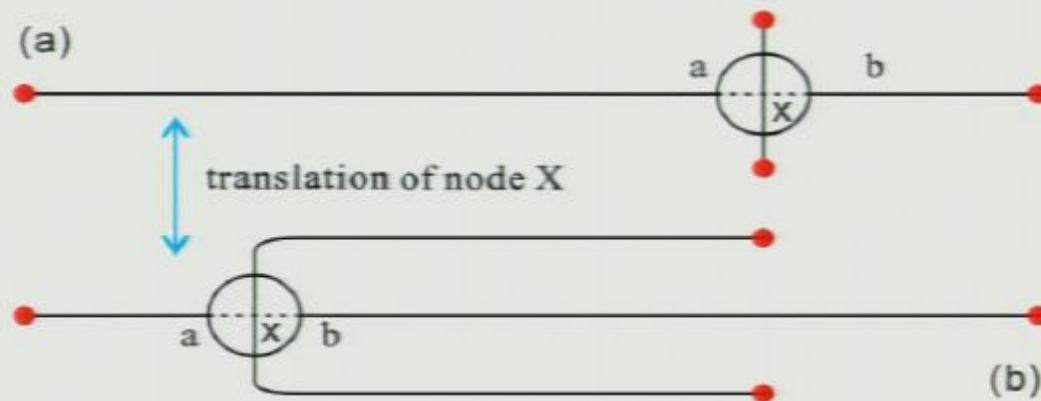
# Translations

- Case 1

- Case 2

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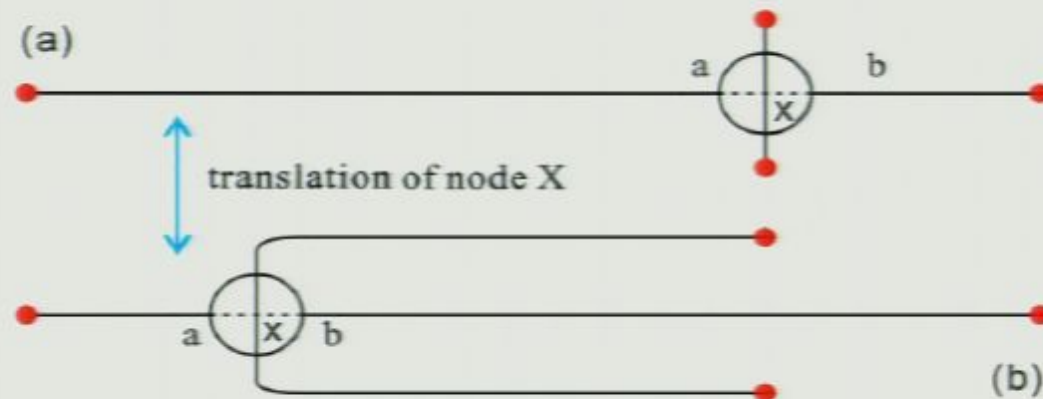
## ● Case 1



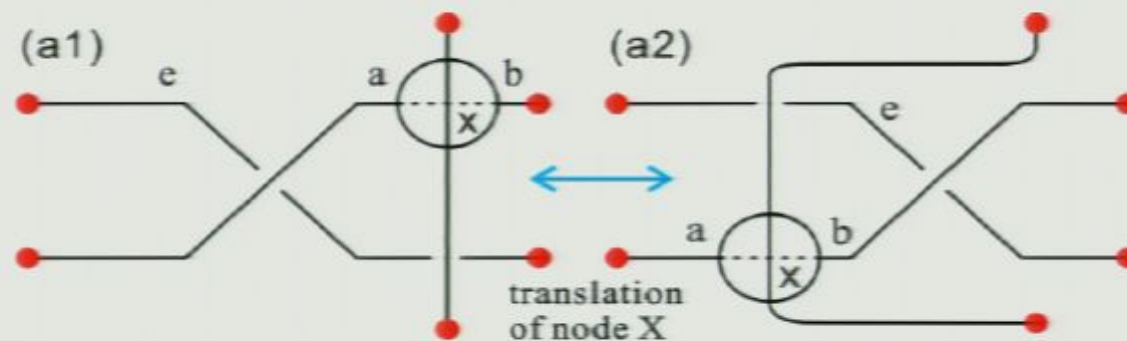
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## ● Case 2





# Effective twist: a conserved quantity

For a subdiagram,

- the effective twist is defined as

$$\Theta = \sum_{\text{all edges}} T_e - 2 \times \sum_{\text{all vertices}} \lambda_v$$

- it is conserved under equivalence moves: rotations and translations.

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# Reducible and Irreducible Braids

## Definition

A braid is **(left) right reducible** if it is equivalent to a braid with fewer crossings by equivalence moves on its (left) right end-node, otherwise it is **(left) right irreducible**. exerted only on its (left) right end-node.

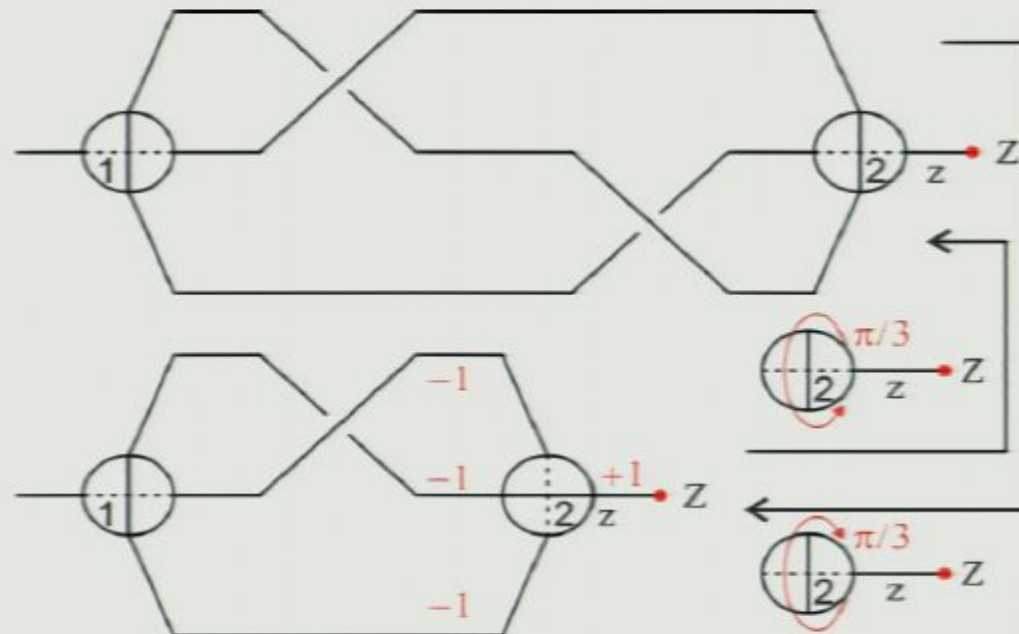
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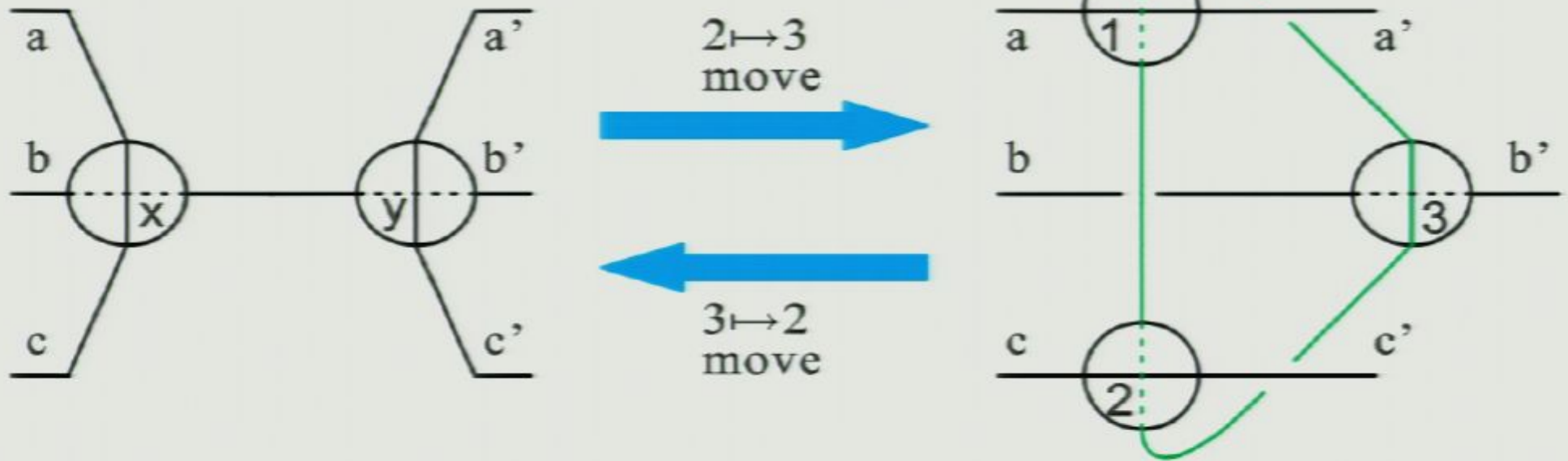
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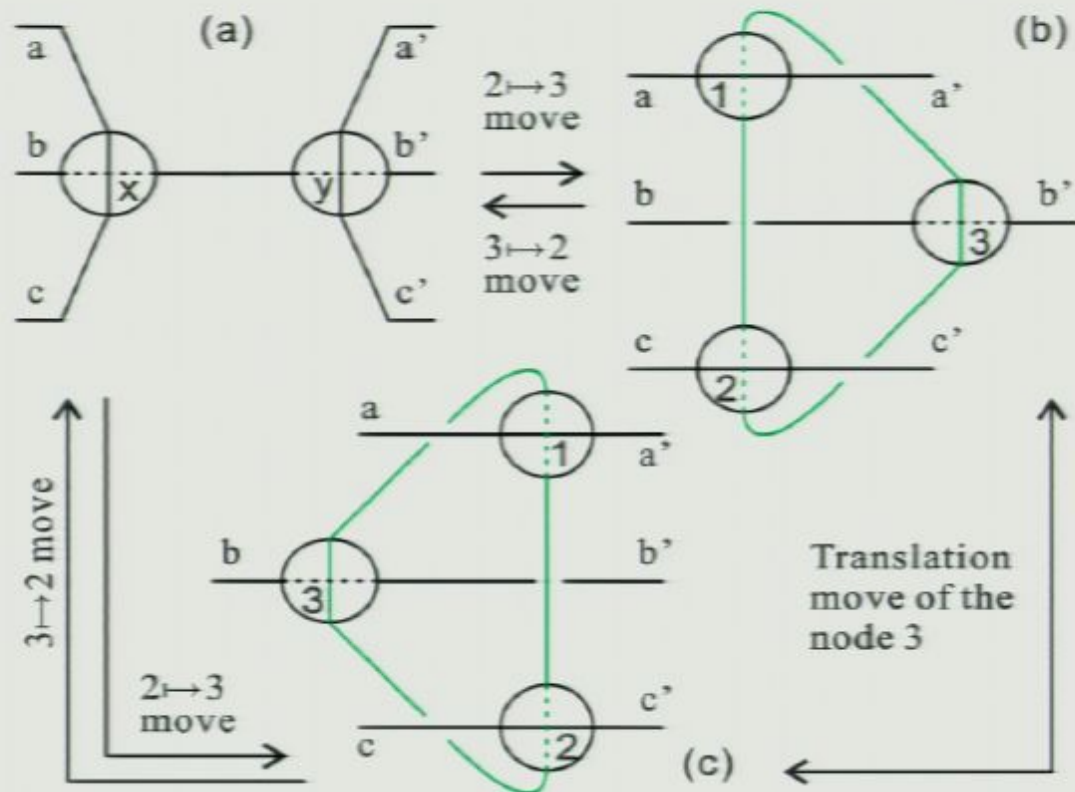


## $2 \longleftrightarrow 3$ Moves

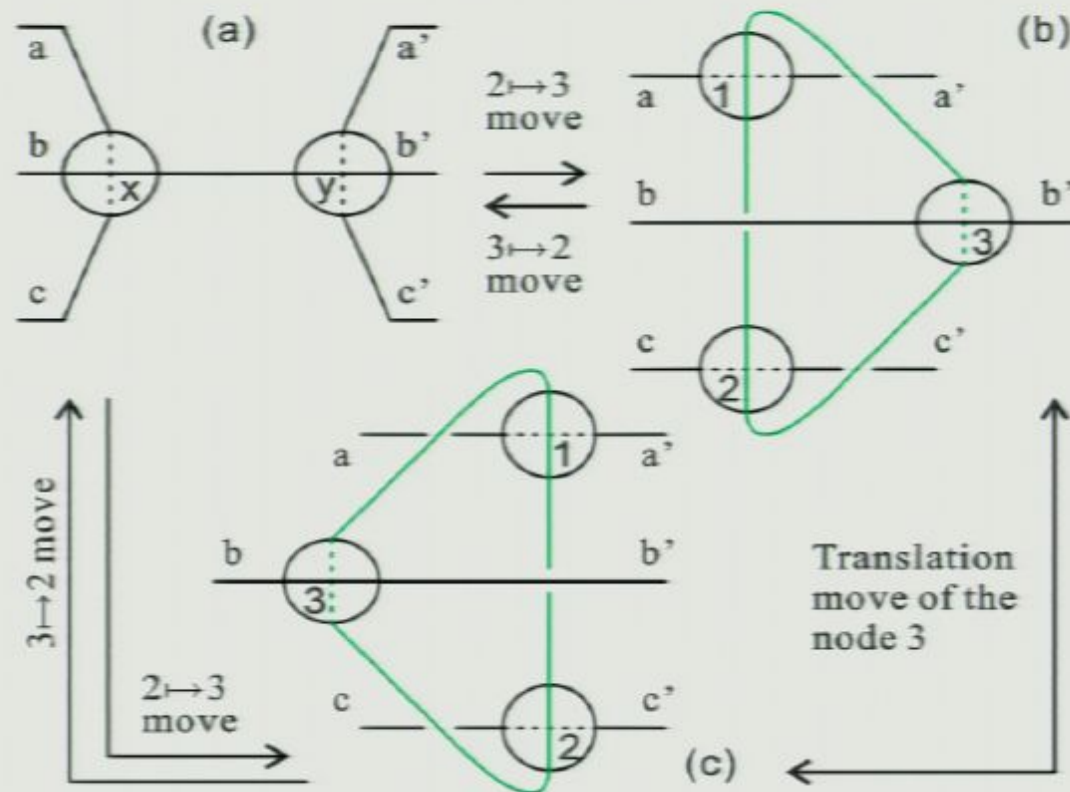
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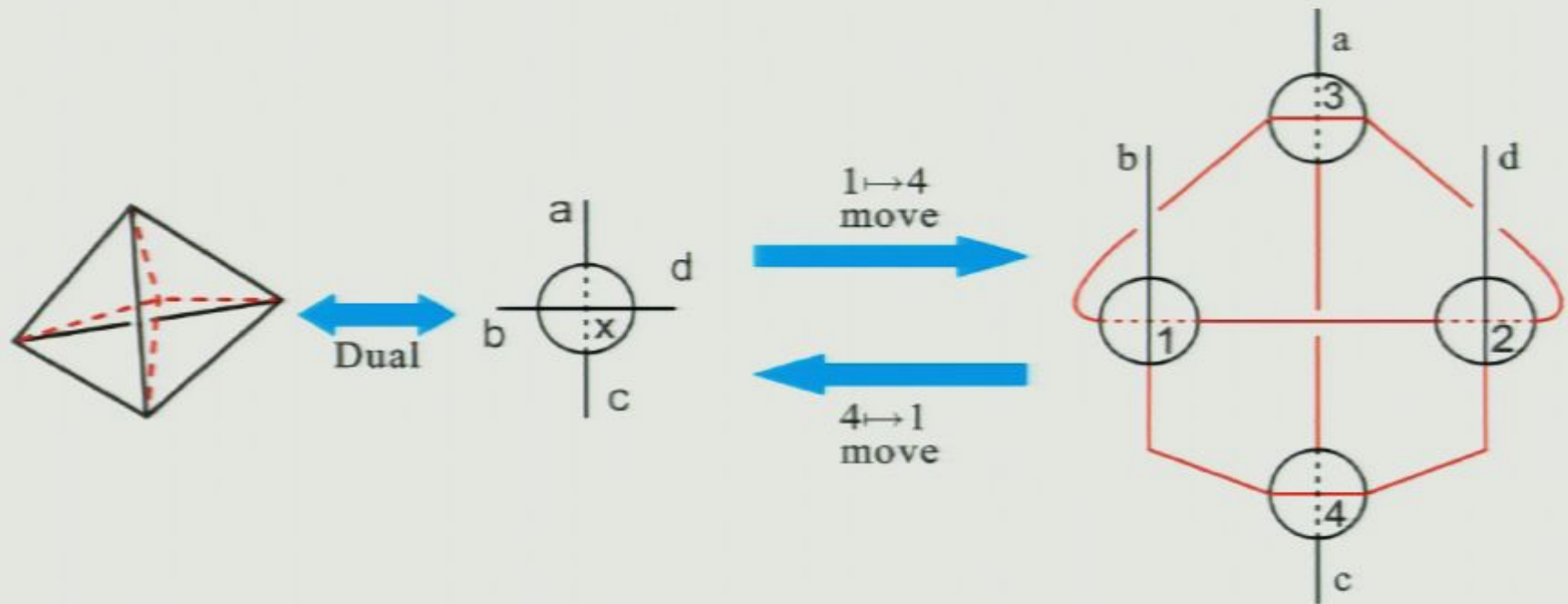
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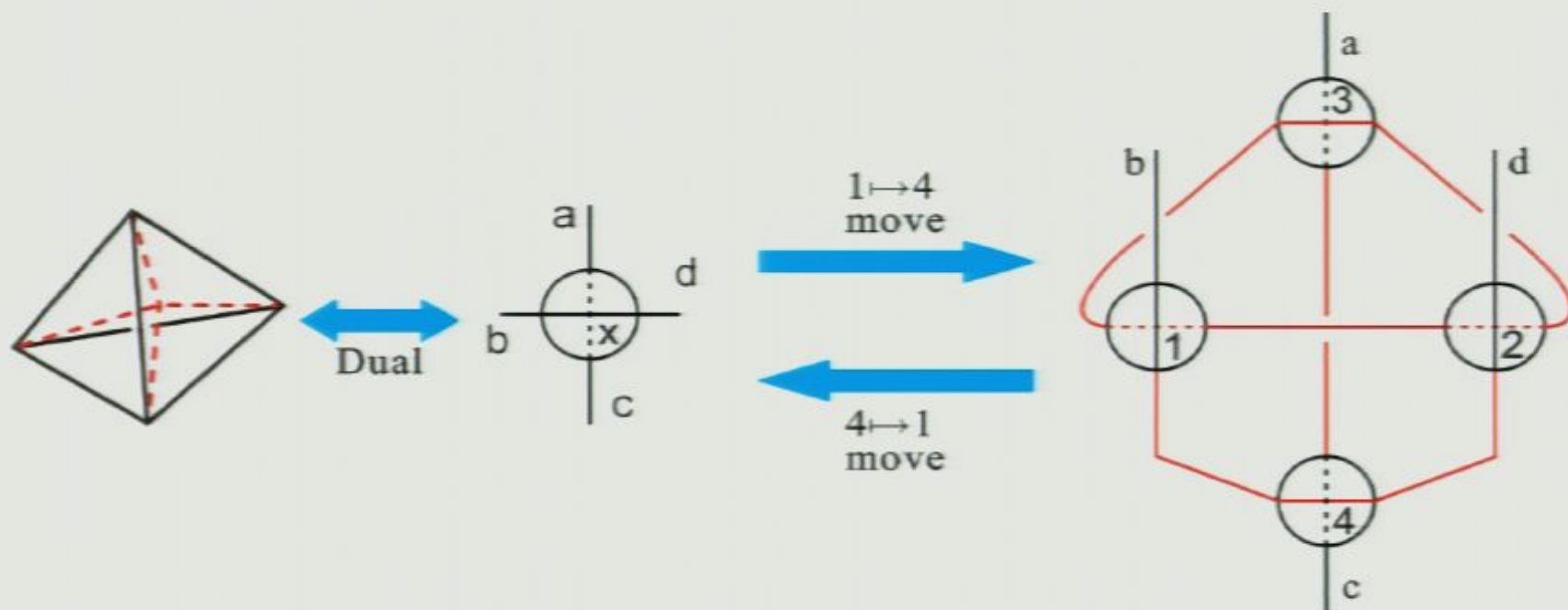
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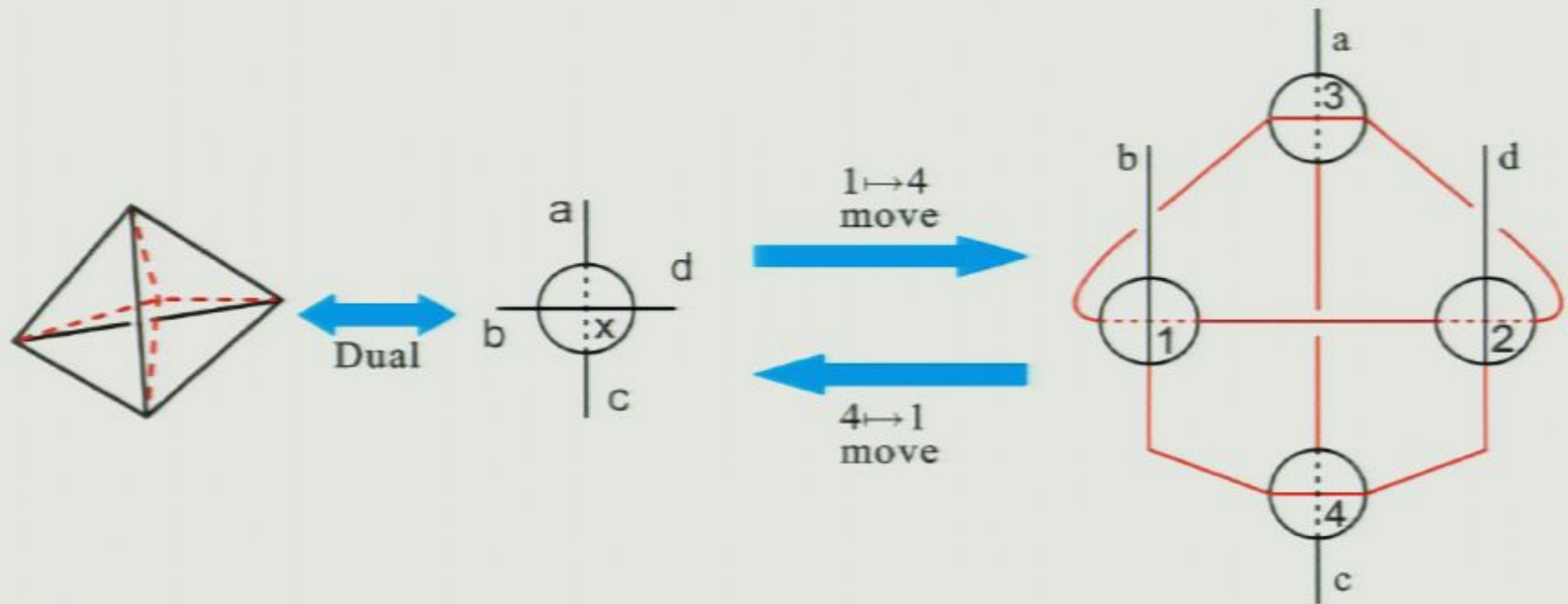
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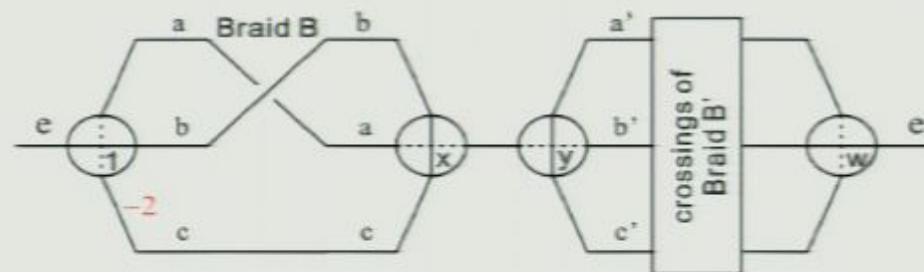
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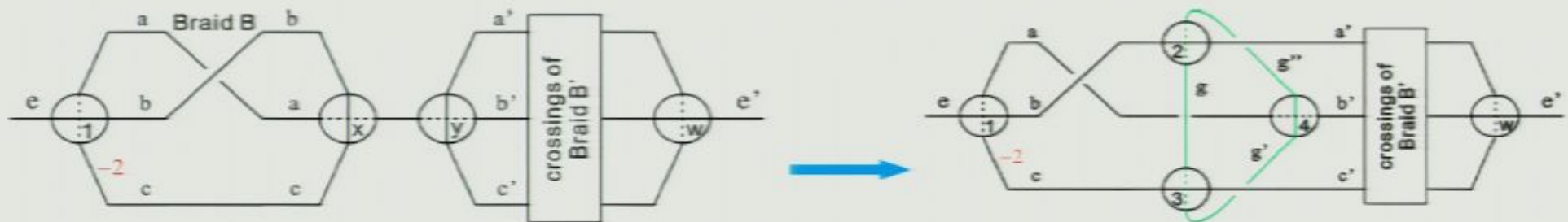
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# An Example of Active Right-Interaction

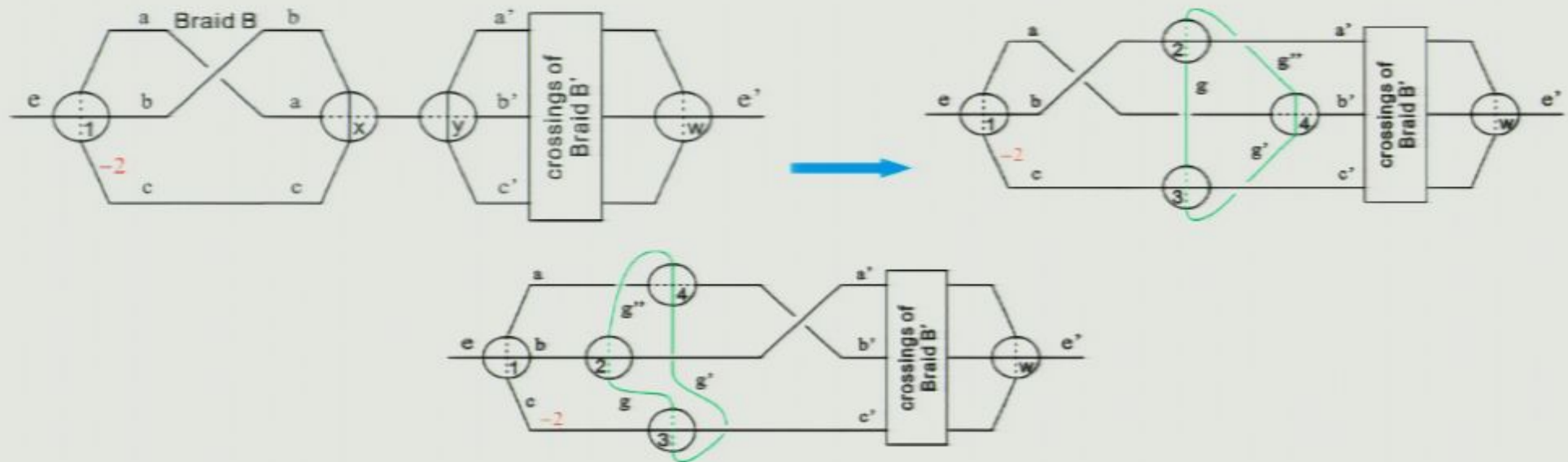


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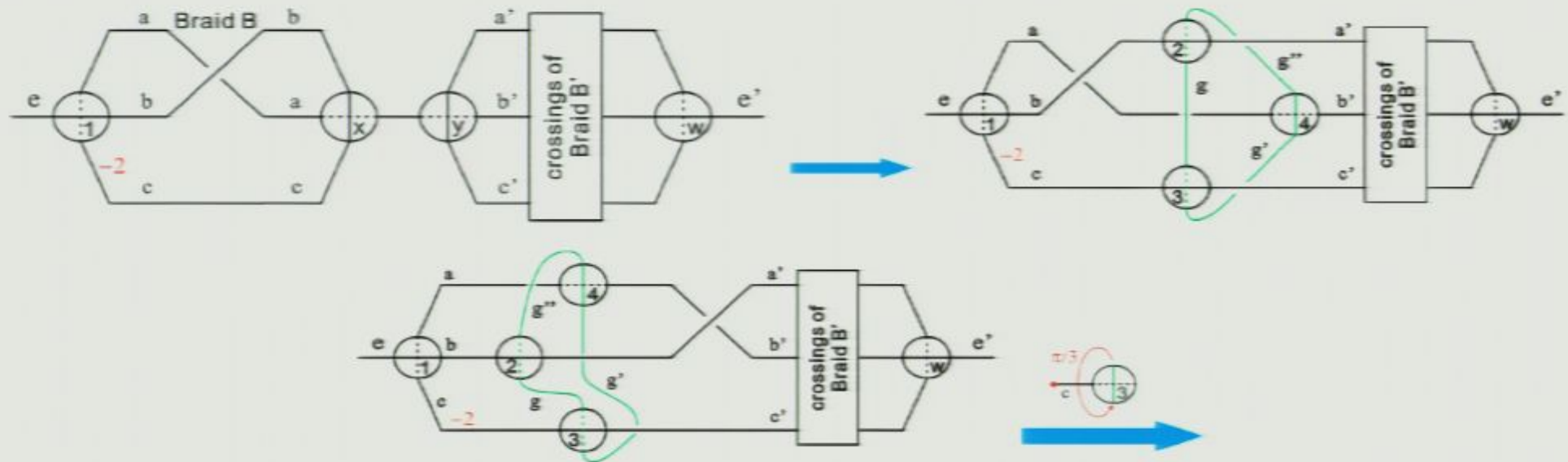




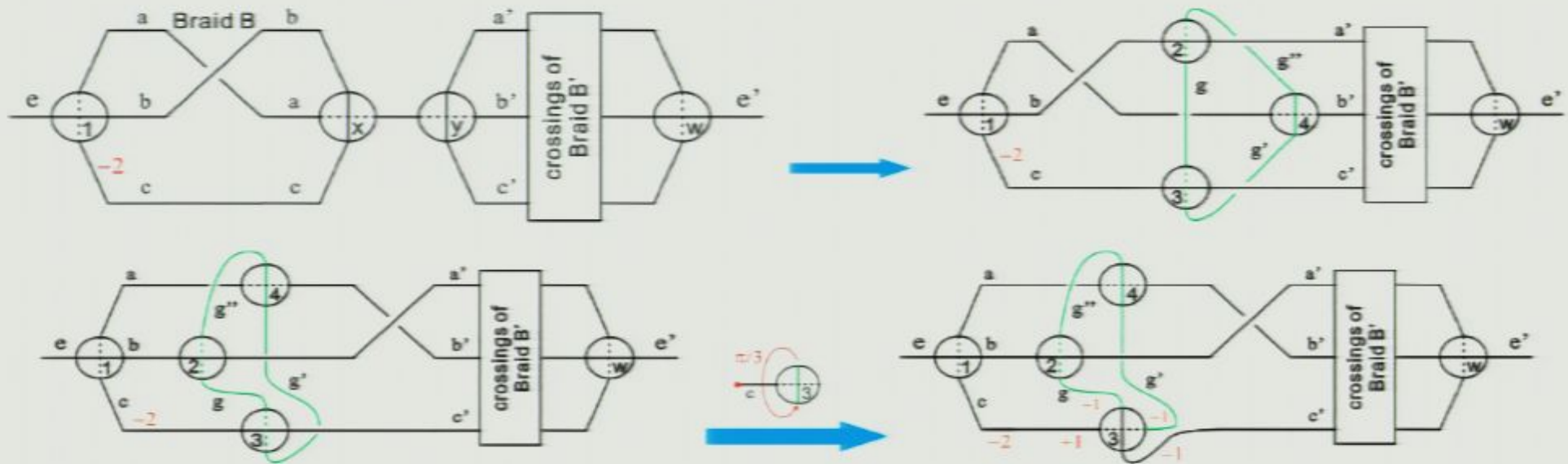
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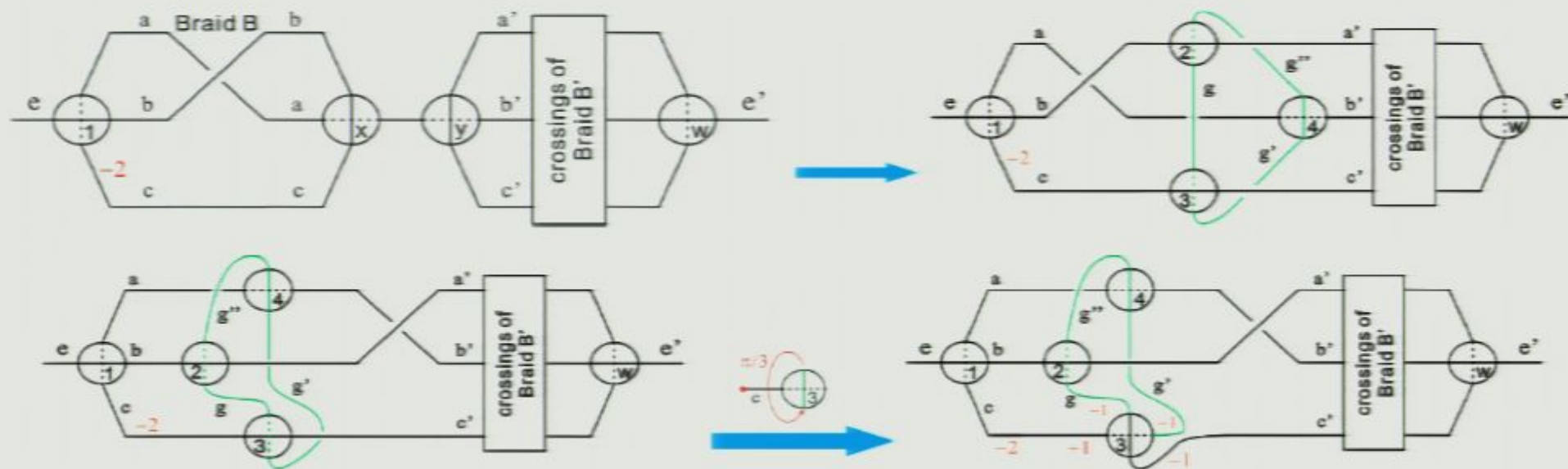
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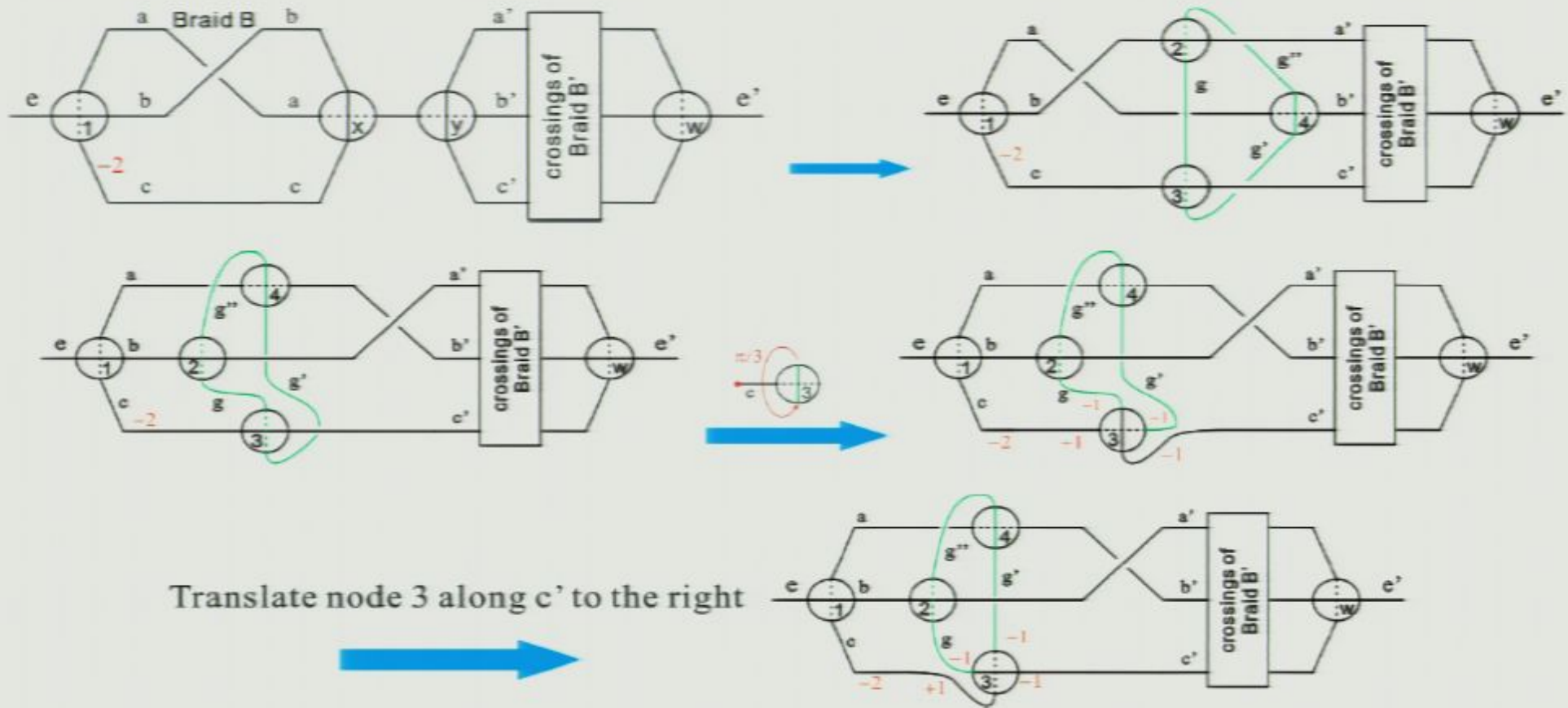


Translate node 3 along  $c'$  to the right



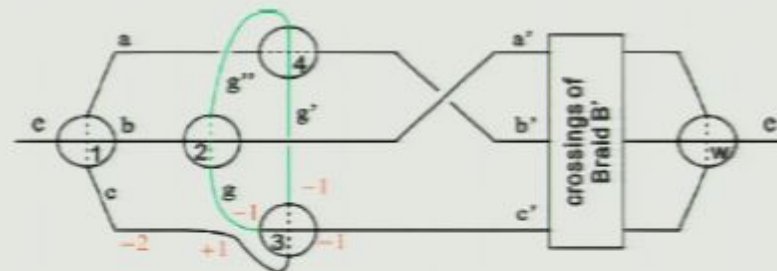


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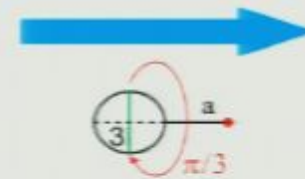
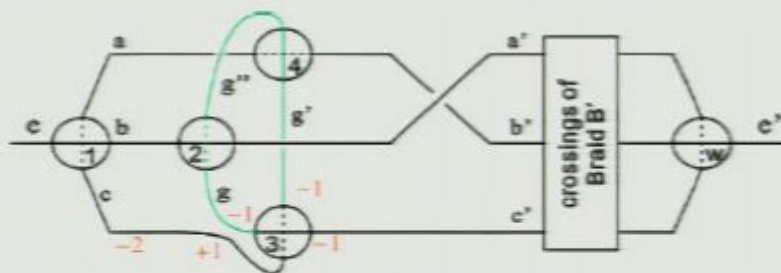




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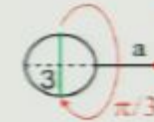
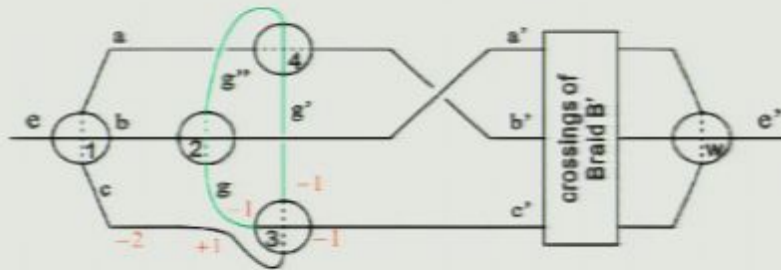


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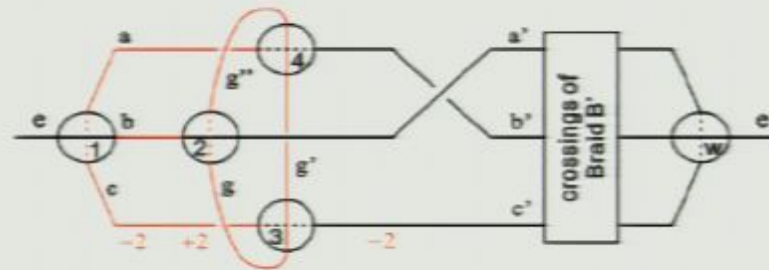


This rotation cancels the twists on  $g$  and  $g'$

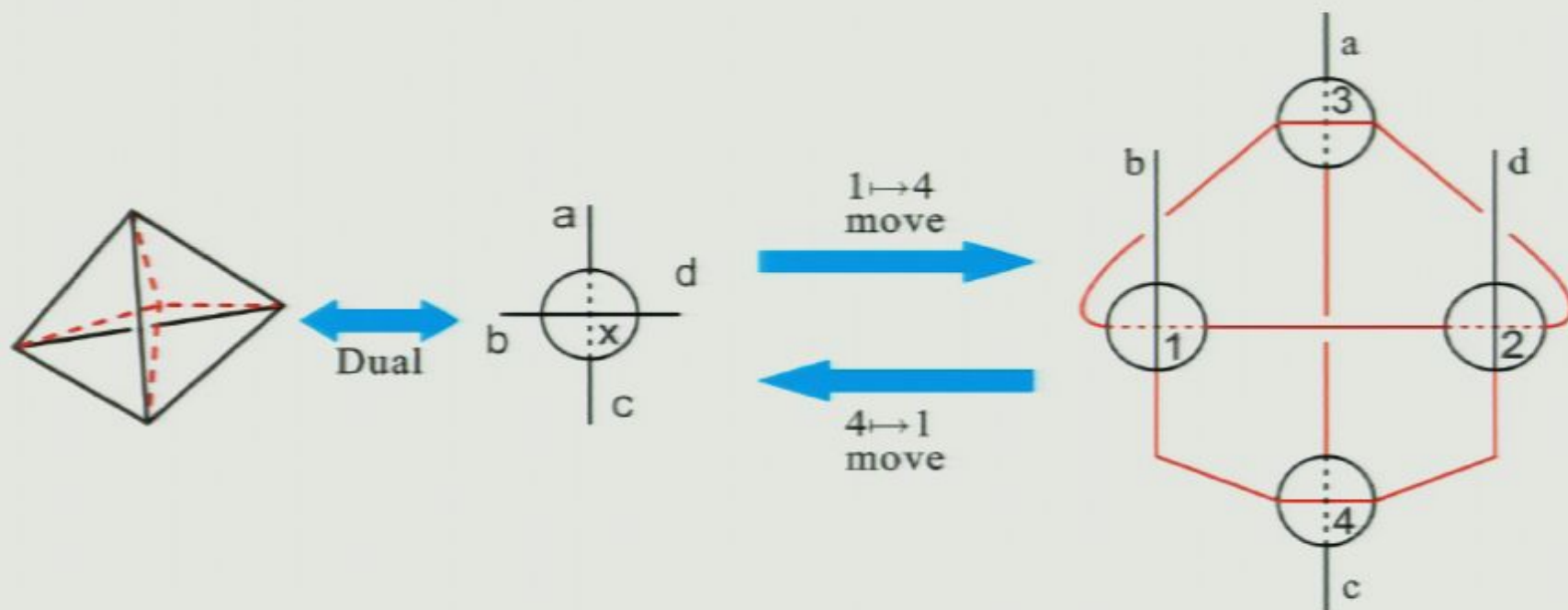
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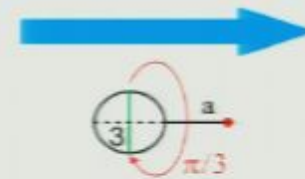
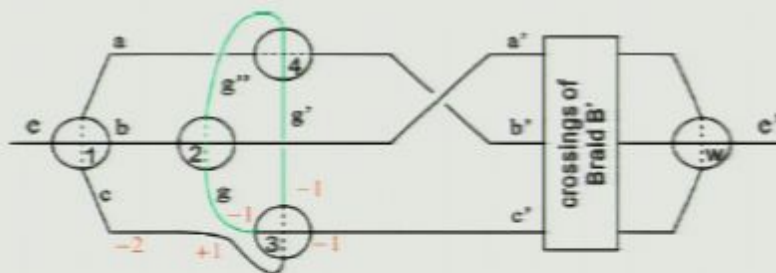
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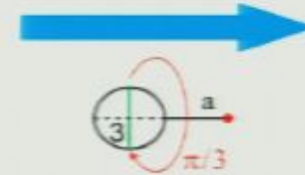
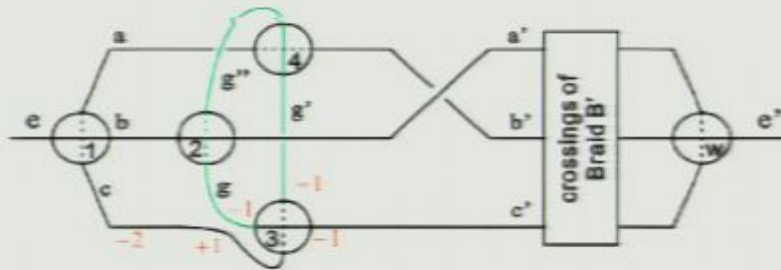


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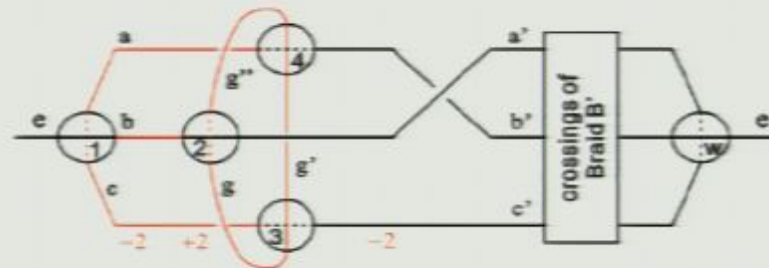


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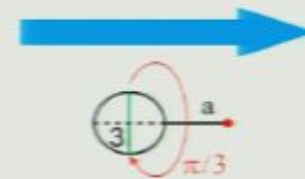
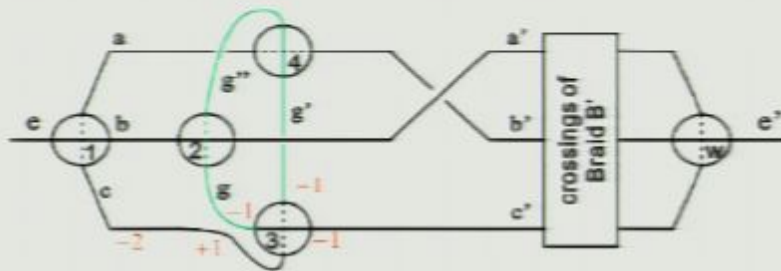
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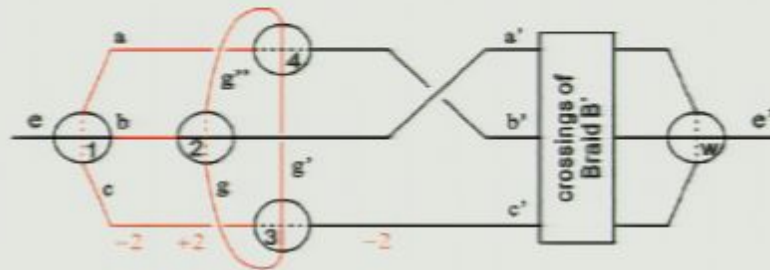




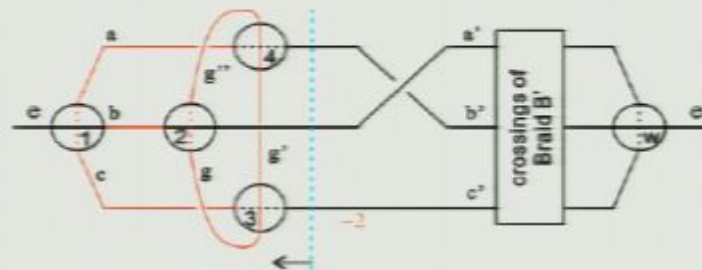
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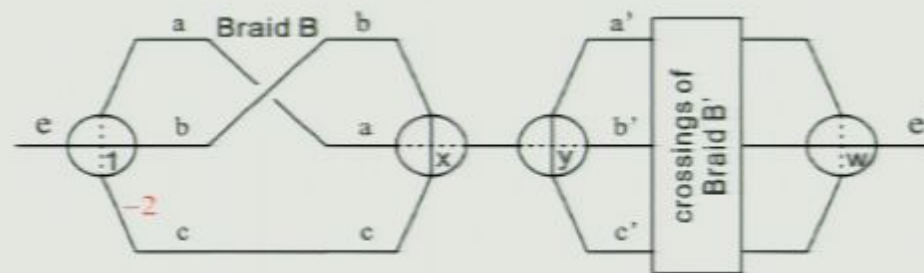


The two twists on edge  $c$ , the initial twist and the twist caused by rotations, are exactly cancelled.



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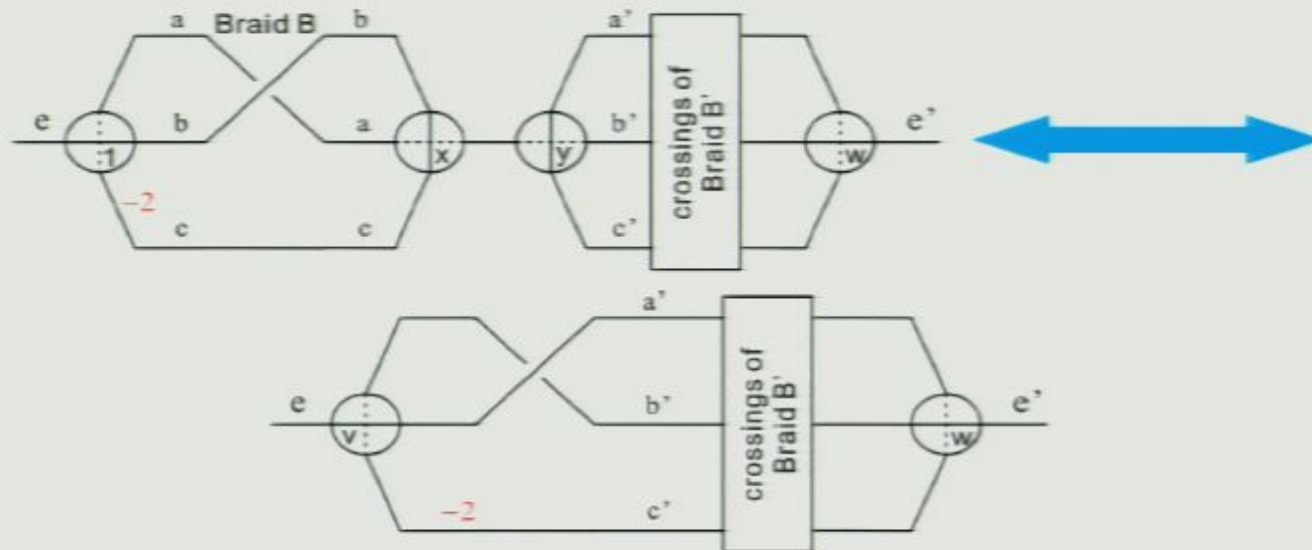
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- Plus the conservation of twist

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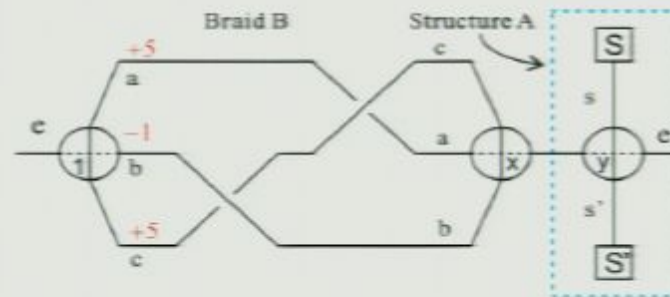
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- Bingo again!!! The braid moves to the right of the structure



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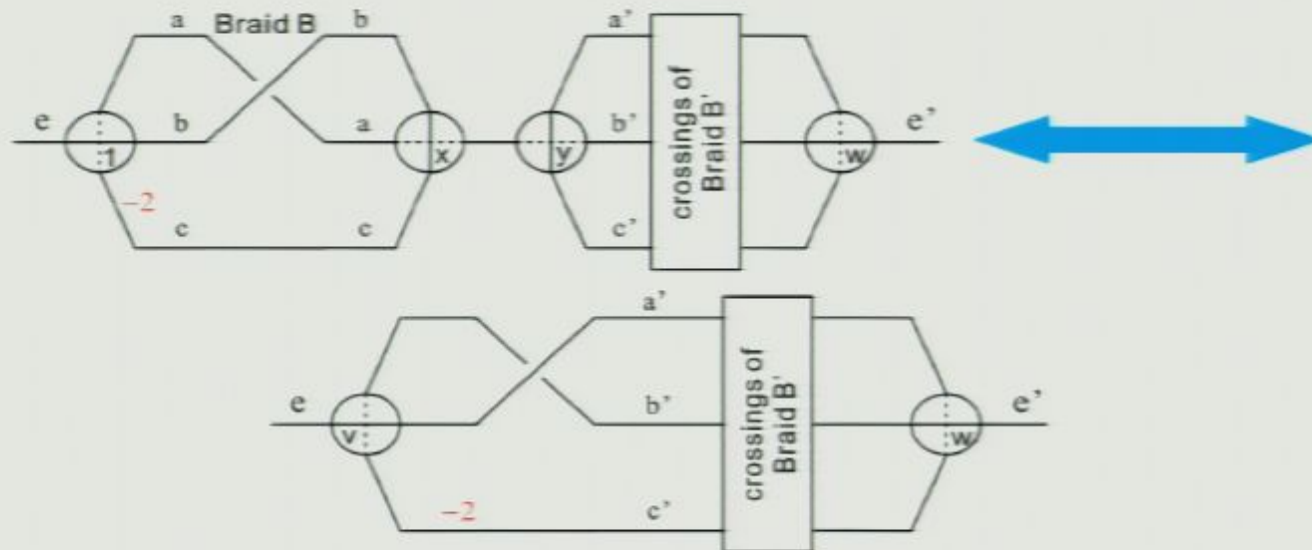


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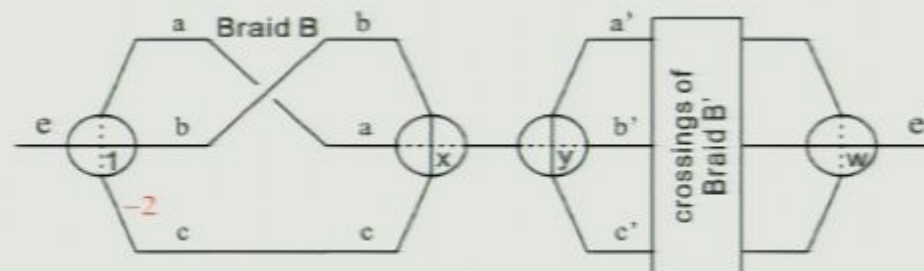
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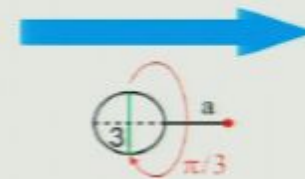
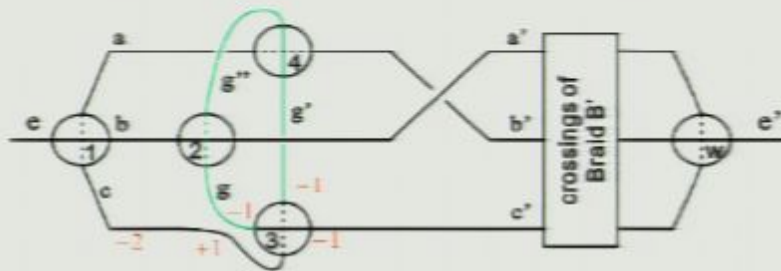
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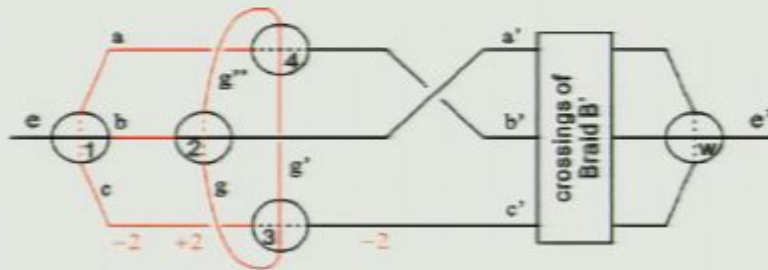


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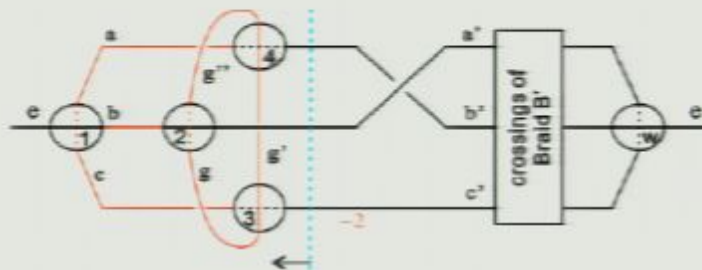
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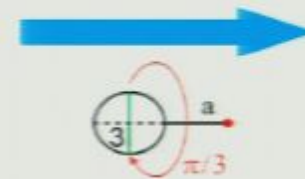
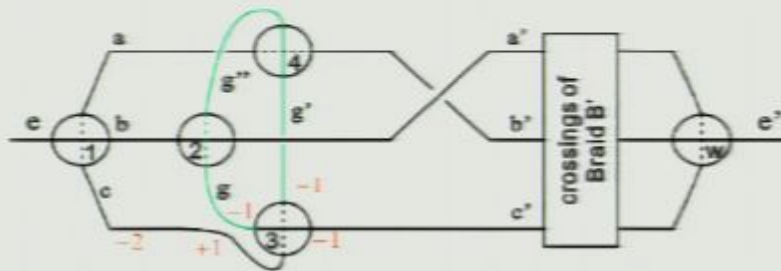


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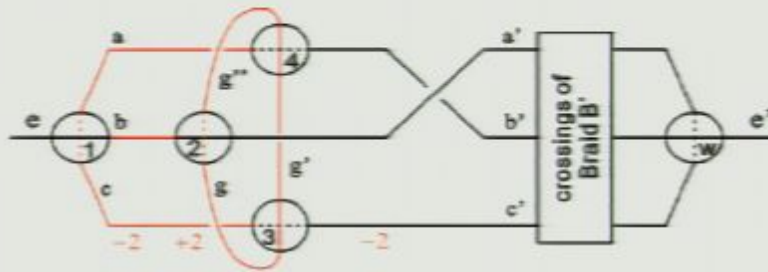


do  $4 \leftrightarrow 1$  move on whatever on the left of the blue line

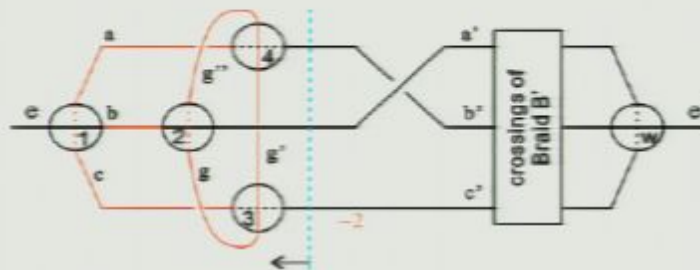
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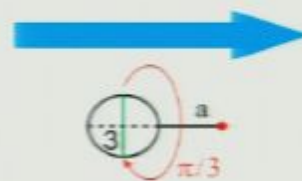
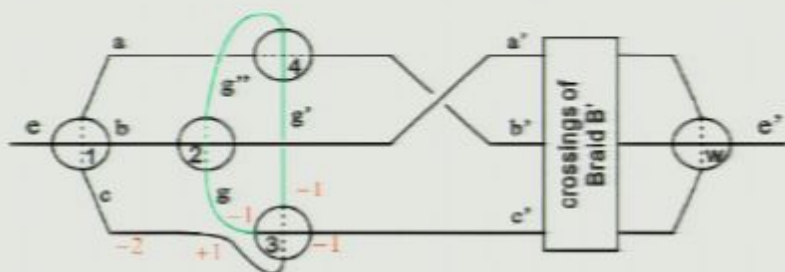
The two twists on edge  $c$ , the initial twist and the twist caused by rotations, are exactly cancelled.



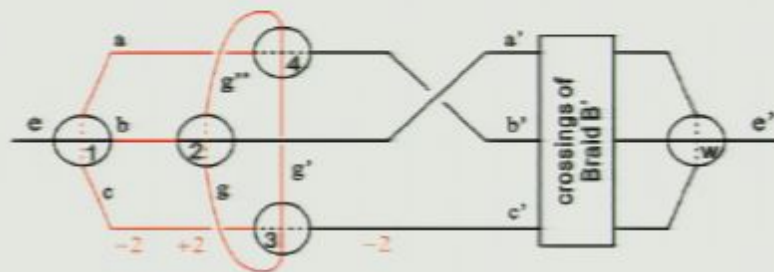




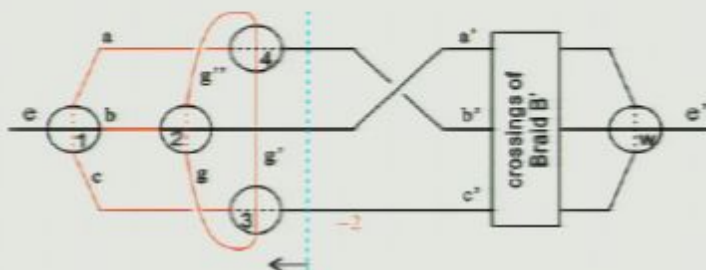
# An Example of Active Right-Interaction: Continued



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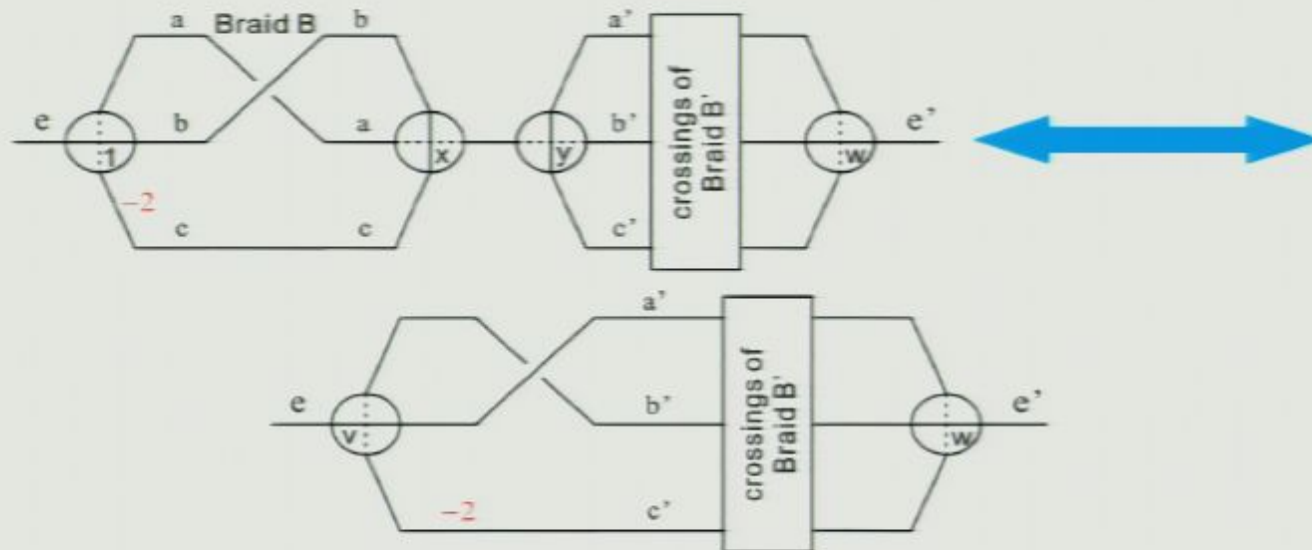
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Bingo!!! We got a new braid!



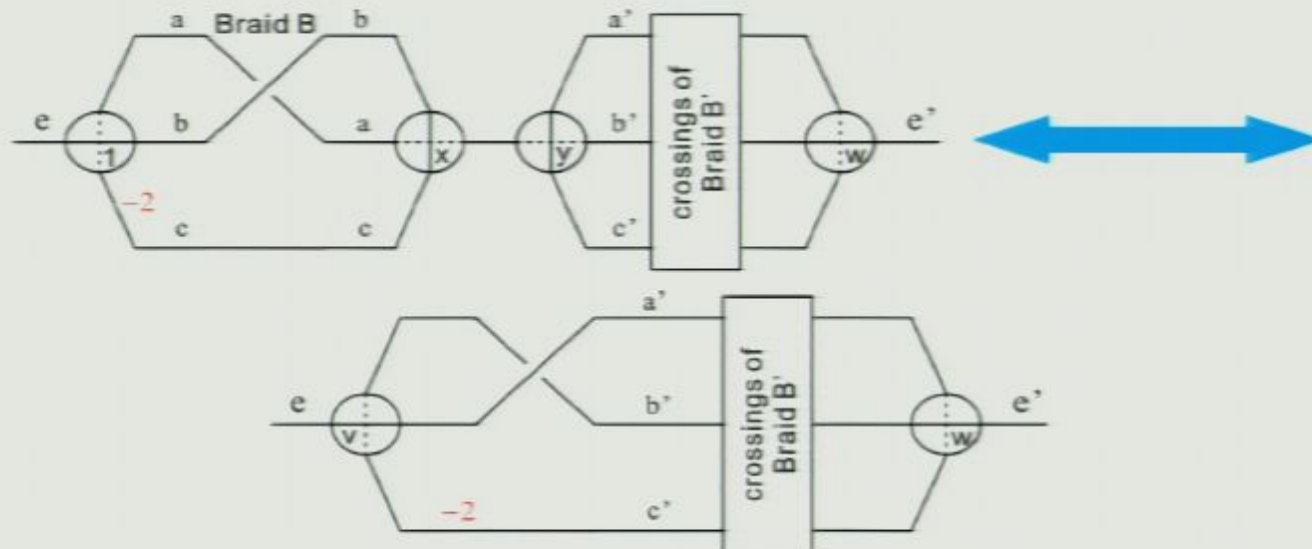
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## An Example of **Right-Propagation**, the framed case

- Bingo again!!! The braid moves to the right of the structure

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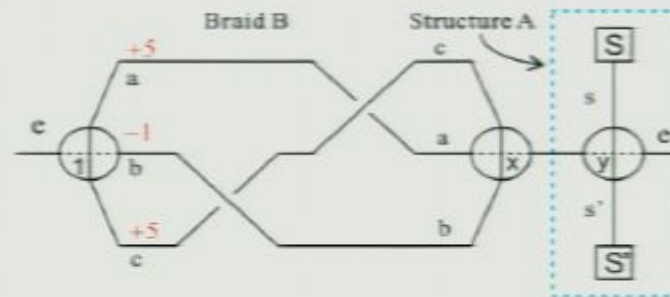


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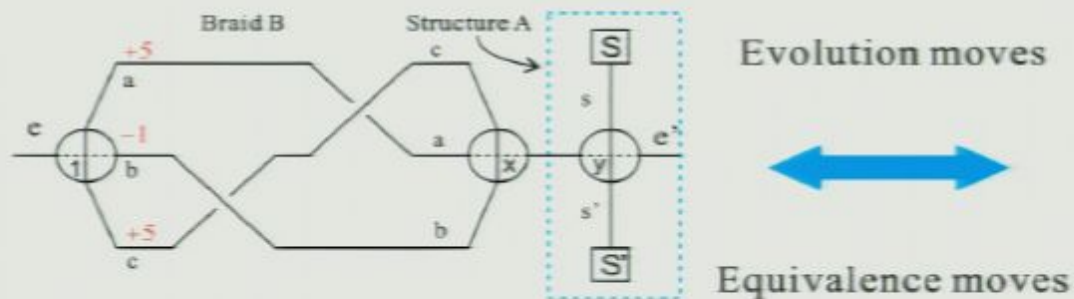
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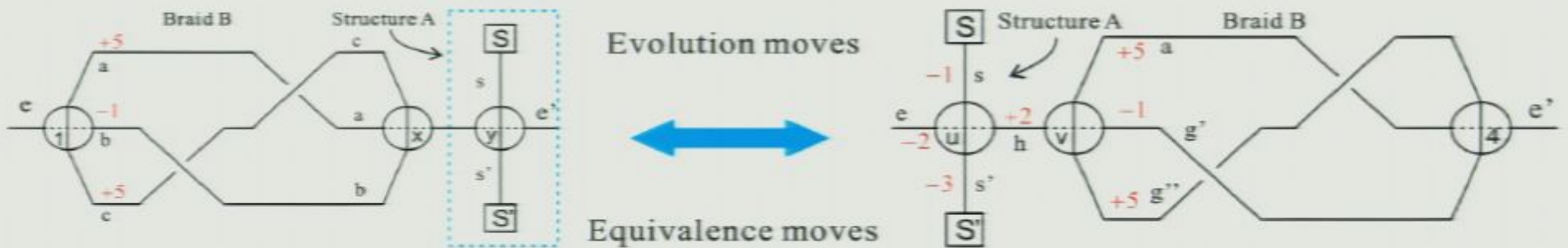
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## Theorem

- A (left) right-irreducible braid is not *actively* (left) right-interacting.
- A irreducible braid is never *actively* interacting.

## Theorem

- A (left) right-irreducible braid is not (left) right-propagating.
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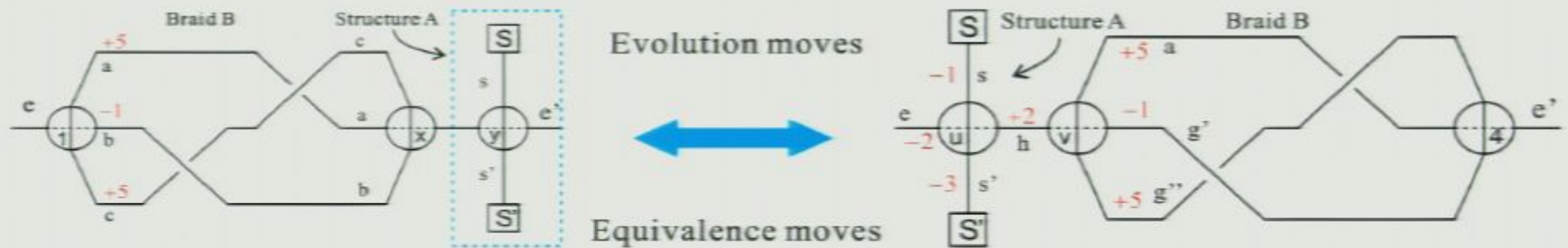
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# Conclusions

- ① We studied the 3-strand braid excitations on embedded 4-valent framed spinnets, both framed and unframed cases;
- ② There are classifications of braids, namely reducible, irreducible braids, and many more.
- ③ There are examples of braids that can propagate
- ④ There are examples of braids that can actively interact
- ⑤ Both propagations and interactions are chiral.
- ⑥ Active interaction implies propagation.

# Future Works

- ① How to classify fermions and bosons?
- ② Find correpondance with physics:
  - Would this recover the Standard Model?
  - Or, would the braids are even more fundamental "particles"?
- ③ What about the unembedded-case?



# Acknowledgement

Thanks Prof. Lee Smolin and the Perimeter Institute!

# (DIS)CLAIMER

*What did Neil Armstrong say when he first time set foot on the moon?*

