Update on braids and preons

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Bilson-Thompson, Hackett, Kauffman, in preparation
Markopoulou, Wan, ls, in preparation

1. Kinematical issues in LQG
2. Dynamical issues in LQG
3. Quantum information and observables in QG
    1. Markopoulou, Kribs…
4. Braid-preon model

    Bilson-Thompson, Markopoulou, ls
5. Propagation of 3-valent braids in ribbon graphs,

    Hackett
6. Systematics of 3-valent braid states,

    Bilson-Thompson, Hackett, Kauffman
7. The 4-valent case, propagation and interactions

    Wan, Markopoulou, ls
8. Adding labels to get results for spin foam models

9. Open problems

Kinematical issues for LQG:

•***Are the graphs embedded in a 3 manifold or not?***

Embedded follows from canonical quantization of GR.

But group field theory and other spin foam models are simplest without embedding.

The geometric operators, area and volume do not measure topology of the embedding

What observables or degrees of freedom are represented by the braiding and knotting of the embeddings?

Kinematical issues for LQG:

How should the graphs be labeled?

•*SU(2) labels come from canonical quantization of GR.*

compact group labels lead to discrete spectra of areas + volumes

•*Lorentz or Poincare in some spin foam models*

continuous labels weaken discreteness of theory.

•*Perhaps some or all of the group structure is emergent at low energy. This would simplify the theory.*

Why should the symmetries of the classical limit be acting at Planck scales?

But how could symmetries be emergent in a BI theory?

Are there consequences of dynamics that don't depend on details of labeling and amplitudes?

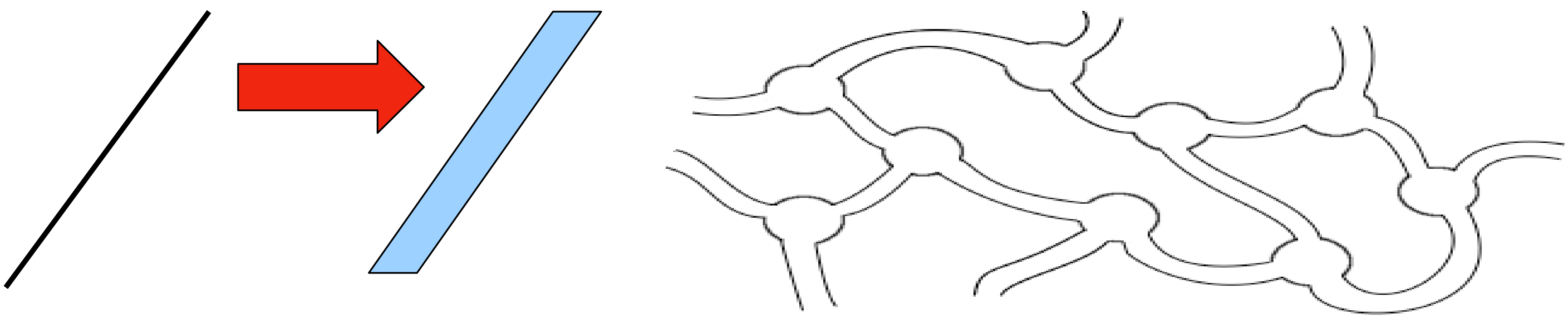
Kinematical issues for LQG:

Are the graphs framed or not?

Framing is needed if there is a cosmological constant; because SU(2) is quantum deformed

$$\boxed{q = e^{2\pi i/k+2} \qquad\qquad k = 6\pi/G\Lambda}$$

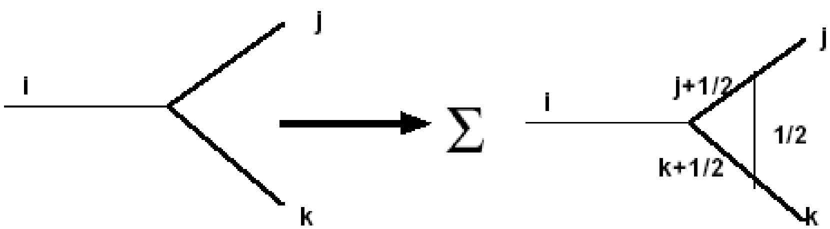
To represent this the spin network graphs must be framed:



Dynamical issues for LQG:

Hamiltonian constraint

only the expansion move



Many conserved quantities with no apparent relation to classical GR

Spin foam models

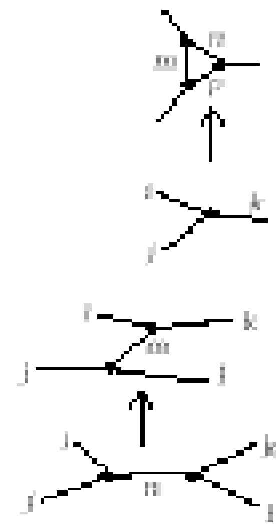
expansion AND exchange moves

3 valent moves

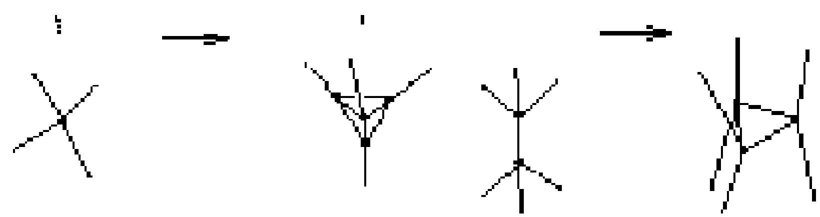
Are there any

conserved

quantities?

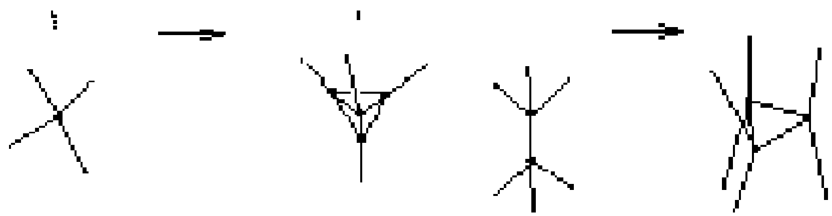


4 valent moves



Dynamical issues for LQG:

Framing is also needed to define exchange moves in spin foam models



who is over and under?

Questions about observables

- The geometric observables such as area and volume measure the combinatorics of the graph. But they don't care how the edges are braided or knotted. What physical information does the knotting and braiding correspond to?
- How do we describe the low energy limit of the theory?
- What does locality mean? How do we define local subsystems without a background?
- How do we recognize gravitons and other local excitations?

Questions about excitations:

- What protects a photon traveling in Minkowski spacetime from decohering with the noisy vacuum?

  ANSWER: The photon and vacuum are in different irreducible representations of the Poincare group.

- In quantum GR we expect Poincare symmetry is only emergent at low energies, at shorter scales there are quantum flucations of the spactime geometry not governed by a symmetry,

- So what keeps the photon from decohering with the spacetime foam?

Some answers: **(Markopoulou, Kribs)**

hep-th/0604120 gr-qc/0510052

- Define local as a characteristic of excitations of the graph states. To identify them in a background independent way look for *noiseless subsystems*, in the language of quantum information theory.

- Identify the ground state as the state in which these propagate coherently, without decoherence.

- This can happen if there is also an emergent symmetry which protect the excitations from decoherence. Thus the ground state has symmetries because this is necessary for excitations to persist as pure states.

Hence, photons are in noiseless subsectors which have the symmetries of flat spacetime.

Suppose we find, a set of emergent symmetries which protect some local excitations from decoherence. Those local excitations will be emergent particle degrees of freedom.

Two results:

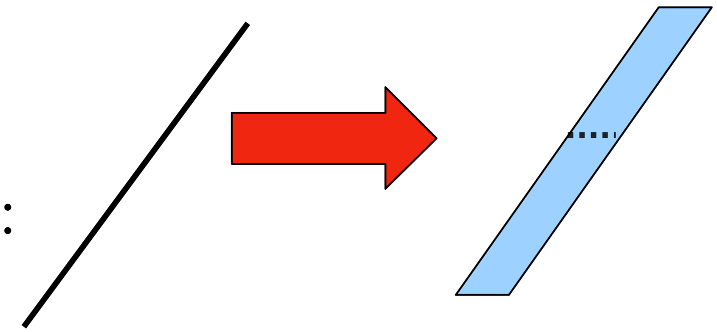
A large class of causal spinnet theories have noiseless subsystems that can be interpreted as local excitations.

There is a class of such models for which the simplest such coherent excitations match the fermions of the standard model.

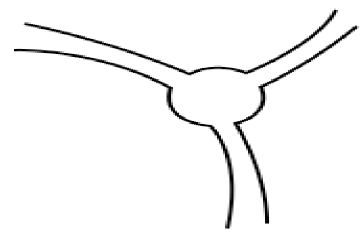
S. Bilson-Thompson, F. Markopoulou, LS hep-th/0603022

We study theories based on framed graphs in three spatial dimensions.

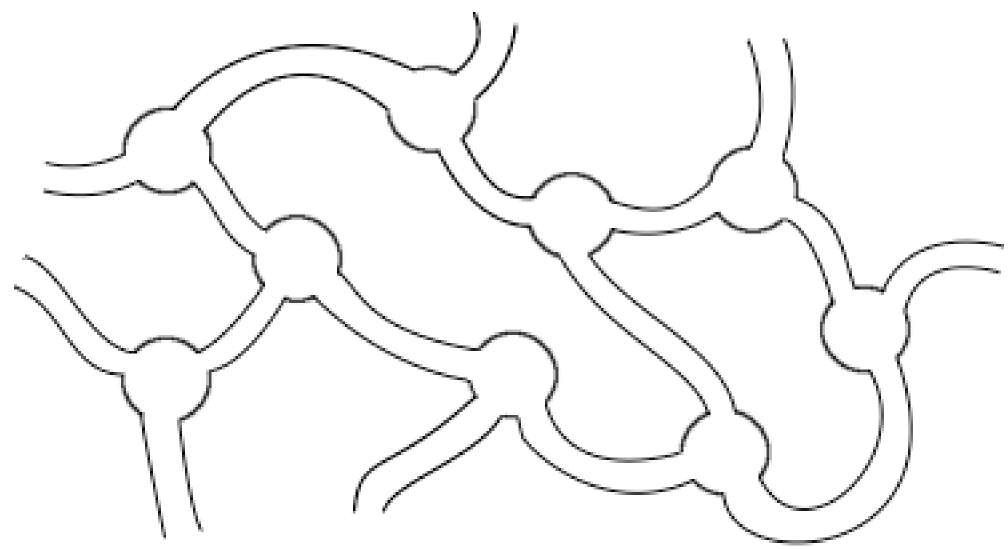
The edges are framed:



The nodes become trinions:



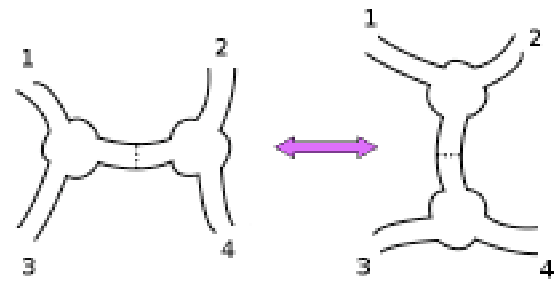
Basis States: *Oriented, twisted ribbon graphs, embedded in S^3 topology, up to topological class*.



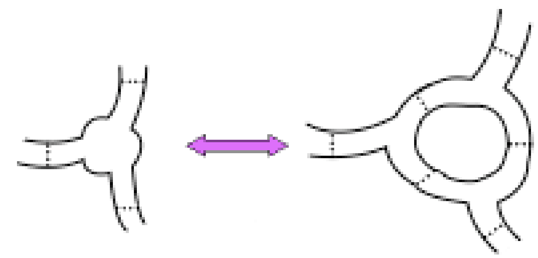
Labelings: any quantum group…or none.

The evolution moves:

Exchange moves:



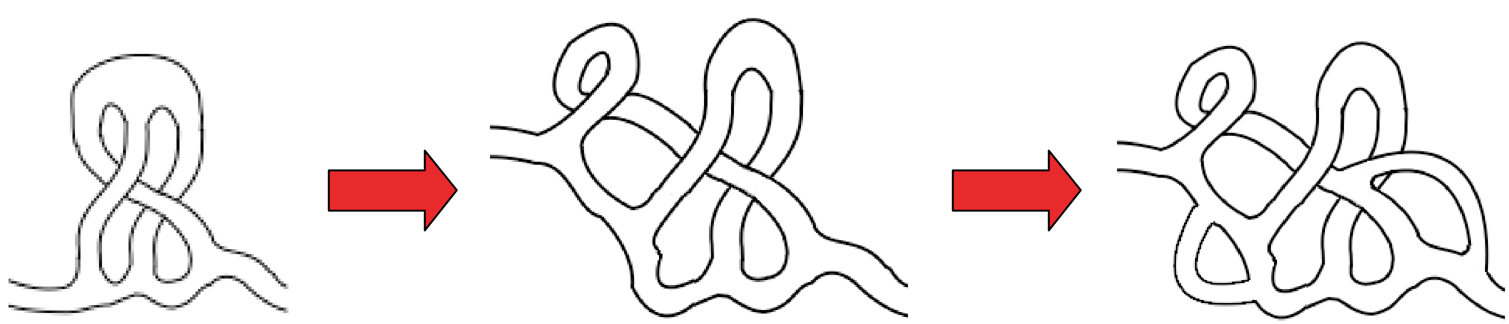
Expansion moves:



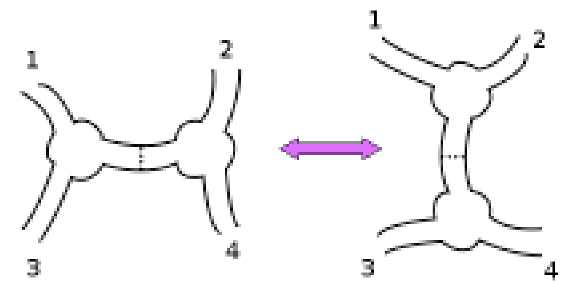
The amplitudes: arbitrary functions of the labels

Questions: Are there invariants under the moves?

What are the simplest states preserved by the moves?



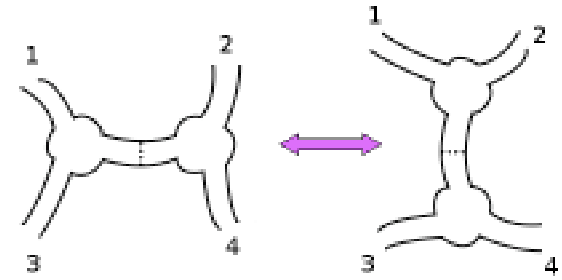
Invariance under the exchange moves:



The topology of the embedding remain unchanged

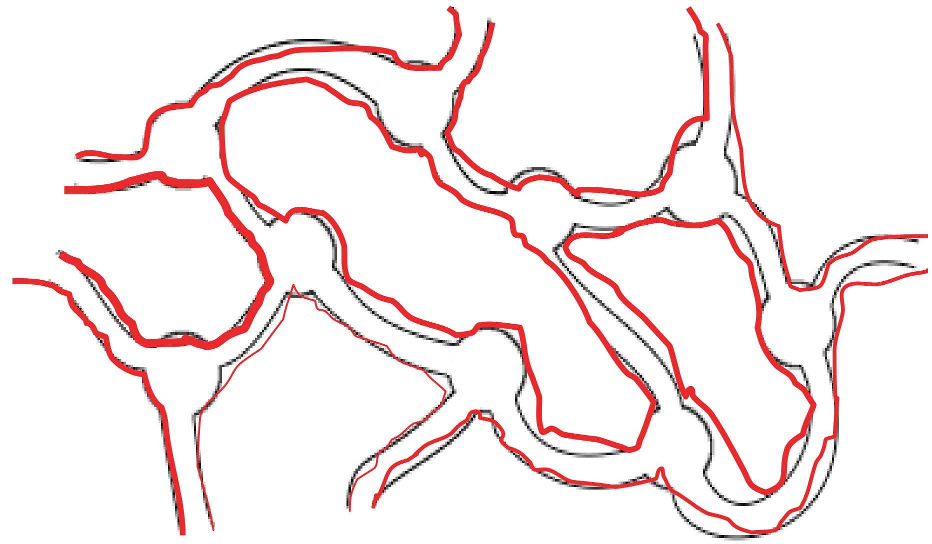
All ribbon invariants are constants of the motion.

Invariance under the exchange moves:

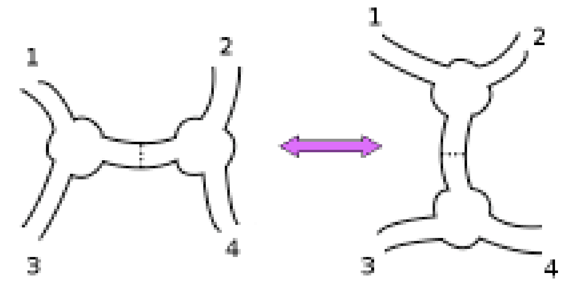


The topology of the embedding:
All ribbon invariants

For example: the link of the ribbon:

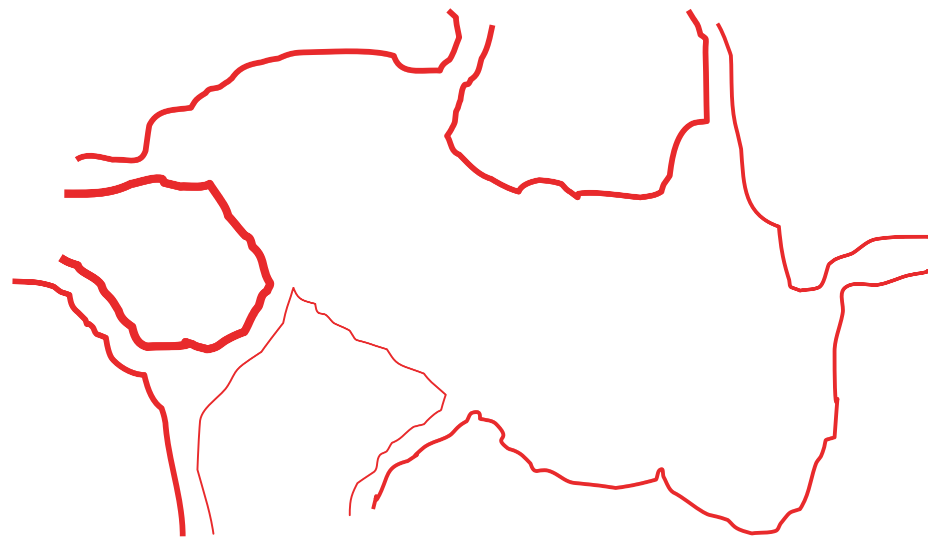


Invariance under the exchange moves:

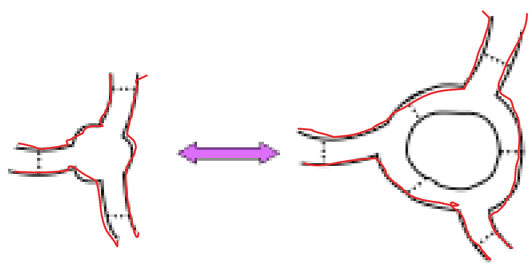


The topology of the embedding:
All ribbon invariants

For example: the link of the ribbon:



But we also want invariance
under the expansion moves:

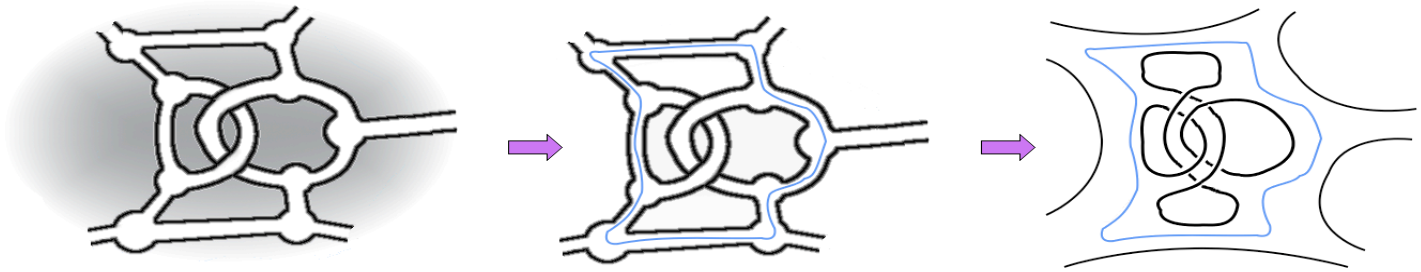


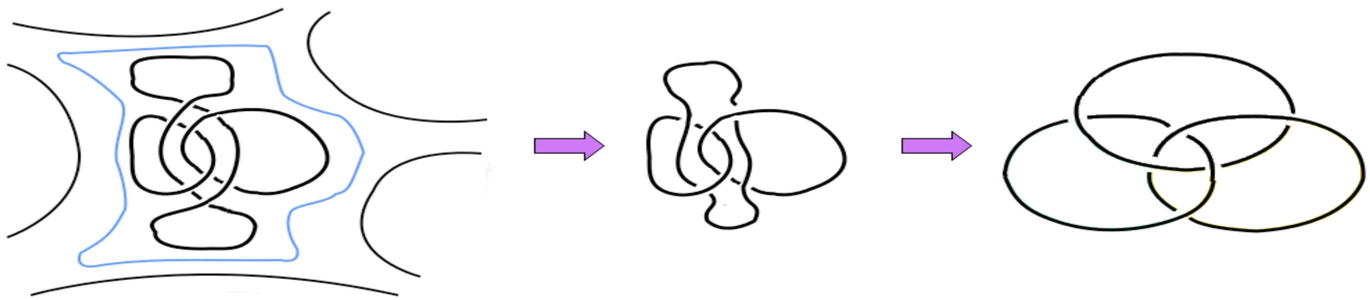
The reduced link of the ribbon is a constant of the motion

Reduced = remove all unlinked unknotted circles

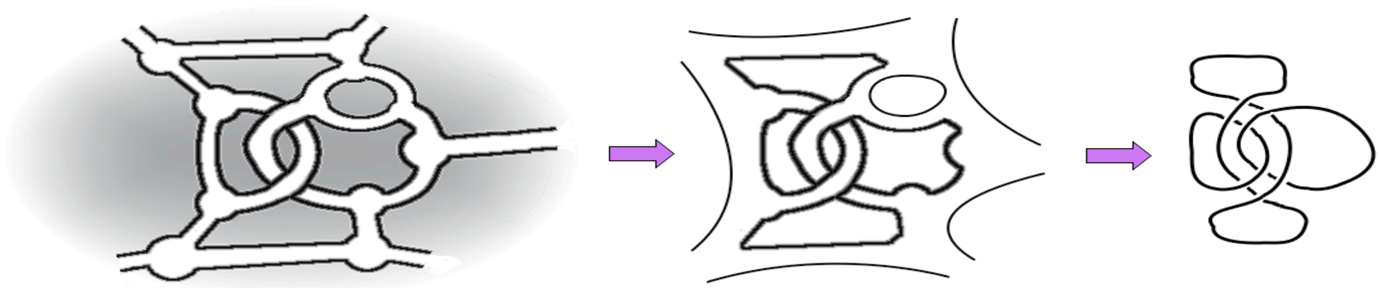
Definition of a subsystem: The reduced link disconnects from the reduced link of the whole graph.

This gives conserved quantities labeling subsystems.



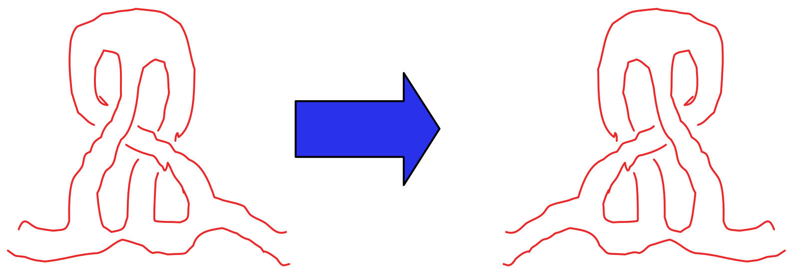


After an expansion move:



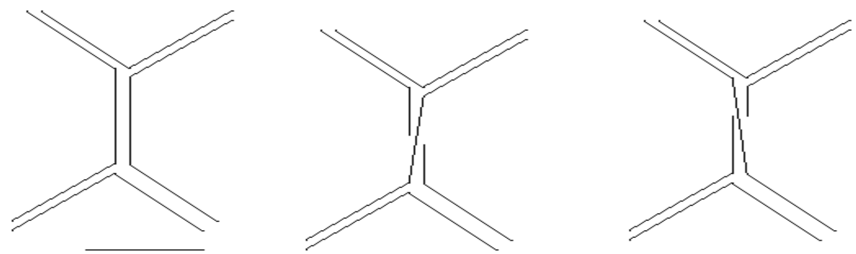
Chirality is also an invariant:

***P*:**



Properties of these invariants:

- Distinguish over-crossings from under-crossings
- Distinguish twists

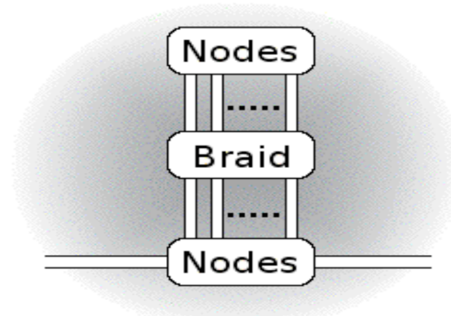


- Are chiral: distinguish left and right handed structures

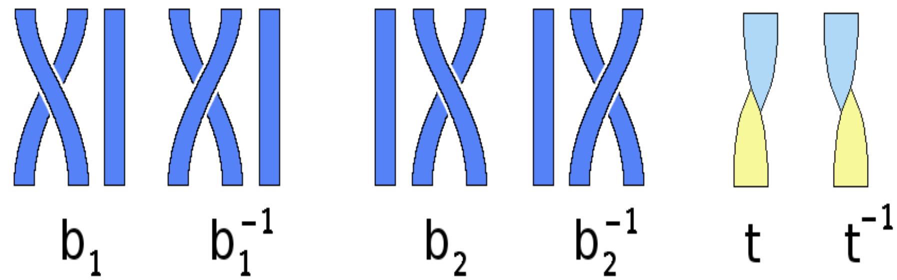
These invariants are independent of choice of algebra G and evolution amplitudes. They exist for a large class of theories.

What are the simplest subsystems with non-trivial invariants?

Braids on N strands, attached at either or both the top and bottom.



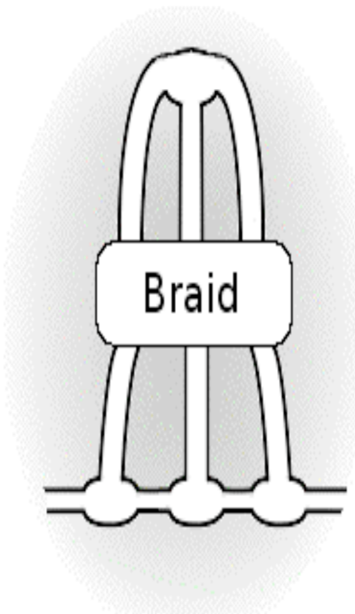
The braids and twists are constructed by sequences of moves. The moves form the braid *group*.



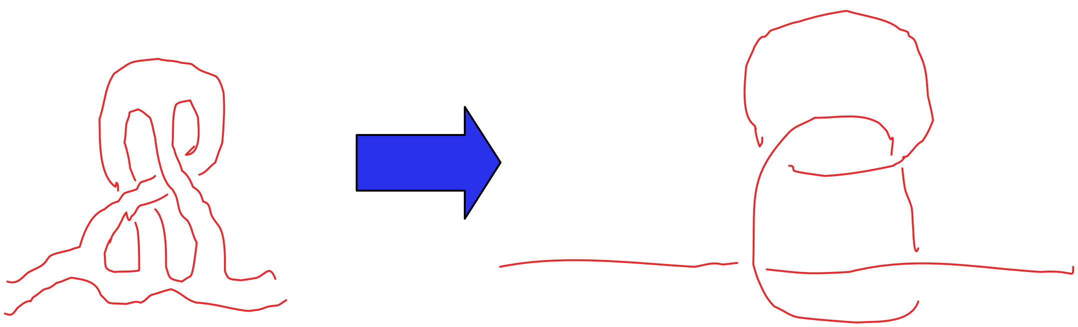
To each braid B there is then a group element g(B) which is a product of braiding and twisting.

Charge conjugation: take the inverse element.
hence reverses twisting.

We can measure complexity by minimal crossings required to draw them:

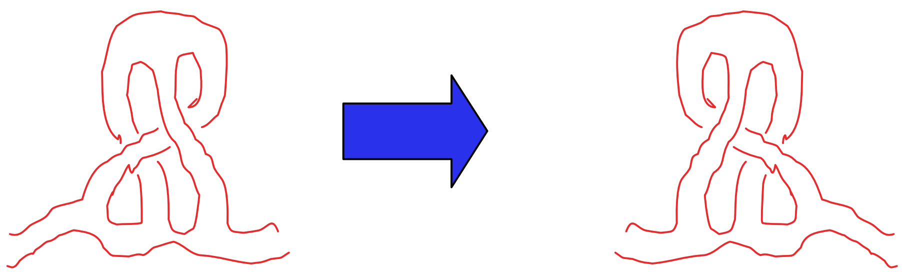


The simplest conserved braids then have *three* ribbons and *two* crossings:



Each of these is chiral:

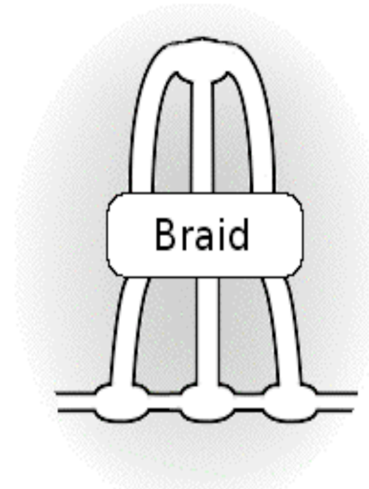
P:



Other two crossing braids have unlinked circles.

Braids and preons ***(Bilson-Thompson)*** *hep-ph/0503213*

preon	ribbon
Charge/3	twist
P,C	P,C
triplet	3-strand braid
Position??	Position in braid



In the preon models there is a rule about mixing charges:

No triplet with both positive and negative charges.

This becomes: *No braid with both left and right twists.*

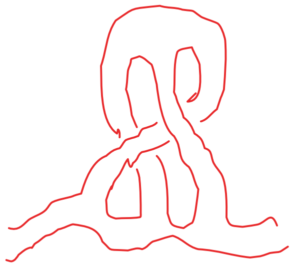
This should have a dynamical justification, here we just assume it.

The preons are not independent degrees of freedom, just elements of quantum geometry. But braided triplets of them are bound by topological conservation laws from quantum geometry.

Two crossing left handed + twist braids:

Charge= twist/3

No twists:

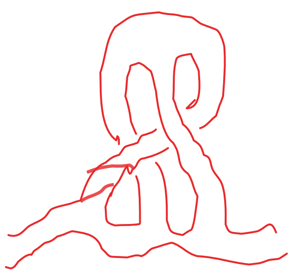


ν_L

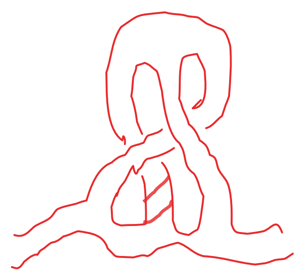
3 + twists

$e_L^{\ +}$

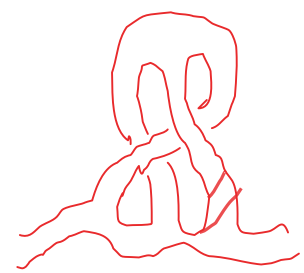
1+ twist



$\overline{d}_L^{\ r}$



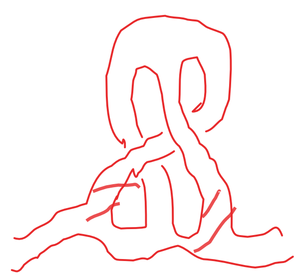
$\overline{d}_L^{\ b}$



$\overline{d}_L^{\ g}$

2+ twists

$u_L^{\ r}$



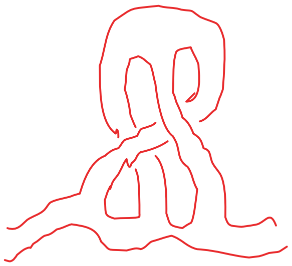
$u_L^{\ b}$

$u_L^{\ g}$

Two crossing left handed + twist braids:

Charge= twist/3

No twists:



ν_L

3 + twists

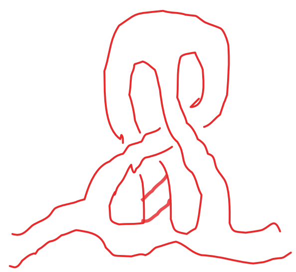
e_L^{+}

Including the negative twists (charge) these area exactly the 15 left handed states of the first generation of the standard model.

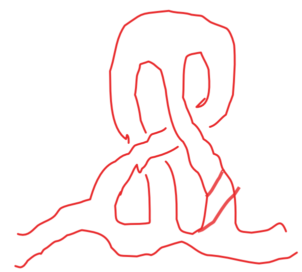
Straightforward to prove them distinct.

1+ twist

$\overline{d}_L^{\,r}$



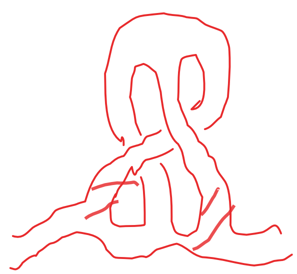
$\overline{d}_L^{\,b}$



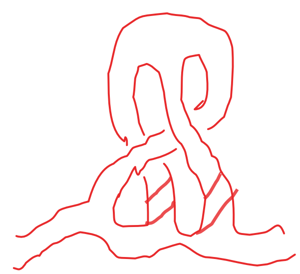
$\overline{d}_L^{\,g}$

2+ twists

$u_L^{\,r}$



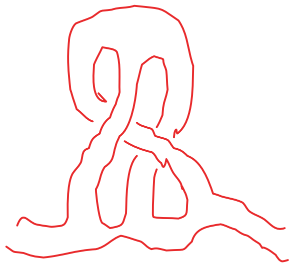
$u_L^{\,b}$



$u_L^{\,g}$

The right handed states come from parity inversion:

No twists:



ν_R

3 - twists

e_R^-

1- twist

d_R^r

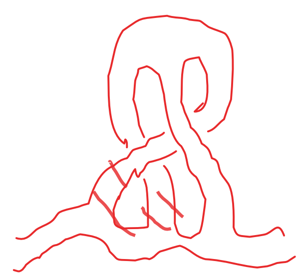
d_R^b

d_R^g

2- twists

$\overline{u}_R^r$

$\overline{u}_R^b$



$\overline{u}_R^g$

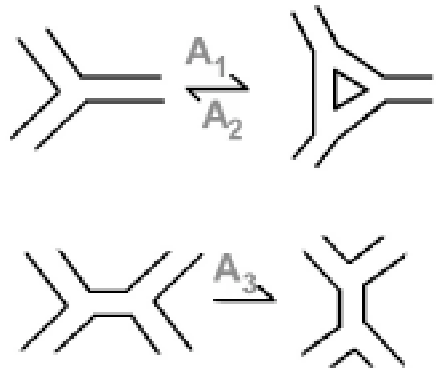
Locality and translation in braided ribbon networks

Jonathan Hackett: hep-th/0702198

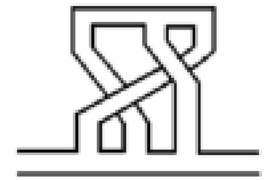
Jonathan Hackett: hep-th/0702198

Under the dual pachner moves, 3-valent dual graphs propagate but do not interact.

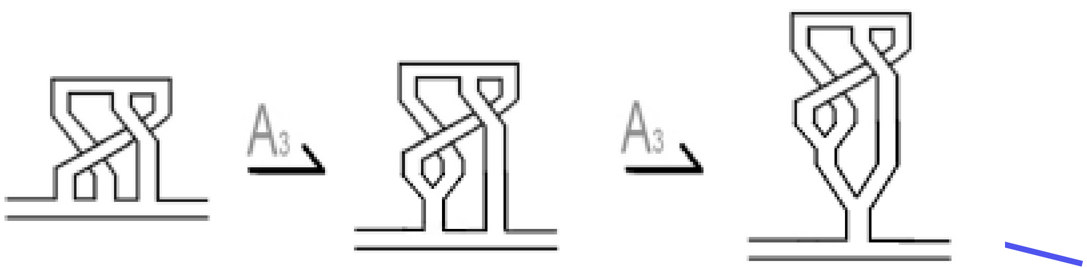
local moves:



Propagation of 2-crossing braids



A braid can evolve to an *isolated structure (a subgraph connected to a larger graph with a single edge, called the tether):*

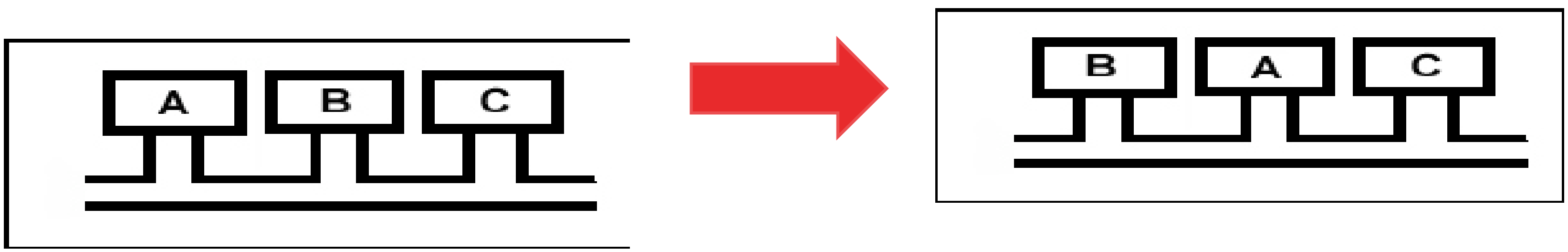


tether

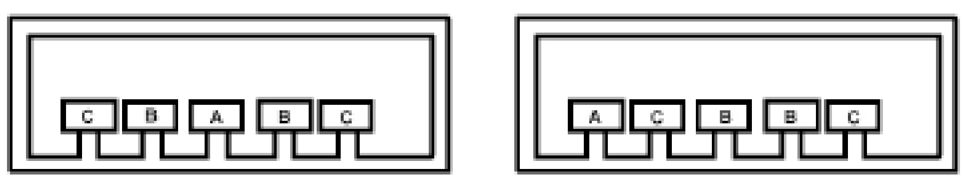
Basic results on propagation of 3-valent ribbon graphs:

•*If a and b are two edges in a link of a ribbon graph, and they are connected (ie part of the same curve in the link) , there is a sequence of local moves that takes an isolated structure tethered at a to be tethered at b.*

•*One isolated structure can be translated across another isolated structure.*



Hence there are no interactions.



Key issues:

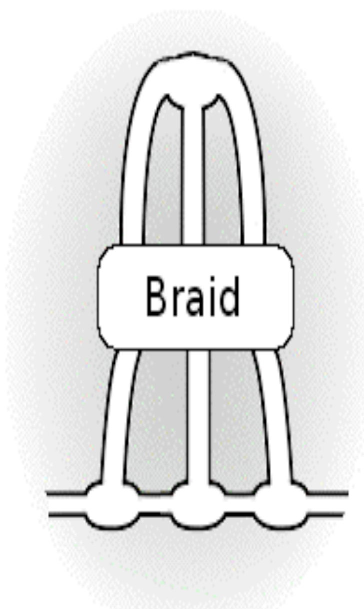
Interactions.. *To get interactions we must add additional local moves.*

Too many and the braids become unstable.
Too few and there are no interactions.
Is there a natural proposal for additional local moves that are just right, and lead to locally stable braids that interact?

Generations, charges: *does the model work for higher generations?*

Three-valent framed graphs: open case

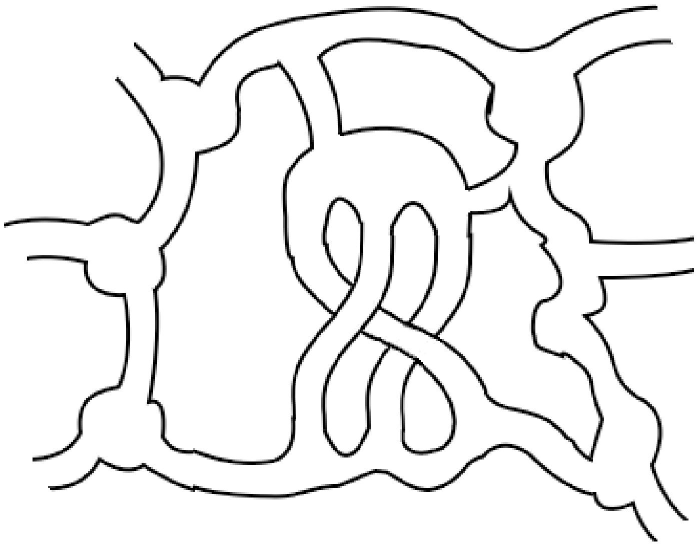
Bilson-Thompson, Hackett, Kauffman, in preparation



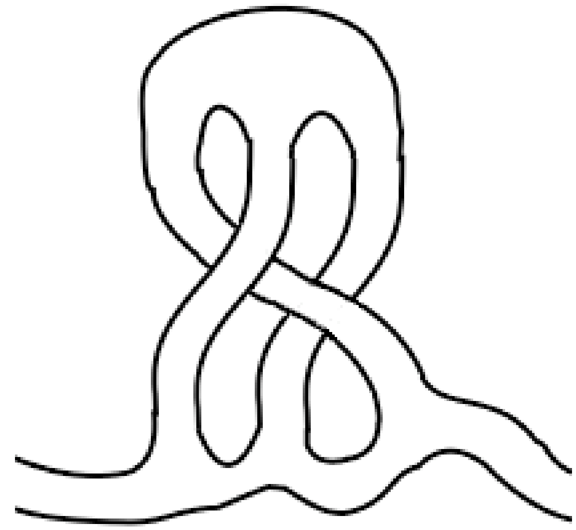
This is the case where the braid is connected to a large network at one end.

This is composed of four trinions

braids can be joined on both ends
to the network



or on one end, or capped

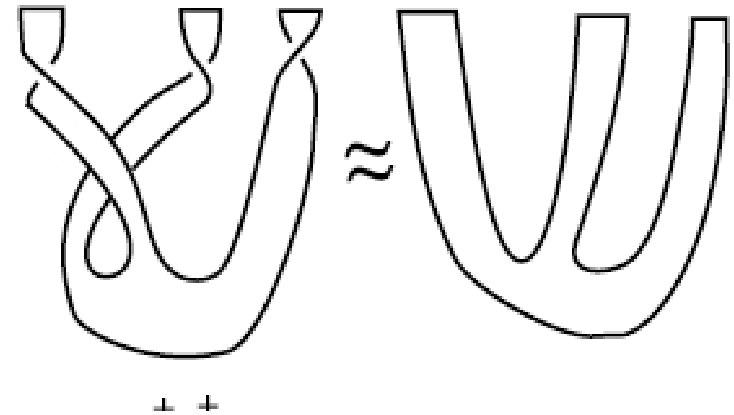


in the following we discuss the capped 3-valent case

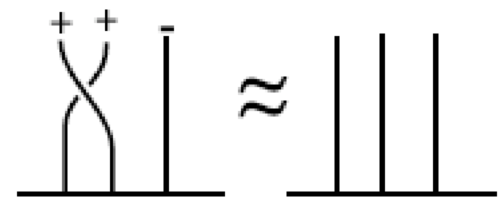
Since we can twist the top end, ***braids are equivalent to half-twists***

Note that before we identified charge with whole twists

We can apply this to eliminate all braids in favor of half-twists

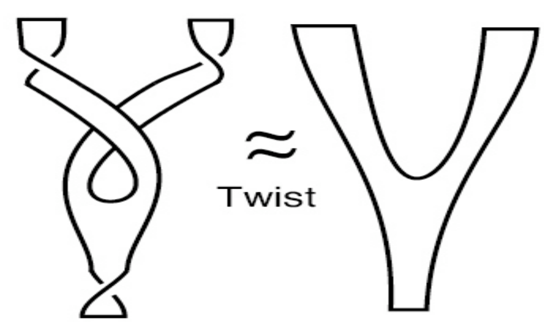


New notation:



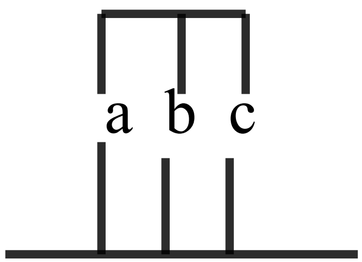
+= half twist

Proof:

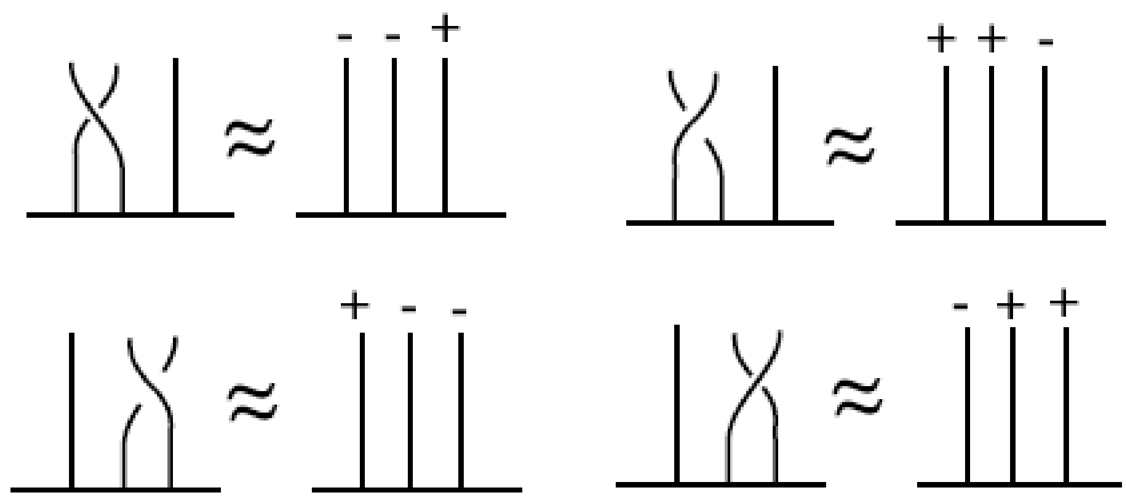


We then have a new notation for a capped braid: (a,b,c)

a triple of half integers that denote the twisted braid in a form with no braids



Lou's numbers



Multiplying braids

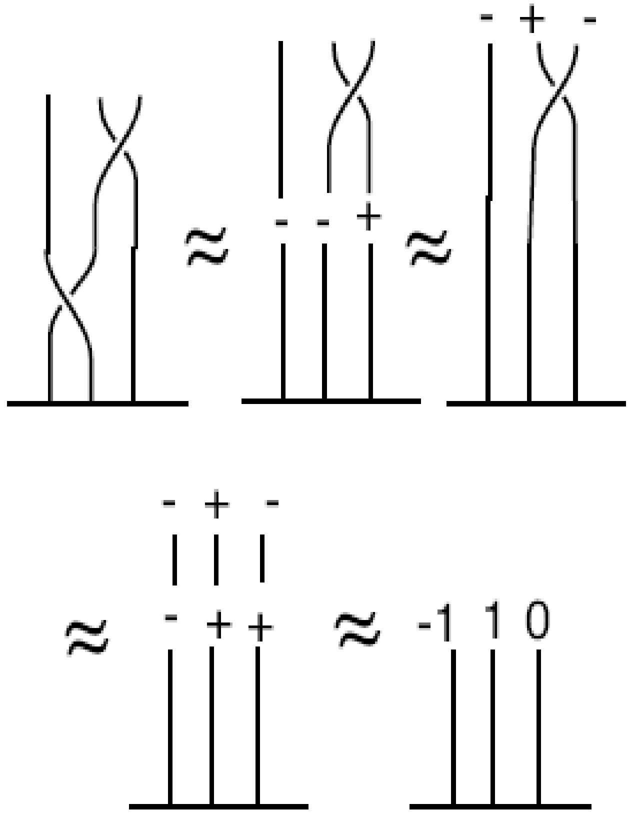
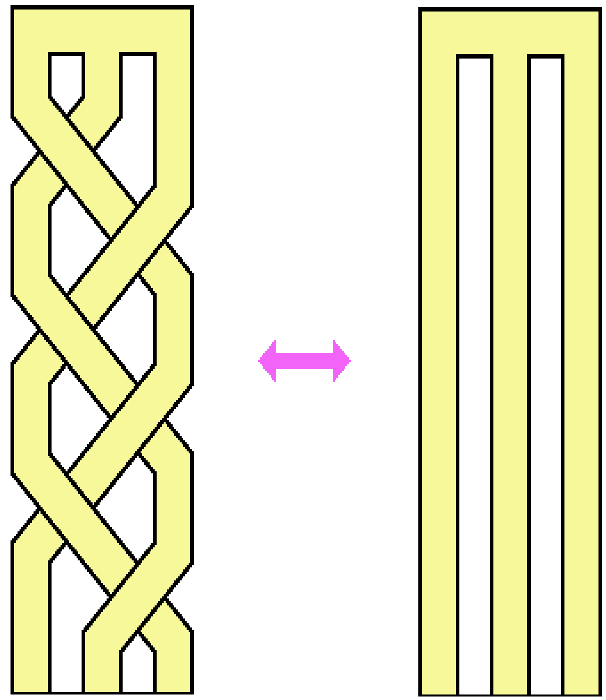


Figure3 - A Product

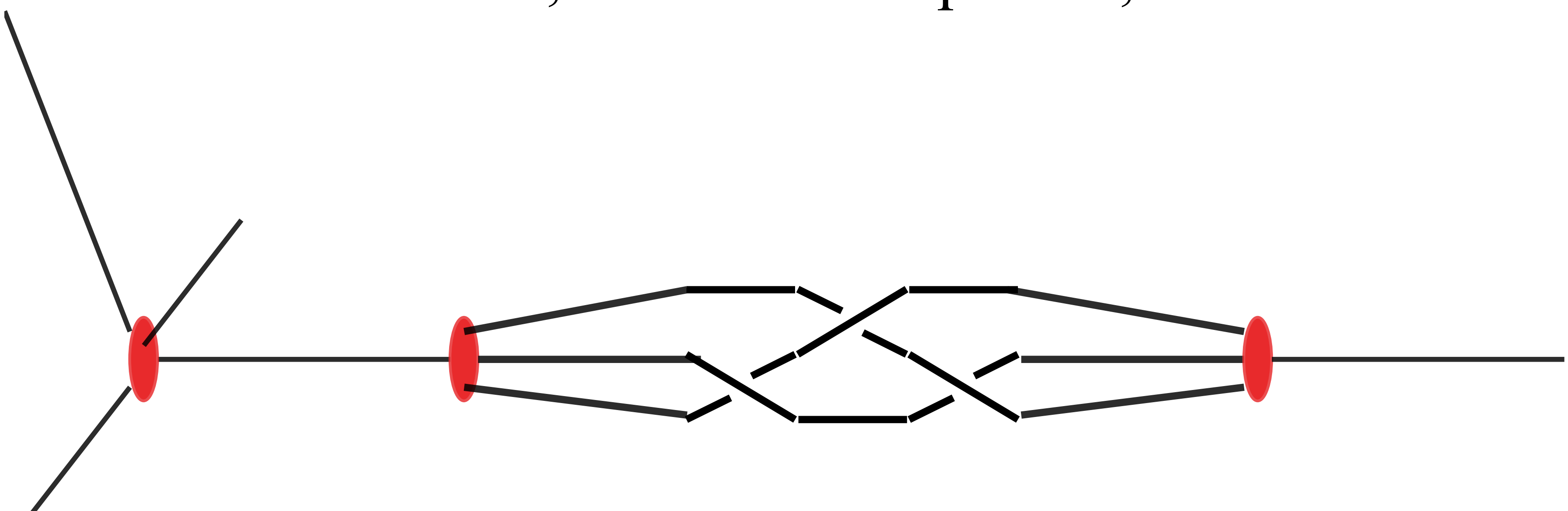
Belt trick identity: $(\sigma_{12}\,\sigma_{32})^3 = I$



Classification, identification of higher genereations in progress.

Four valent framed braids:
propagation and interaction

Yidun Wan, Fotini Markopoulou, ls



Basic observations:

Evolution is via dual Pachner moves:

•Dual Pachner moves only defined for framed graphs.

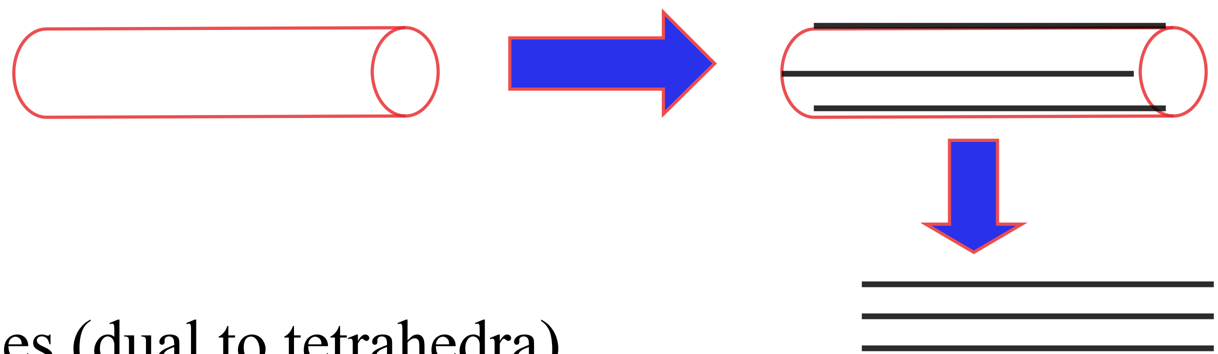
•Braids are stable when moves are only allowed on sets of nodes that* are dual to triangulations of trivial balls in R^3 (Fotini)

•Remaining dual pachner moves naturally give interactions between braids (Yidun)

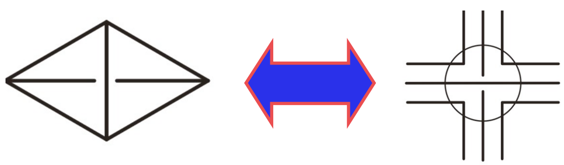
*including any nodes attached to each of the set

The zeroth step is to make a good notation:

Framed edges are rep by tubes which are rep by three edges:

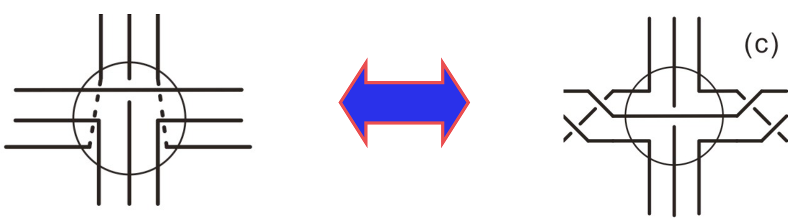


Representation of nodes (dual to tetrahedra)

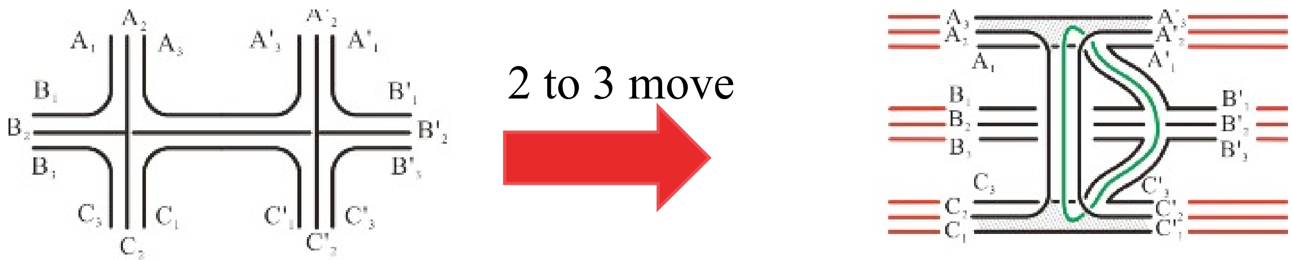


framed edge is dual to a face, which has three edges, these are the 3 edges here

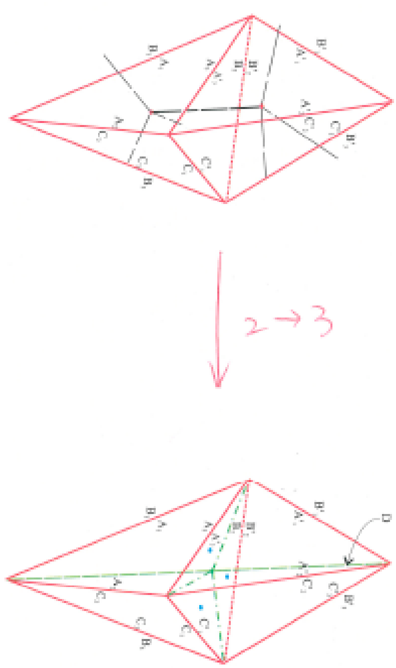
twists and projections sometimes make lines cross in the triplet:



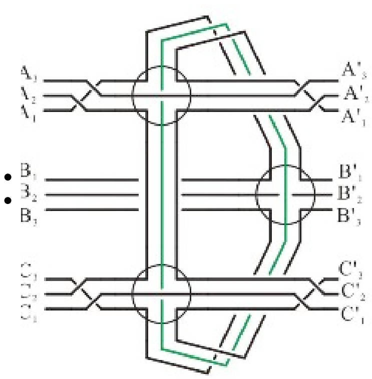
The dual Pachner moves: 2 to 3 move



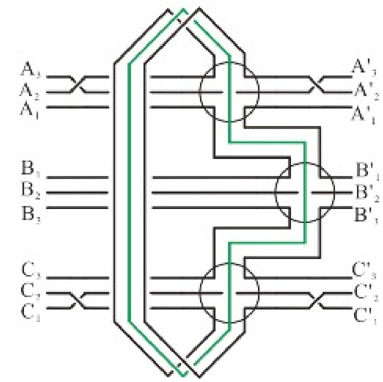
Note: the framing determines who is over and under.



We put this in a canonical notation with nodes flattened:



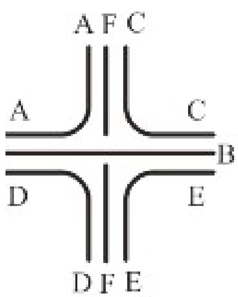
or



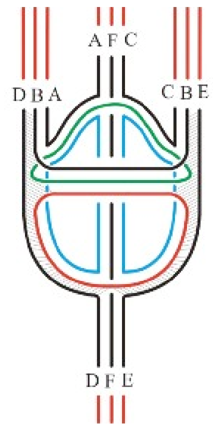
Notice that the flattening of the nodes induces twists in framed edges. These are represented by crossings within triplets of lines.

All moves are invertible

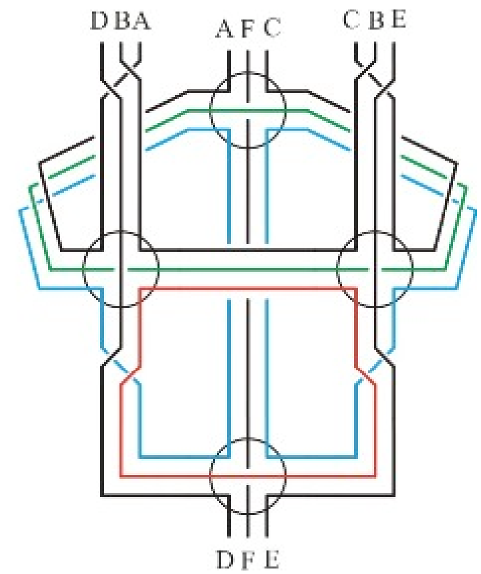
The dual pachner moves: 1 to 4 move

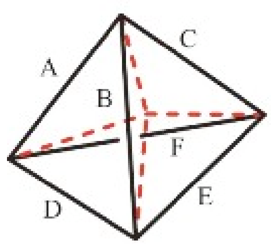


1 to 4 move



or,
flattening
nodes





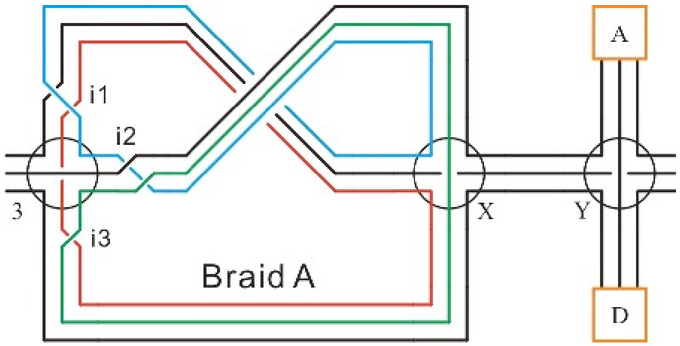
the lines refer to edges of the dual triangulation

The basic rule:

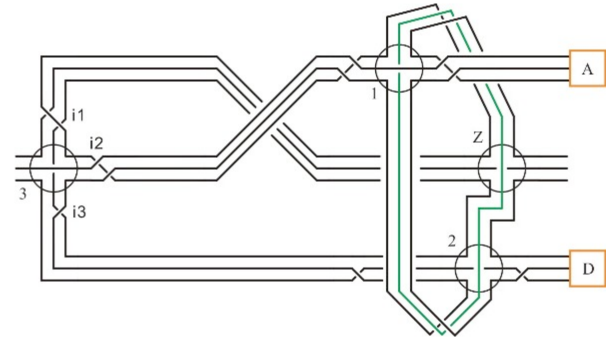
A dual Pachner move on 2, 3 or 4 interconnected nodes is only allowed if they (and any nodes that attach to all of them) are with their shared edges dual to a triangulation of a ball in R^3.

This stablizes isolated non-trivial braids.

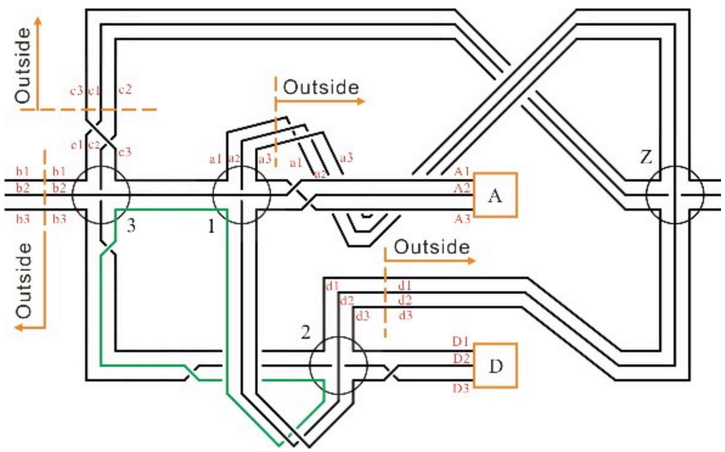
1-crossing states propagate



2 to 3 move

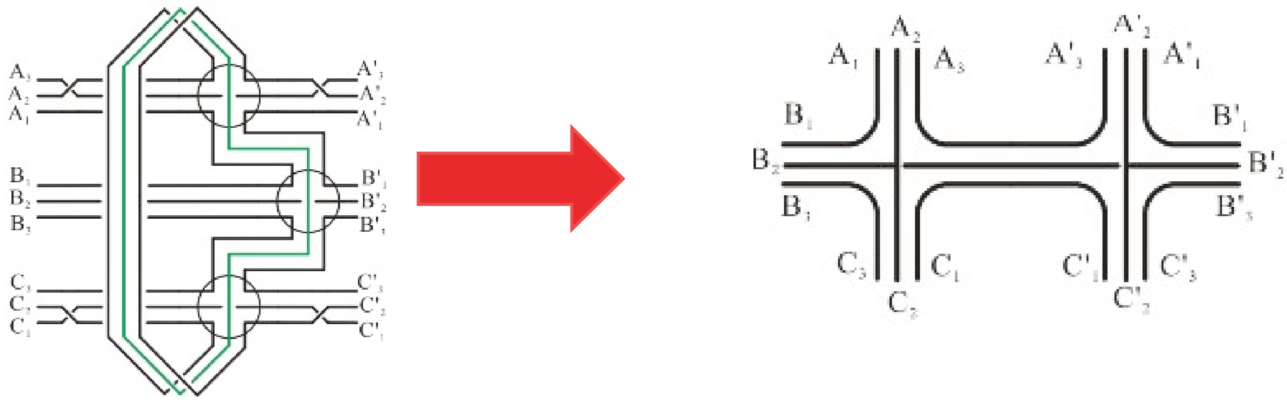


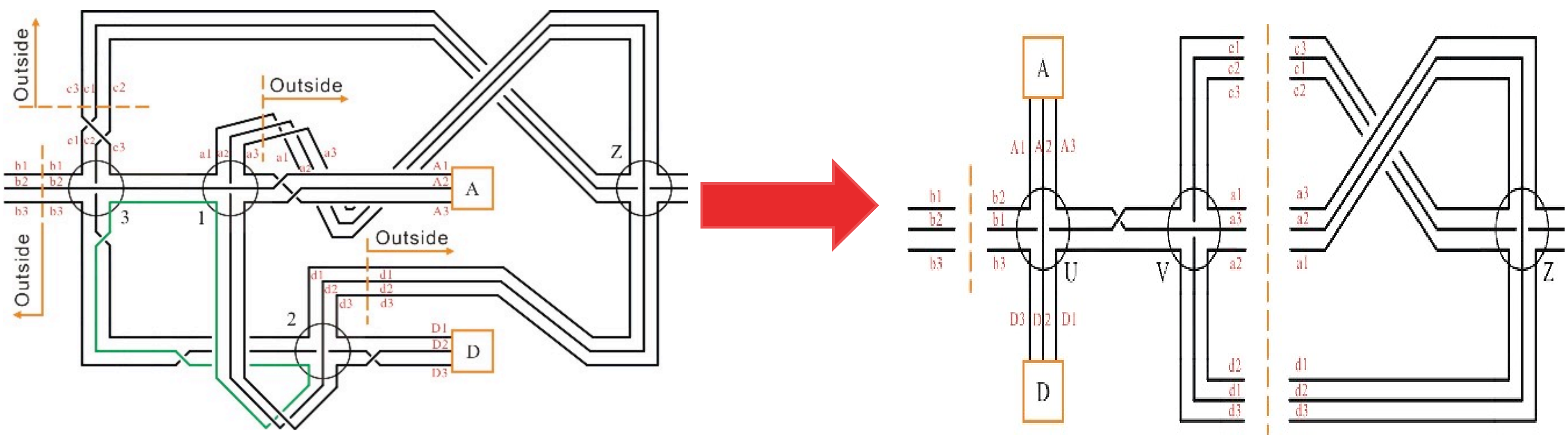
Slide nodes 1 and 2 to the left



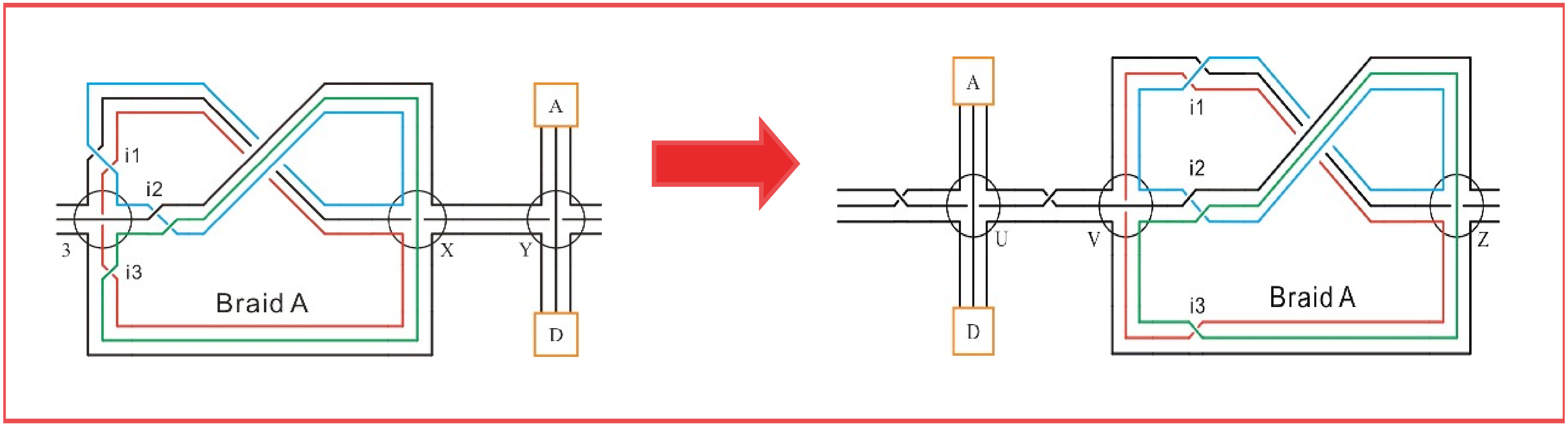
Next step: a 3 to 2 move

Recall the canonical form of the 3 to 2 move:





summary: 2 to 3 + slide + 3 to 2 yields:



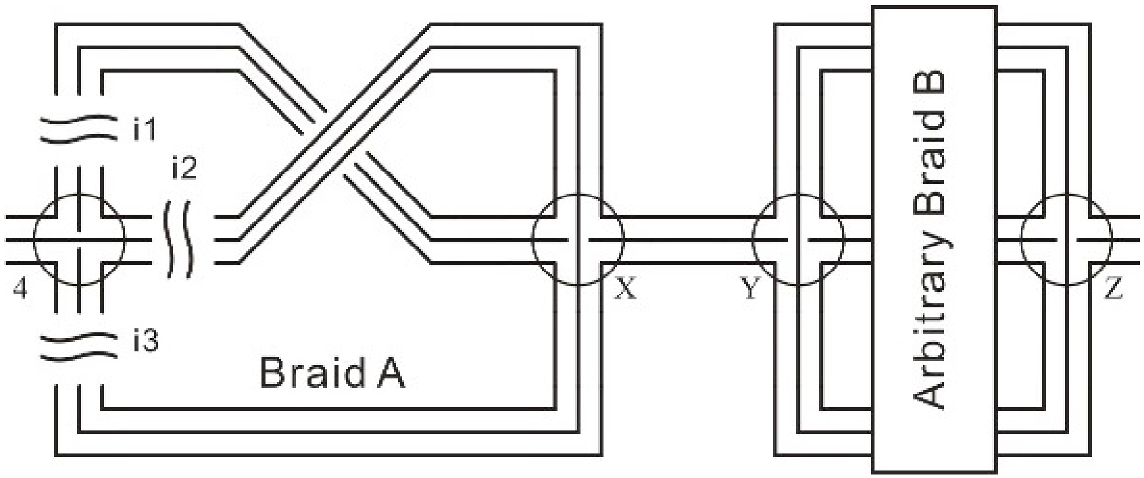
Propagation is chiral: this braid propagates only to the right.

(because it leaves twists behind)

Its mirror image propagates only to the left.

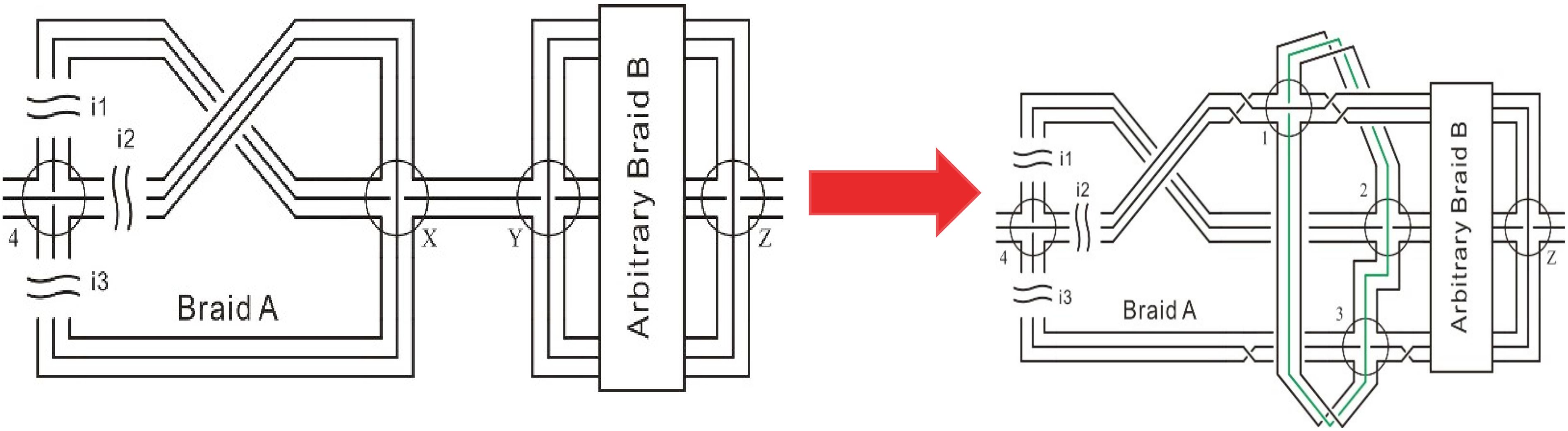
1-crossing interaction

The 1-xing braid's propagation can take it to the left of another braid:

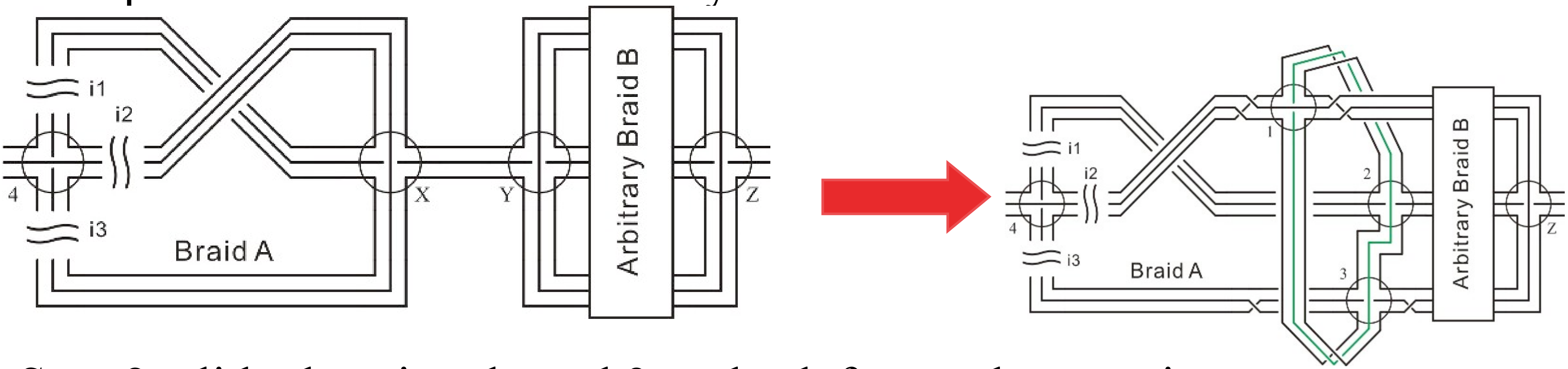


we leave the routing on
the right free for now.

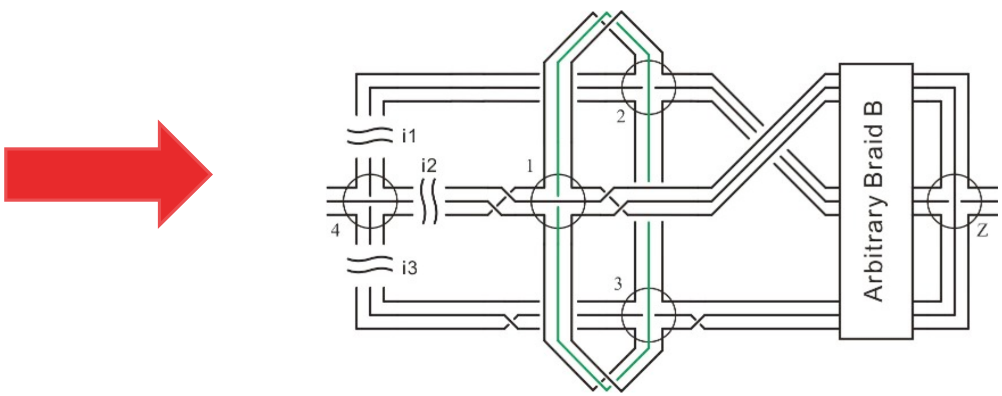
Step 1: a 2 to 3 move on x and y:



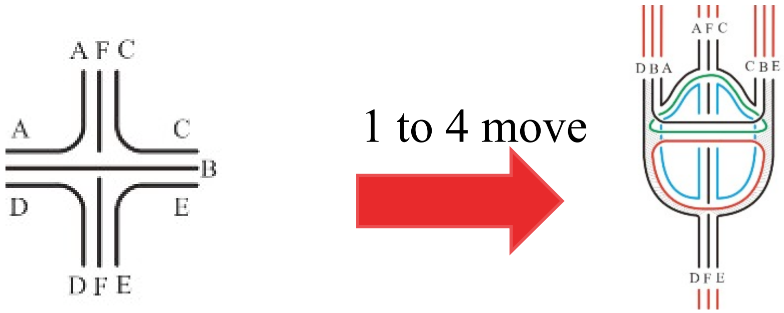
Step 1: a 2 to 3 move on x and y:



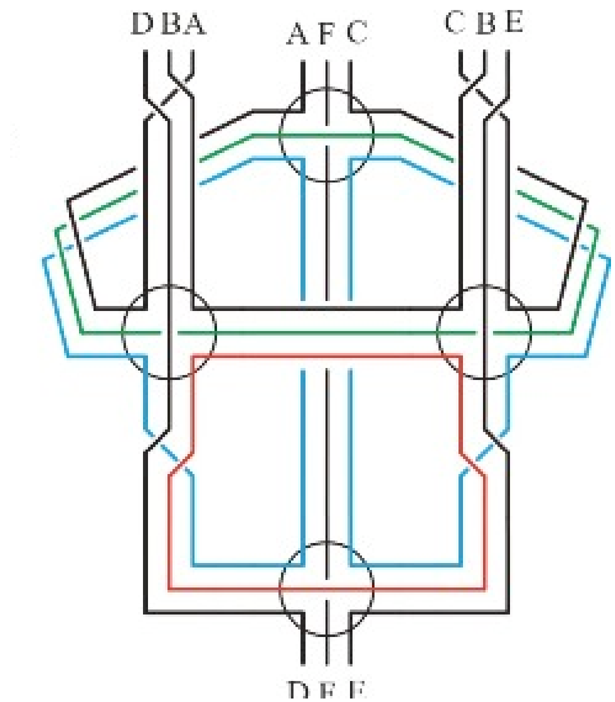
Step 2: slide the triangle and 3 nodes left past the crossing:

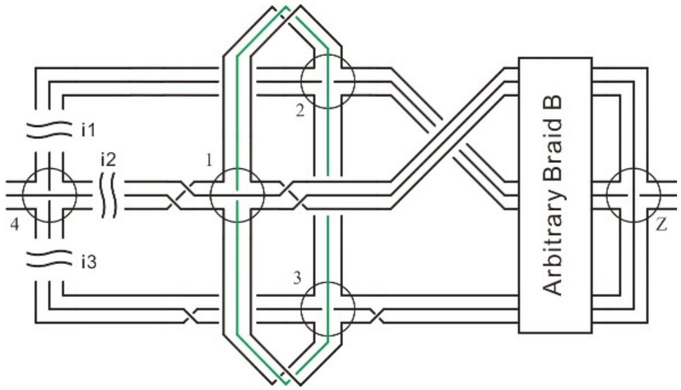


this creates a 4-simplex which we want to collapse by a 4 to 1 move recall the fine print of the 4 to 1 move:

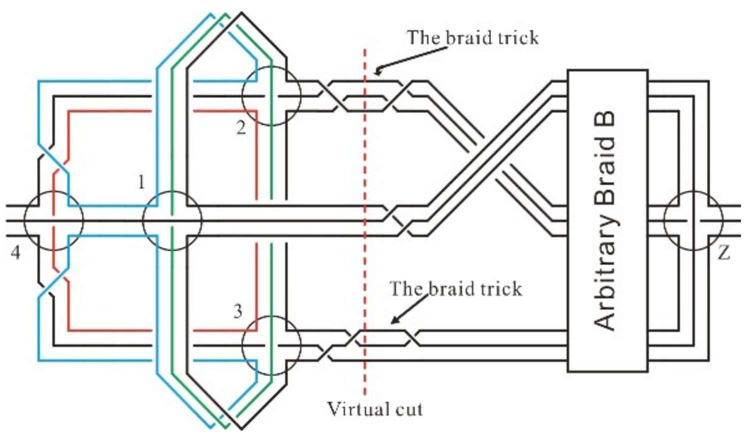


In canonical form:

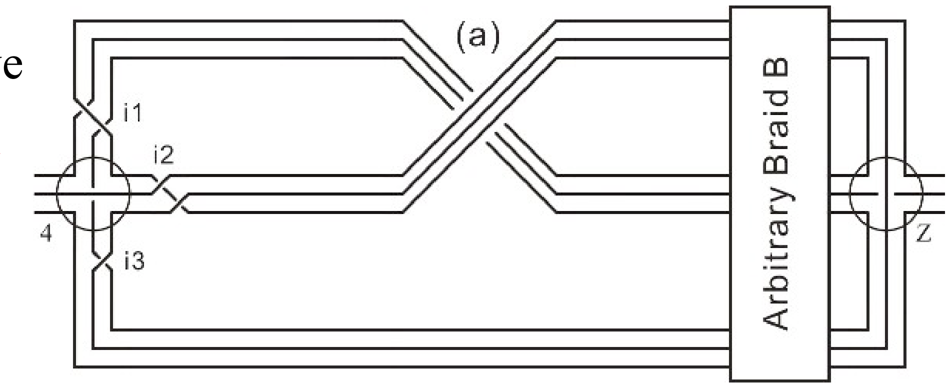




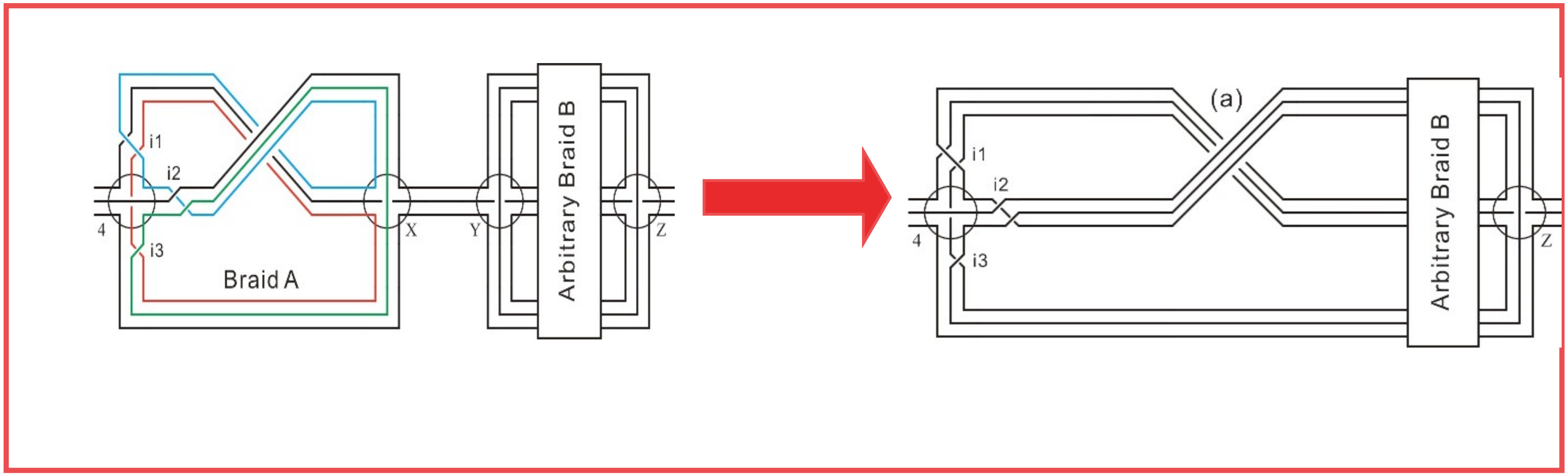
put in
canonical form



4 to 1 move



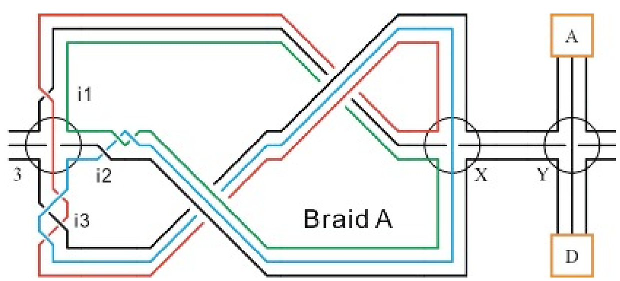
Summary: 1 to 3 + slide + 4 to 1 combines to:



The interaction is chiral, this braid does not ineract with braids on its left.

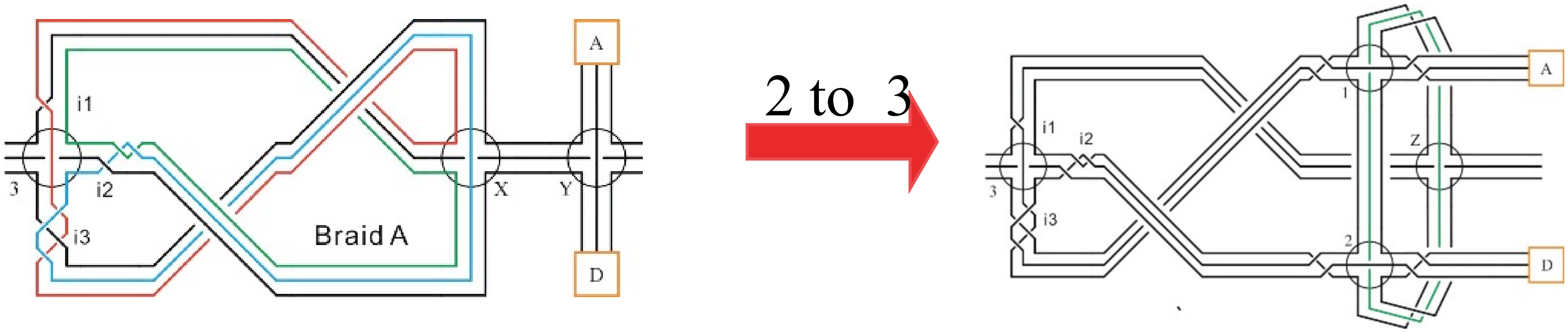
Its mirror image interacts only with braids on the left.

A two crossing braid propagating

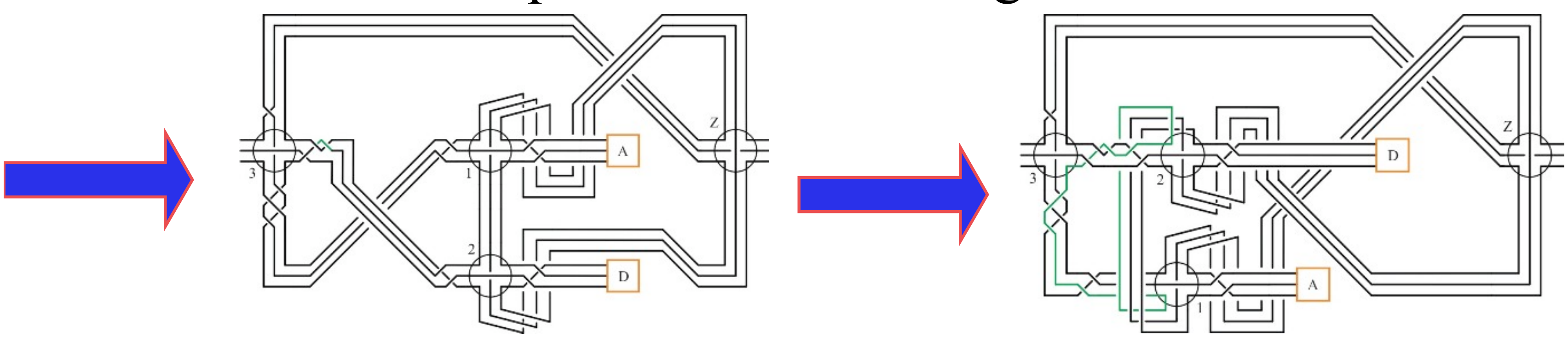


This is an alternating braid

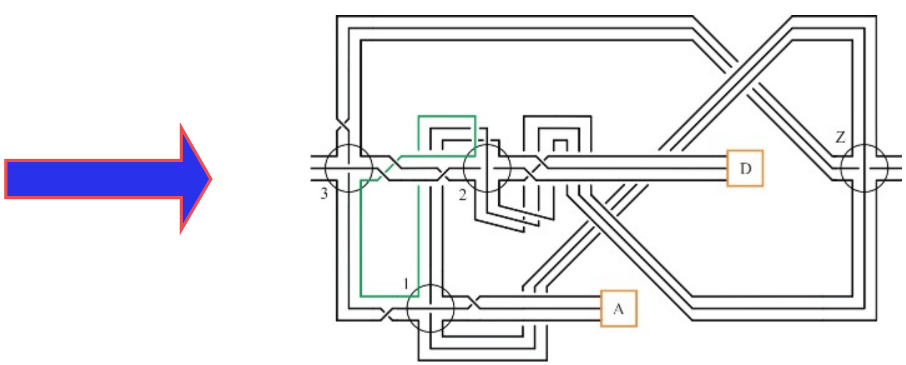
As before, we begin with a 2 to 3 move:



We slide two nodes past the two crossings:

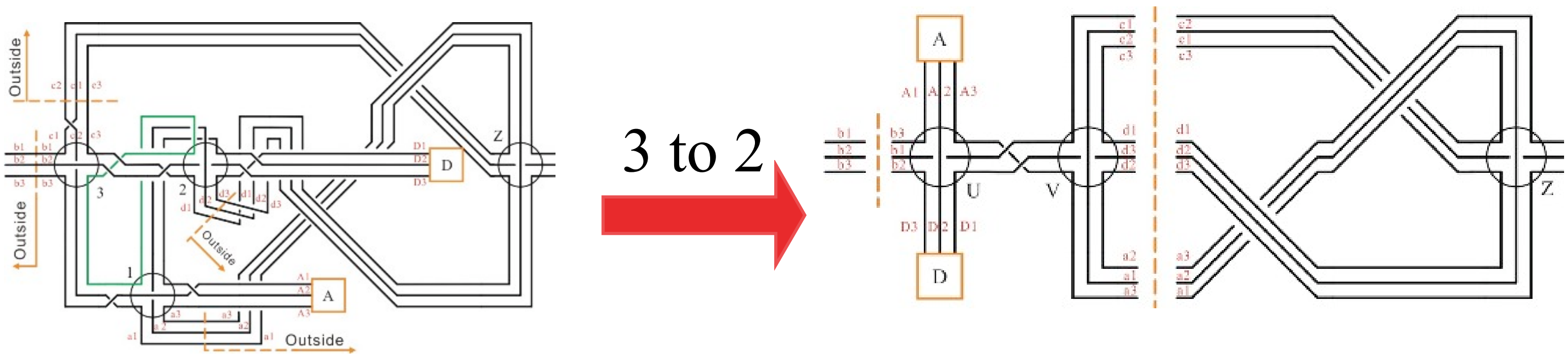


Rotate node 1 and rearrange:

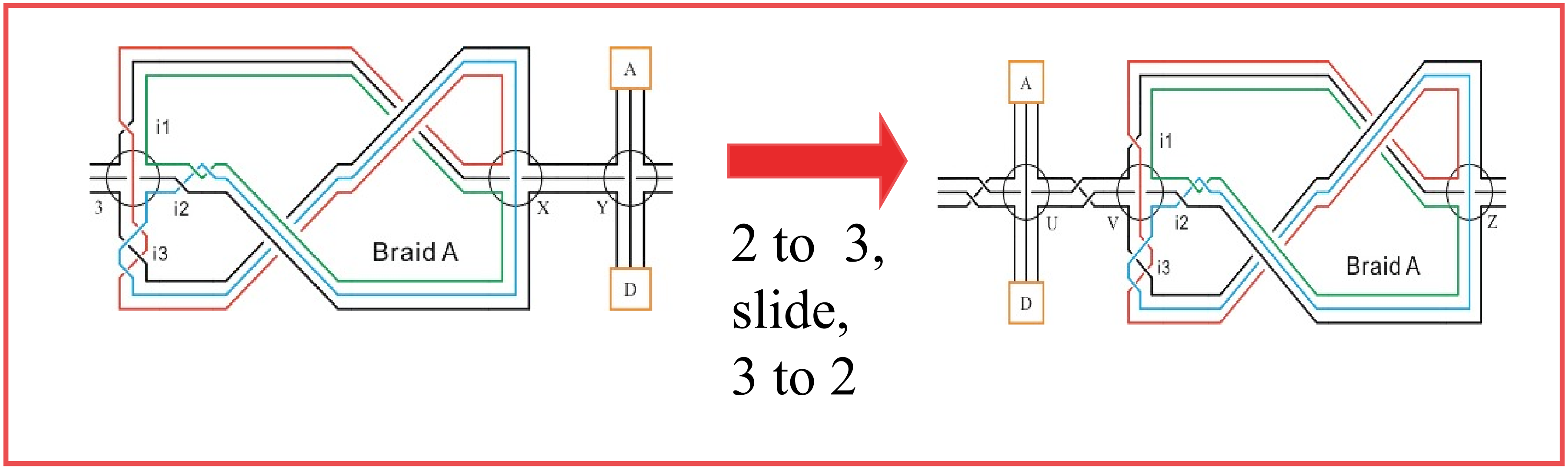


next step: the 3 to 2 move…

The final 3 to 2 move:

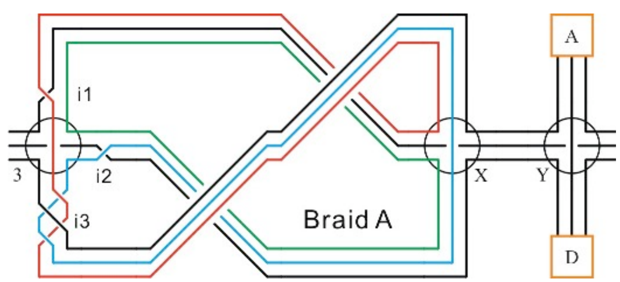


Result:

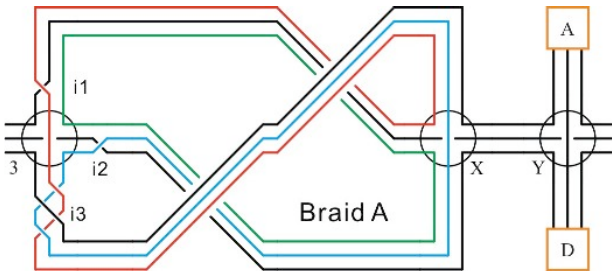


Again propagation is chiral. But this one does not catalyze interactions. The triangle cannot be pulled past the second crossing.

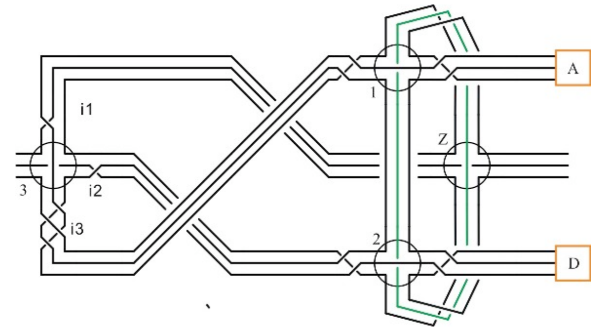
A two crossing braid
that propagates *and* interacts.



Propagation of a simple 2-crossing braid

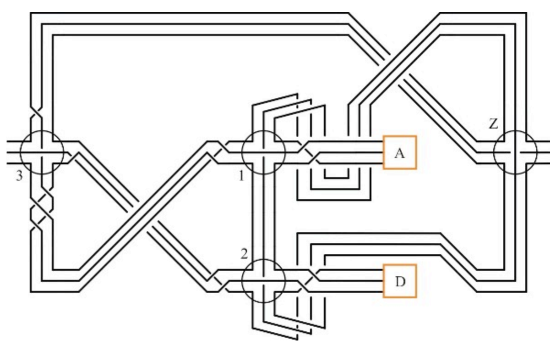


2 to 3 move



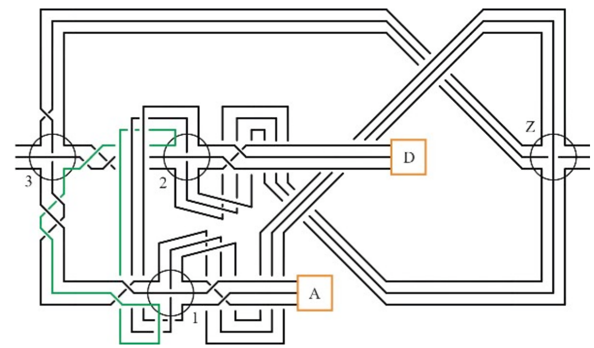
slide past

one link

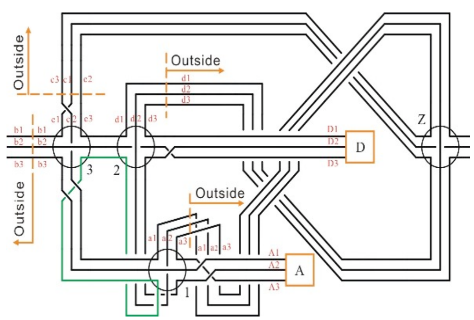


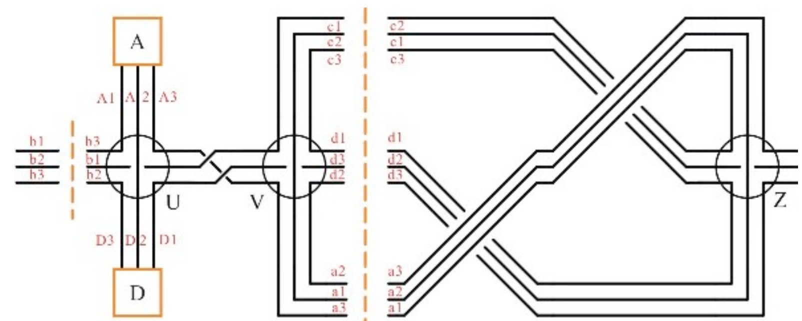
slide past

second

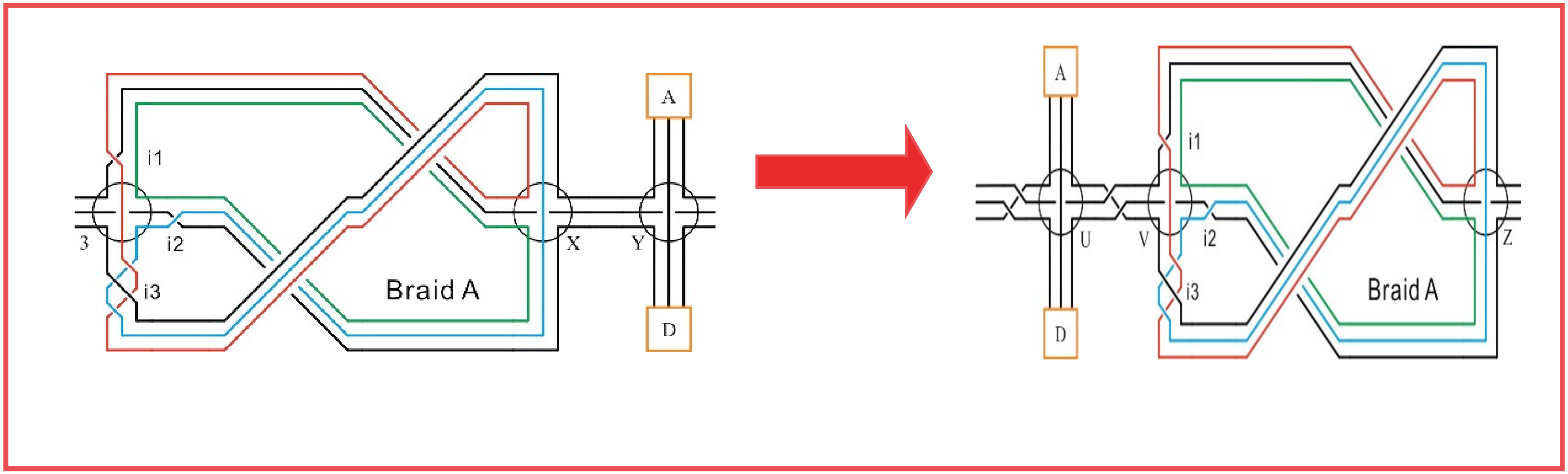


Next we have to do a 3 to 2 move



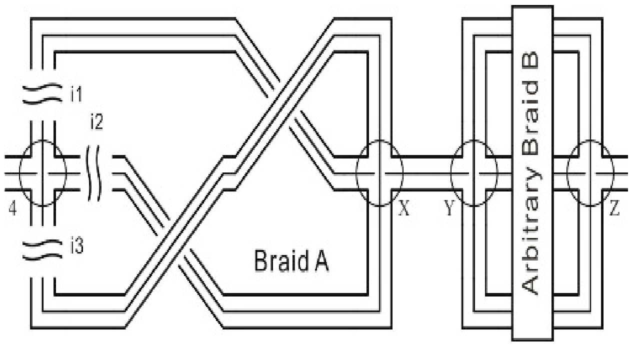


Putting the result back in the initial form we have shown that 2 to 3 + slide + 3 to 2 yields:

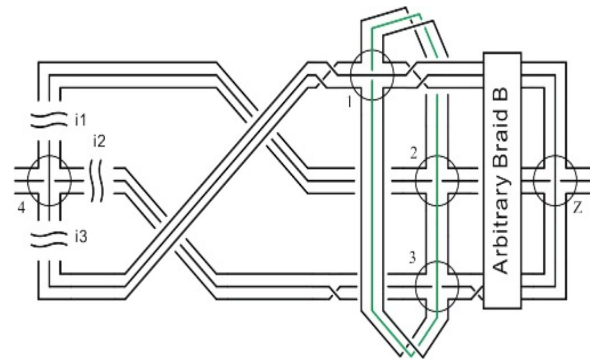


Two-crossing interaction:

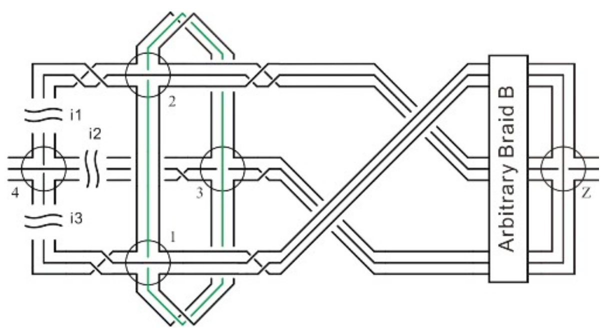
Start:
(we leave left node to fix later)



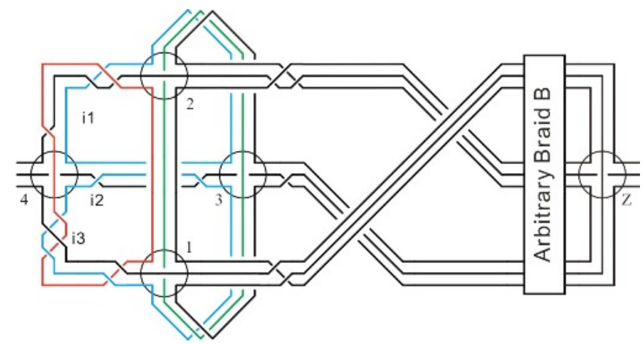
2 to 3



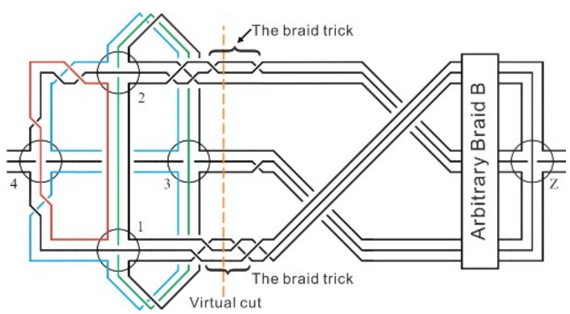
Slide across both crossings:



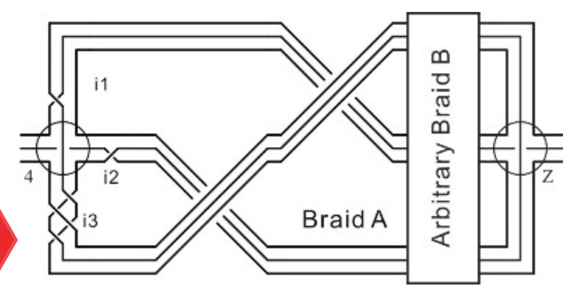
Choose left node so 4 to 1 move works



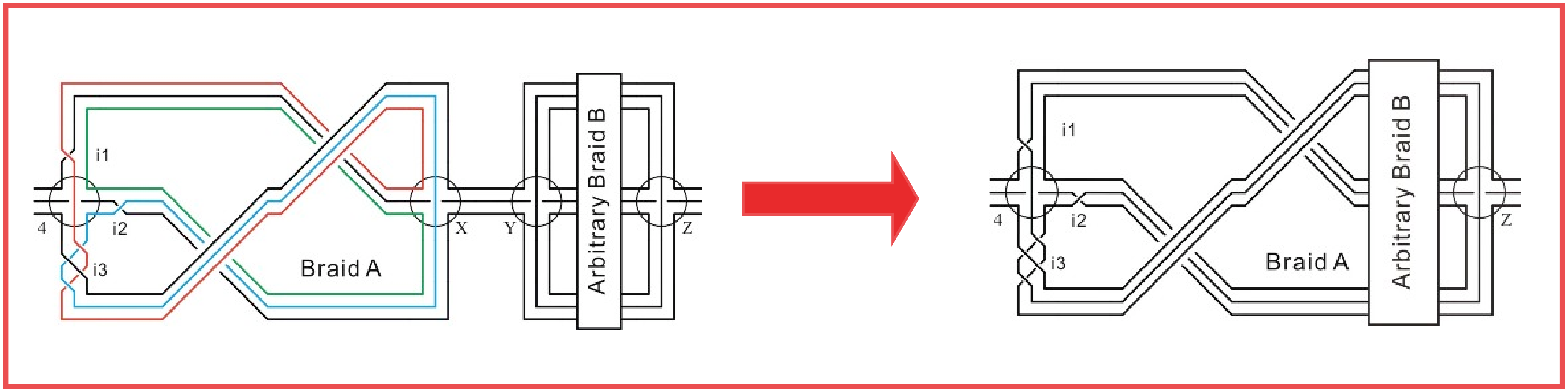
Prepare to do 4 to 1 move:



4 to 1



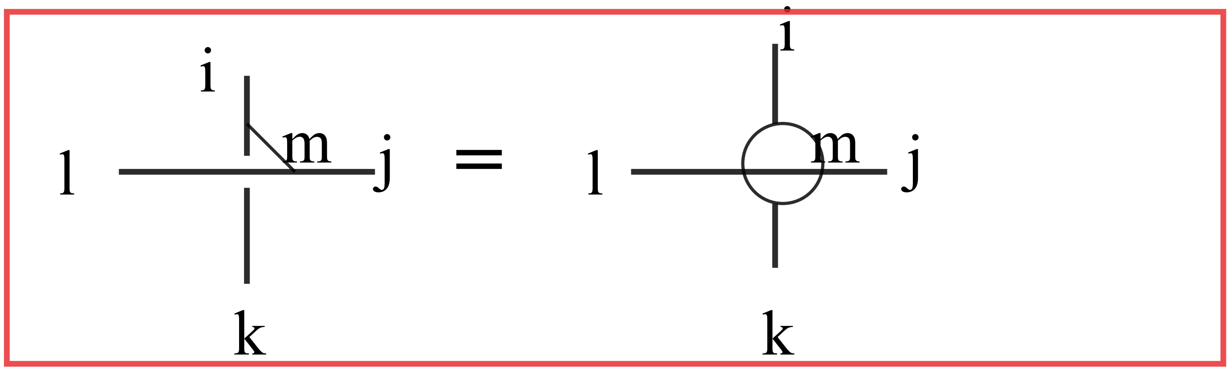
Summary: a 2 crossing interaction:



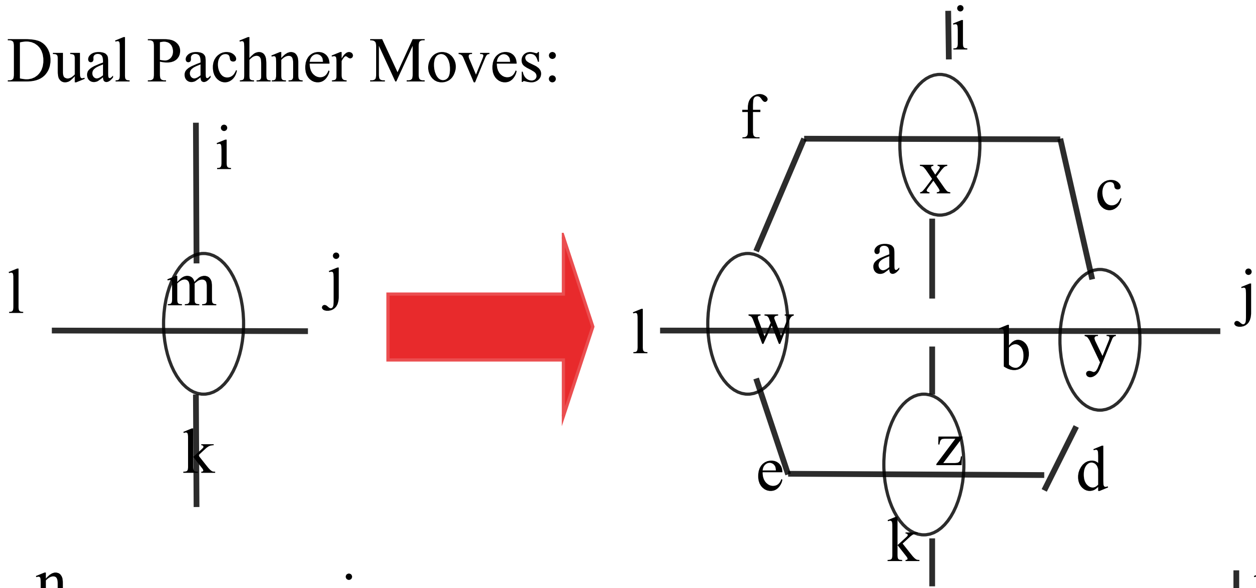
by 2 to 3 + slide + 4 to 1

Spin foam models: add labels and their amplitude dependence

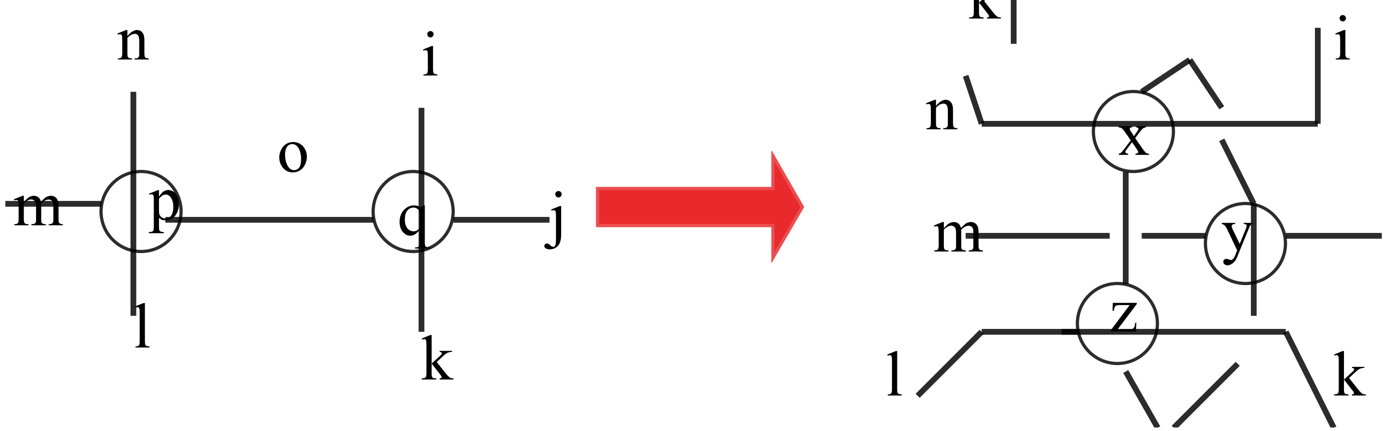
Notation:



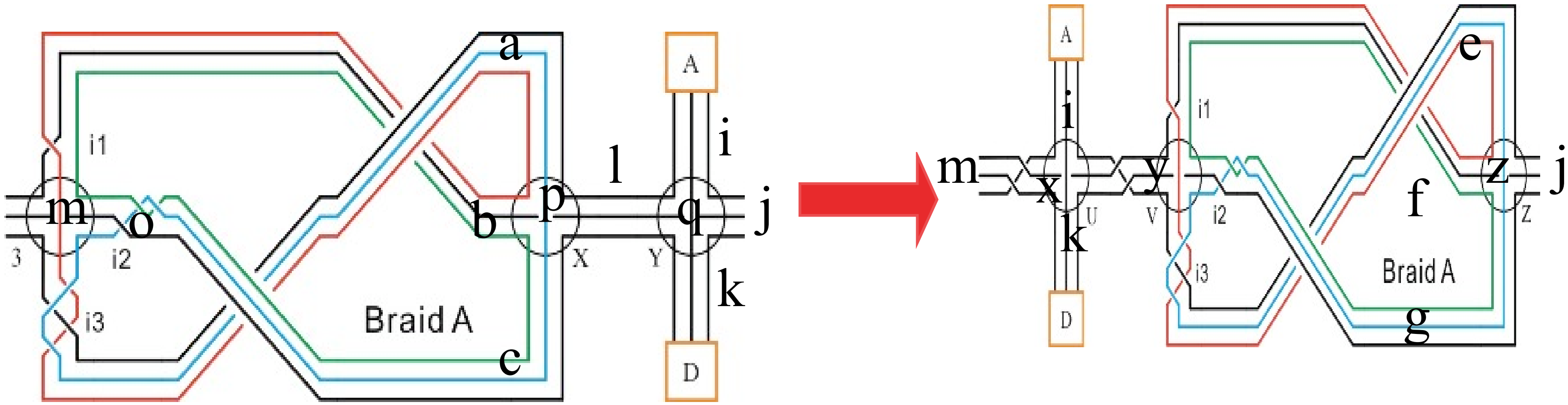
Dual Pachner Moves:



A[labels]



B[labels]



amplitude = Σ B[2 to 3 movc] B[3 to 2 move] $\{\}_{6j}\{\}_{6j}\{\}_{6j}$

Now in progress:

•Are these excitations fermions?

They are chiral but could be spinors or chiral vectors.
Edges can be anyonic in 3d
We seek an inverse quantum Hall effect

•Momentum eigenstates constructed by superposing translations on regular lattice.

•More on twists, charge, generations, interactions etc.

•Many other questions are still open…

Conclusions: (All with standard dual Pachner moves)

3 valent case:

Braids are absolutely conserved, no interactions
New local moves needed to get interactions, under study
Capped braids propagate along edges of ribbons
Capped braid systematics intricate, under investigation
Correspondence to preon model but may have exotic states

4-valent case: (with standard dual Pachner moves for sets dual to triangulations of regions of R^3)

Isolated braids stable.
Braids propagate, propagation is chiral
Some combine with adjacent braids, hence interact
Interactions are chiral.
Correspondence with preons etc not yet established.