Quivers, 3d gauge theories and 3-mfds

Summary workshop: knots, homologies and physics

Shi Cheng

May-10-2024

Fudan University

w/ P. Sułkowski 2302.13371, 2310.07624

Quivers

- Quivers are symmetric matrices

$$P_{C_{ij}}(q;x_1,\cdots,x_N) := \sum_{d_1,\ldots,d_N=0}^{\infty} (-\sqrt{q})^{\sum_{i,j=1}^{N} C_{ij}d_id_j} \frac{x_1^{d_1}x_2^{d_2}\cdots x_N^{d_N}}{(q;q)_{d_1}(q;q)_{d_2}\cdots(q;q)_{d_N}}.$$

- Knots-quivers correspondence

$$\text{Knots} \longrightarrow C_{ij}/\sim$$

Equivalent quivers

Motivation

- We hope to use physics and geometry to understand this correspondence and quivers.

Tools

- 3d N=2 gauge theories: dualities, gauging
- String theories: M-theory/IIB duality, 3d brane webs
- 3-manifolds: surgery, Kirby moves

- We find:

Knots $\leftrightarrow$ Quivers $\leftrightarrow$ 3d N=2 gauge theories $\leftrightarrow$ 3-mfds

3d N=2 plumbing theories

- The vortex part. function some theories can be written as quiver generating functions

$$Z^{\text{1-loop}} Z^{\text{vortex}}_{\mathfrak{a}} = P_{C_{ij}}(x_i)$$

- 3d N=2 theories $U(1) \times \cdots \times U(1) + n\,\Phi_i$

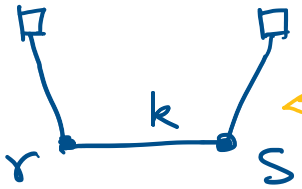
$$K^{\text{eff}}_{ij} = C_{ij}$$ mixed CS levels = quivers

Plumbing graphs

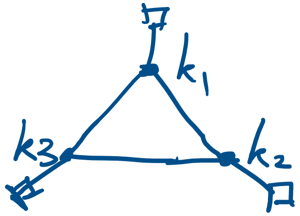
- A new quiver diagram:

Notation: $\underset{k}{\bullet}$ $U(1)_k$ $\square$ $1\ \Phi$

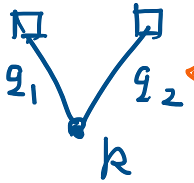
Quiver theories:



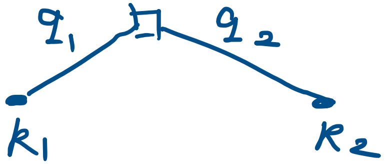
$C_{ij} = \begin{bmatrix} r & k \\ k & s \end{bmatrix}$



Generic theories:



charge



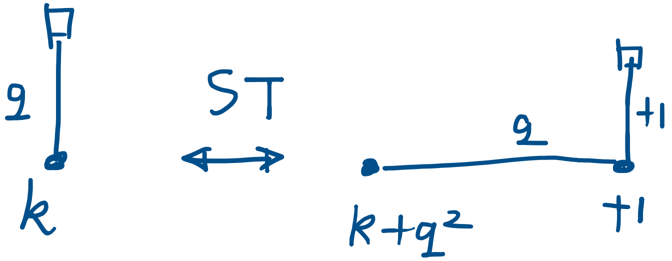
3d dualities

- Gauge the mirror duality -> ST-moves

1 free field <-> U(1) +1 field

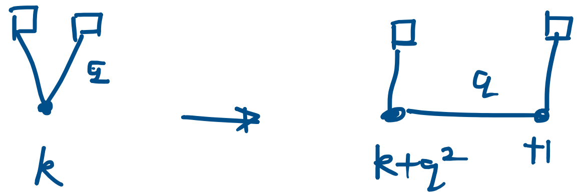
Flavor symmetry $U(1)_F \leftrightarrow U(1)_T$

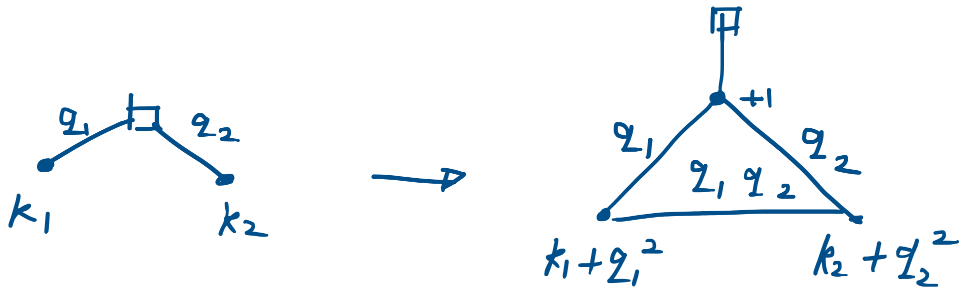
Gauge the U(1)

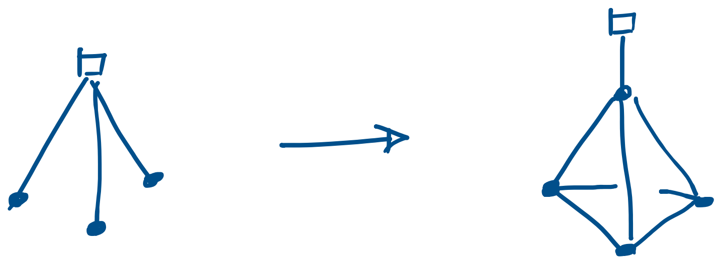


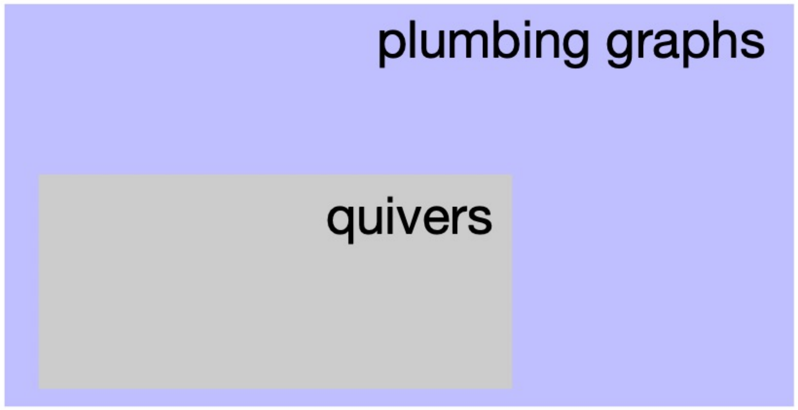
ST-moves: application

- Examples



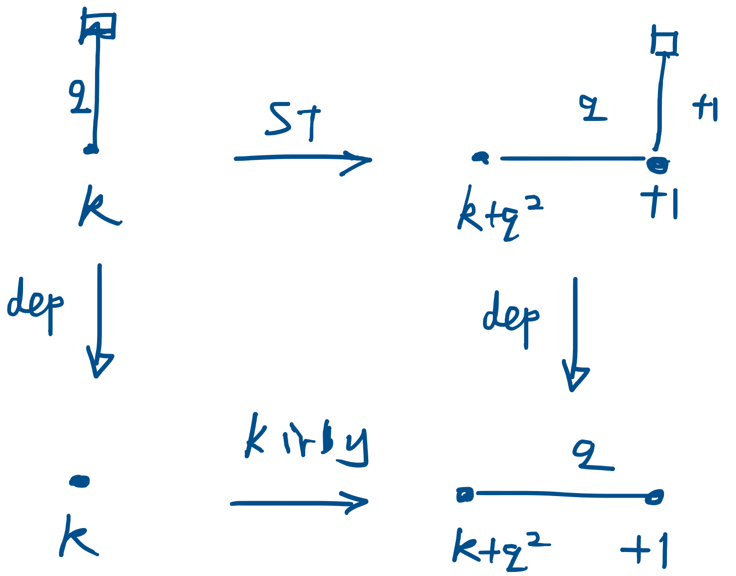






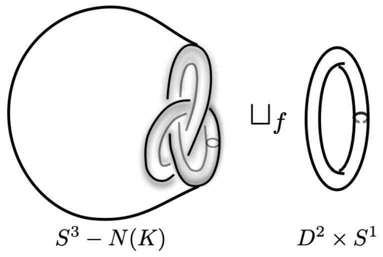
Decoupling

- After decoupling the matter, ST-moves reduce to Kirby moves

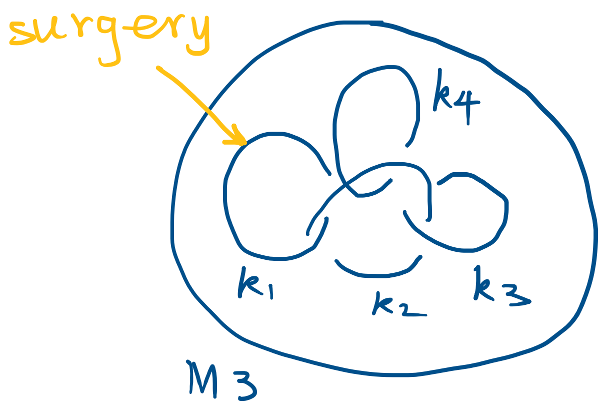


- Why is it a Kirby move?

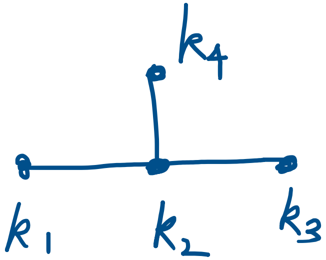
Closed 3-manifolds, T[M_3] theories



- In Gadde, Gukov, Putrov "Fivebranes and 4-mfds" [1306.4320]. Pure plumbing theories are realized by wraping a single M5-brane on closed three-manifolds.



3d T[M3] :

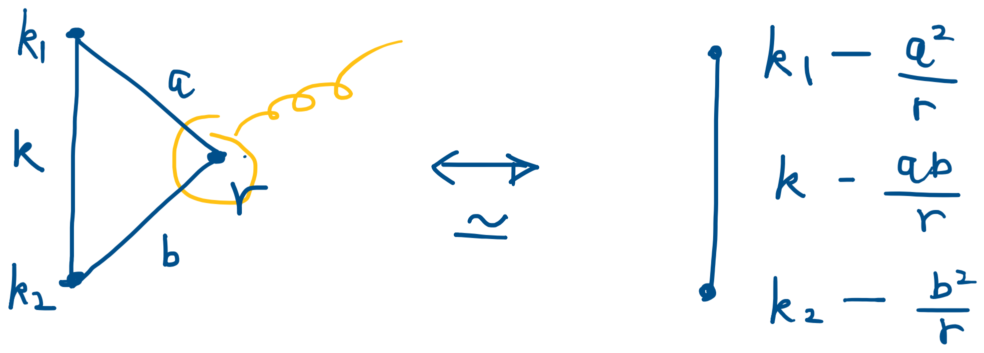


Linking number = CS levels

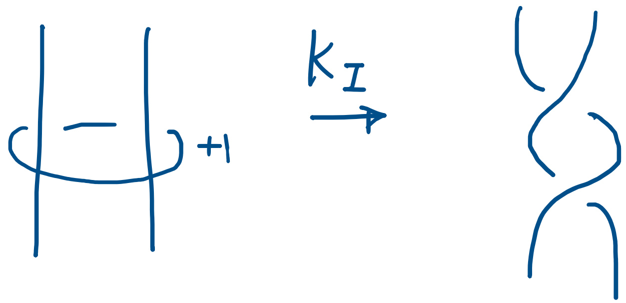
$$L_{ij} = K_{ij}$$

Kirby moves

- Kirby moves are integrating in/out gauge nodes U(1)_k:

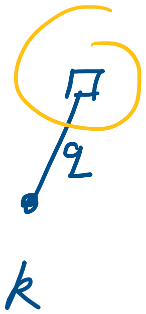


- For 3-mfds, the Kirby-I move is an equivalent surgery.



Question: how to add matters?

- Does the matter $\square$ corresponde to some structure on the 3-mfds?

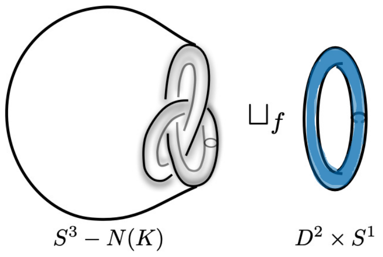


what is this guy ?

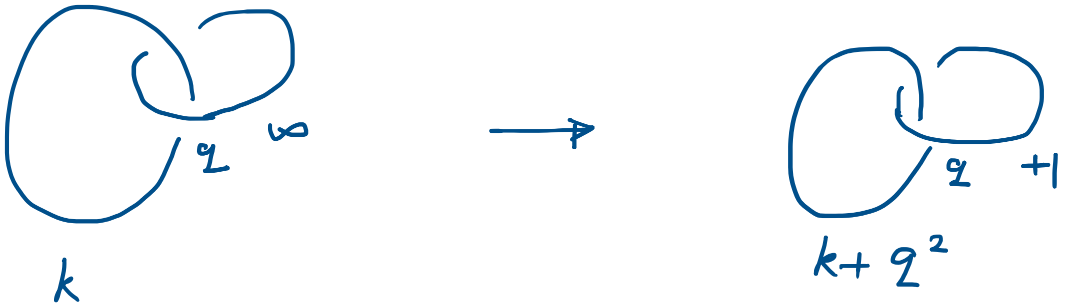
* Is it real ?

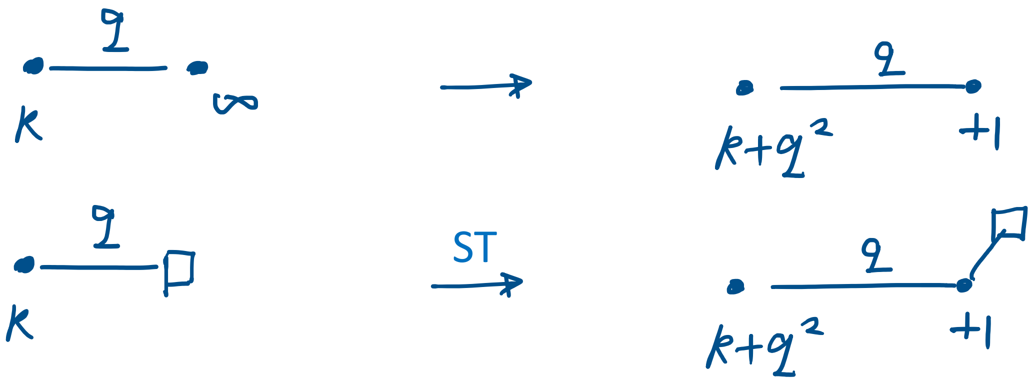
* How to geometrically realize it ?

Rational equivalent surgery



- The identical surgery, and rational equivalent surgery





} looks similar 🙂

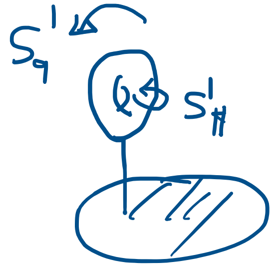
An observation

- Is the matter an circle for identical surgery?

$$\square \overset{?}{\longleftrightarrow} \bigcirc_{\infty}$$

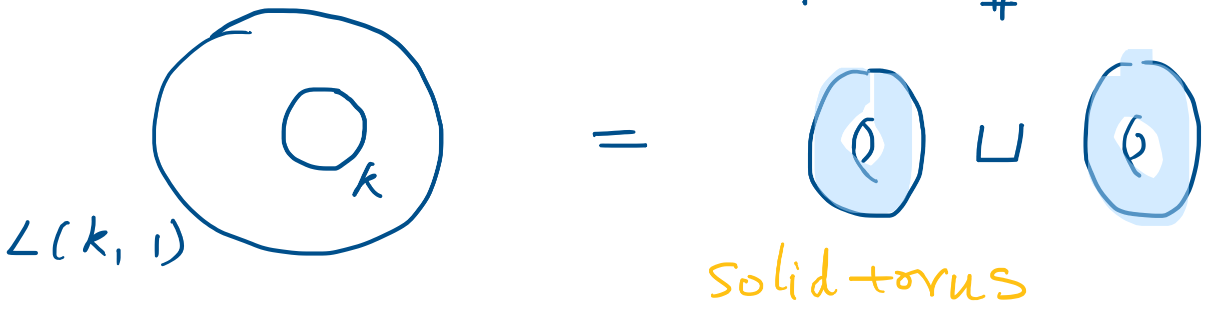
- However, the identical circle can be ignored on 3-mfds and is not physical, while the matter field is physical.
- So, we should do something to make it physical.
- Before that, let us revisit the GGP’s construction using string theory.

Revisit GGP's construction



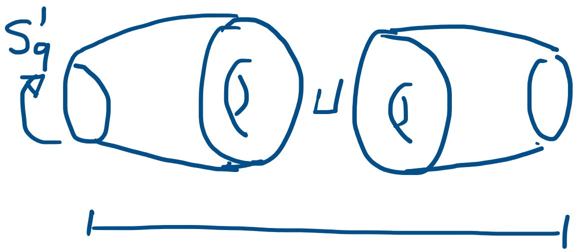
- Lens space L(k,1) in M-theory should be elliptically fibered:

$T^2 = S^1_9 \times S^1_\sharp$

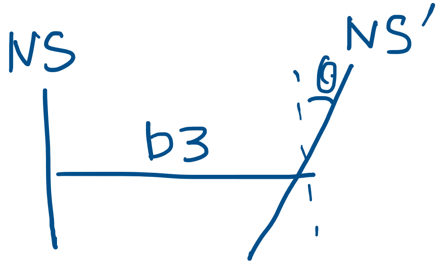


		$S^1\times\mathbb{R}^2$			N_{345}			$I_6\times T^2_{9\sharp}$		
11d	branes	0	1	2	3	4	5	6	9	$\sharp$
M-theory	N_c M5	0	1	2				6	9_A	$\sharp$
IIA	N_c D4	0	1	2				6	9_A	
IIB	N_c D3	0	1	2				6		
IIA	D0									$\sharp$
IIA	D6	0	1	2	3	4	5		9_A	
IIB	D5 $\xrightarrow{S}$ NS5	0	1	2	3	4	5			
M-theory	M5″	0	1	2	3	4			9_A	
IIA	NS5″	0	1	2	3	4			9_A	
IIB	NS5″ $\xrightarrow{S}$ D5	0	1	2	3	4			9_B	
M-theory	M2	0					5		9_A	
IIB	D1 $\xrightarrow{S}$ F1	0					5			

- Putting a M5-brane on it duals to a 3d brane web of U(1)_k



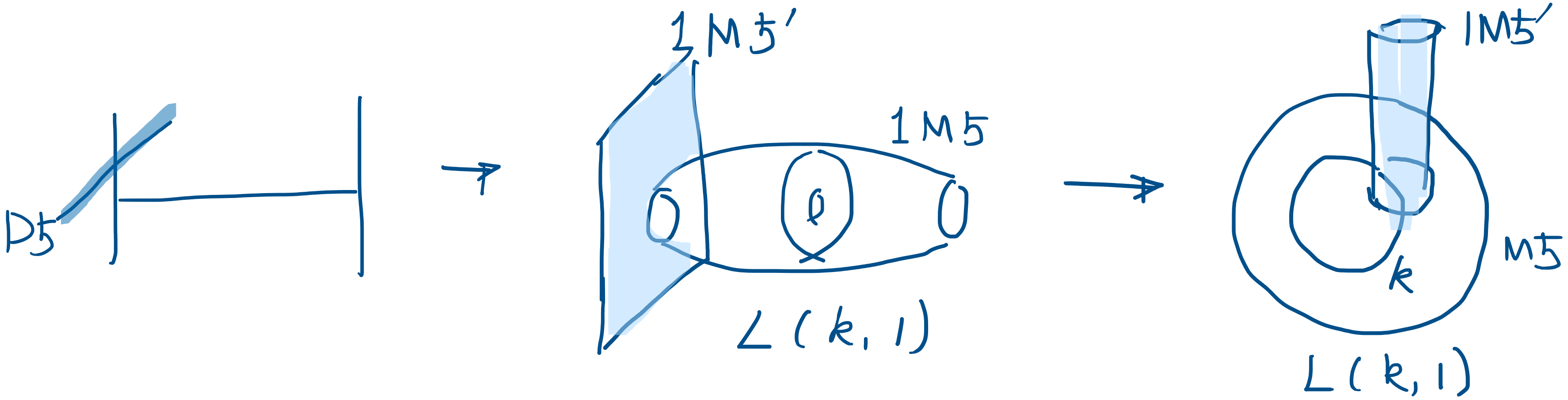
M / IIB

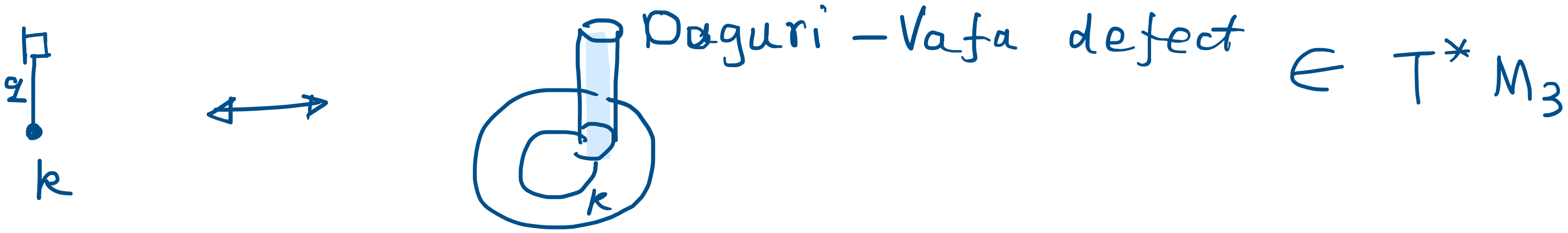


$k = \tan\theta$

OV defect -> matter

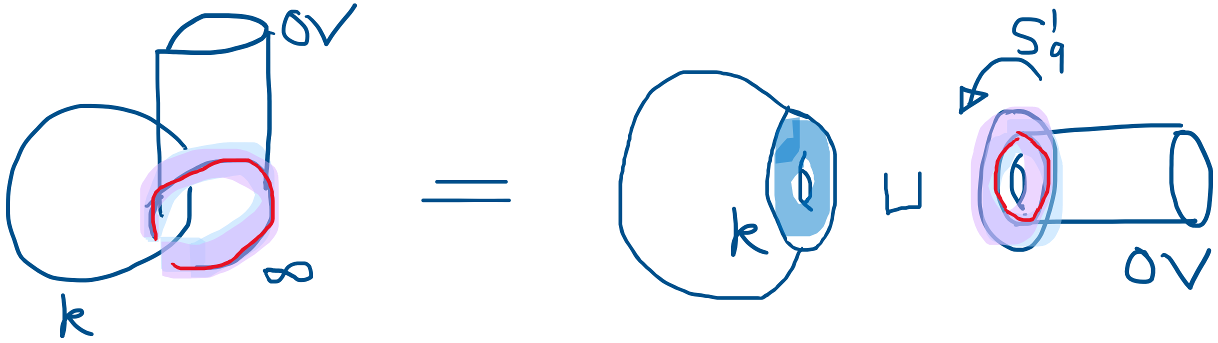
- Adding D5-branes lead to matters





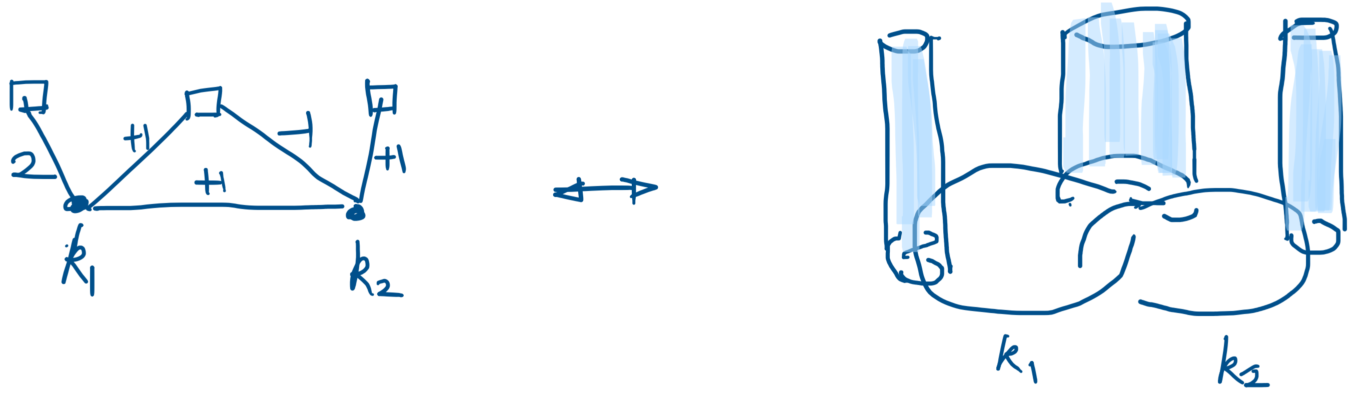
Adding a 1 M5-brane on OV defect in the cotangle bundle realizes a matter field.

- The neighbourd of the intersection is always an idnetical surgery circle:



- The matter circle/intersection has to be S^1_q

- Example:

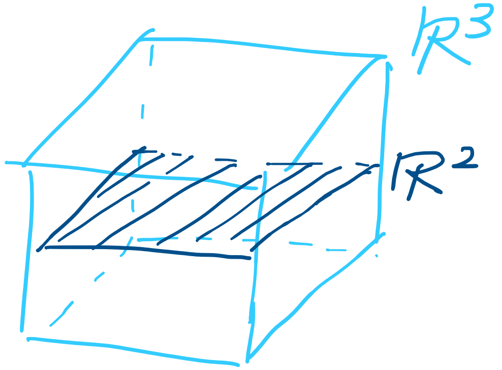


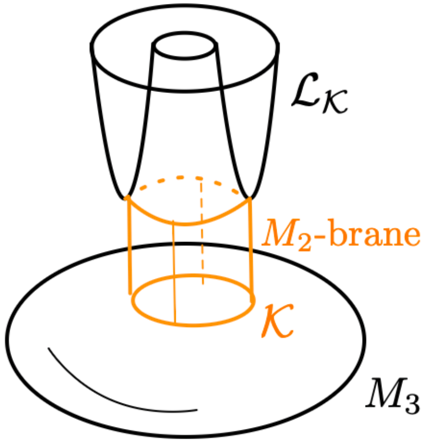
The Ooguri-Vafa construction

- A point to clarify: the OV-defect/brane does really interect with the 3-mfds.

$$\mathcal{L}_K \in T^* M_3 \ , \qquad \mathcal{L}_K = K \times \mathbb{R}^2$$

$$T^* M_3 = M_3 \times \underset{\uparrow \text{ fiber}}{\mathbb{R}^3}, \qquad K \subset M_3, \quad \mathbb{R}^2 \subset \mathbb{R}^3$$





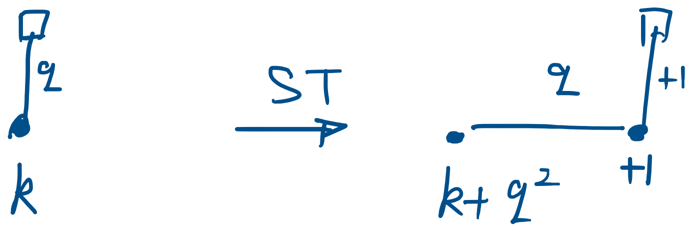
M2-brane : $K \times I$

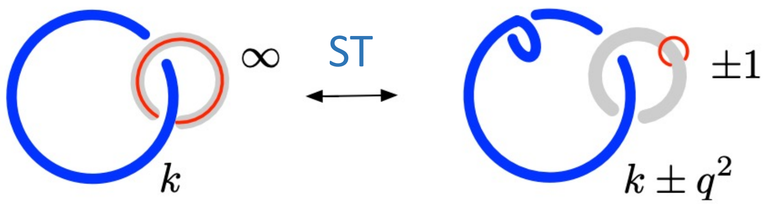
* The M2-brane is a cylinder, and only when it is massless, the L_K and M_3 could kiss each other:

$$\mathcal{L}_K \cap M_3 = K$$

ST-move and 3-mfds

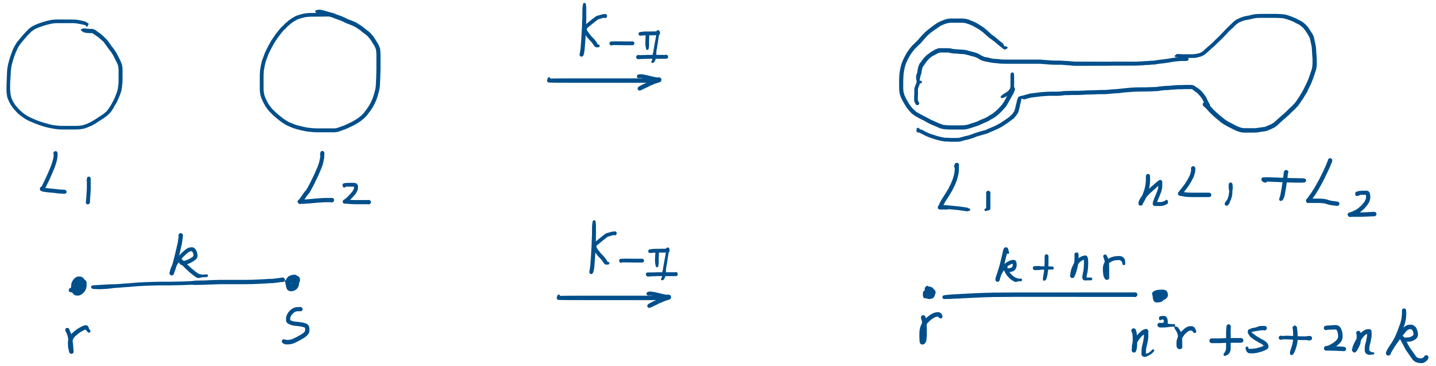
- ST-move is a particular Kirby-I move with an OV-defect/brane:



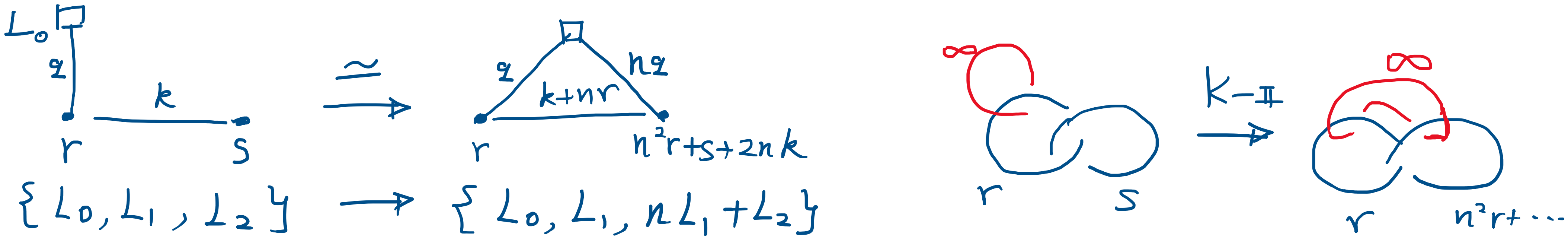


Kirby-II: handle-slides

- Kirby-II is a connected sum of surgery circles (gauge circles):



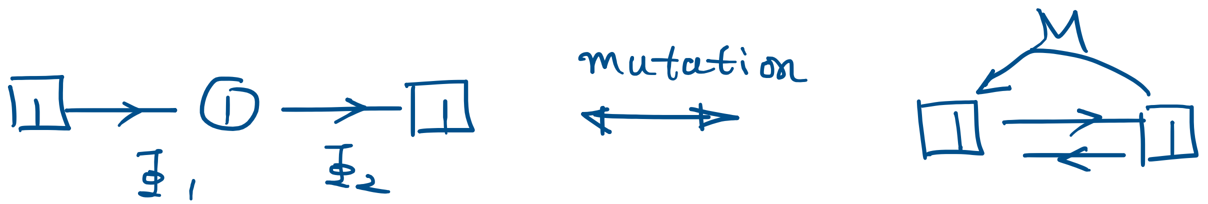
- In the presence of the OV defect (or matter):



- Kirby-II is the linear sum of scalar fields: $\phi_1' = n\phi_2 + \phi_1\,,\, \phi_2' = \phi_2$

Seiberg duality

- SQED-XYZ duality

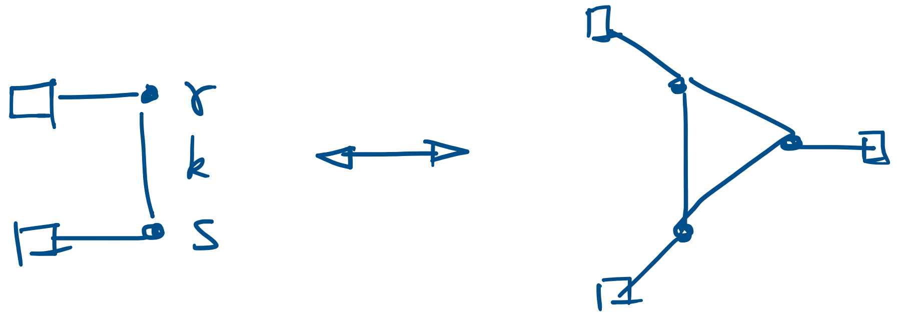


- Superpotential

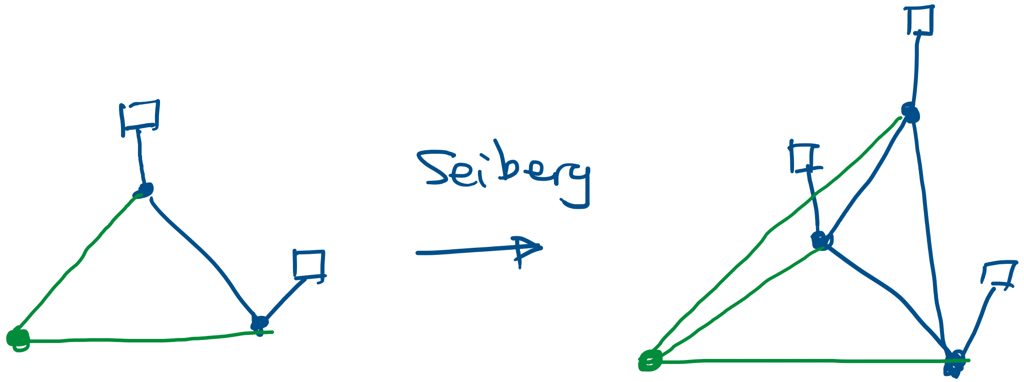
$$W = 0 \qquad\qquad W = \Phi_1 \Phi_2 M.$$

- Flavor symmetry $U(1)_1 \times U(1)_2$

- Gauging these flavor symmetries leads to unlinking, linking, and other two cases.



- Seiberg dualities is local, so it can couple to external nodes.



- Unfortunately, we have not found the geometrical realization of the Seiberg-duality, or in other words, cubic superpotentials.

Dictionary

Quivers	**3d gauge theories**	**3-mfds**
C_{ij}	Mixed CS levels	Linking numbers
Equivalent quivers	Various dualities	Kirby moves w/ OV-branes
$(q,q)_{d_i}$	Matter fields	OV-defects/matter circles
$\sum_{d_i}$	Gauge symmetries	surgery circles/gauge circles

Open questions:

- What is the geometrical realization of Seiberg-dualities?
- It looks that both quivers and knots can be constructed by OV construction. How to directly connect them? The answer may lead to the KQ correspondence.
- Non-abelian theories, and F_K invariants

Thank you!