Twist Fields and Anomalies for non-Invertible Symmetries

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Generalized Symmetries and Charges

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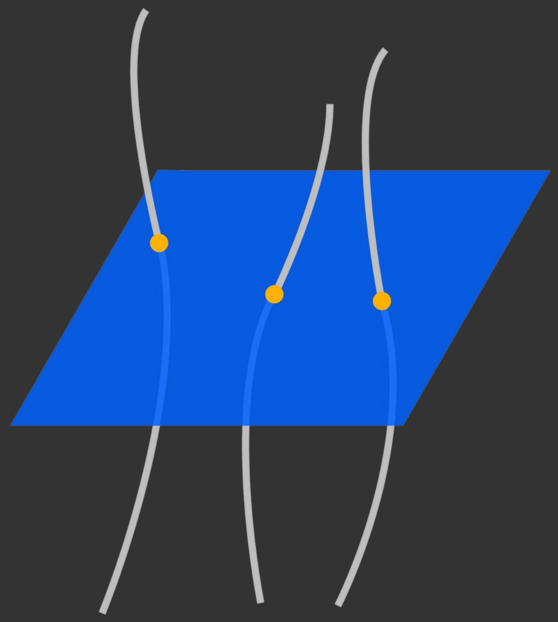

Gaiotto, Kapustin,Seiberg, Willett, 2015

This defines a U(1)-valued topological operator:

$$U_\alpha(\mathcal{M}_{d-p}) = \exp\left(i\alpha \int_{\mathcal{M}_{d-p}} \star j_p \right)$$

Non-invertible Symmetries

One possible generalization is relax the group-like composition rule and allow for a sum. A categorical symmetry:

$$\mathcal{L}_a \times \mathcal{L}_b = \sum_c N_{ab}^c \mathcal{L}_c$$

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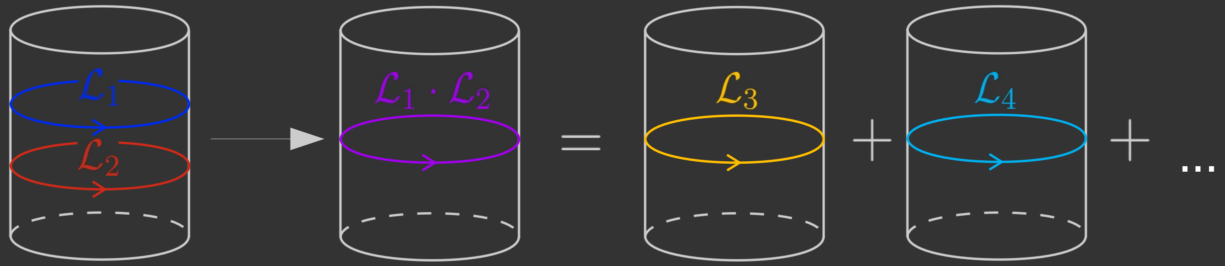
In 2-dimensional CFTs we can have at most codimension-1 operators: lines. In RCFTs internal symmetries are generally represented by Verlinde lines:

Verlinde, 1988



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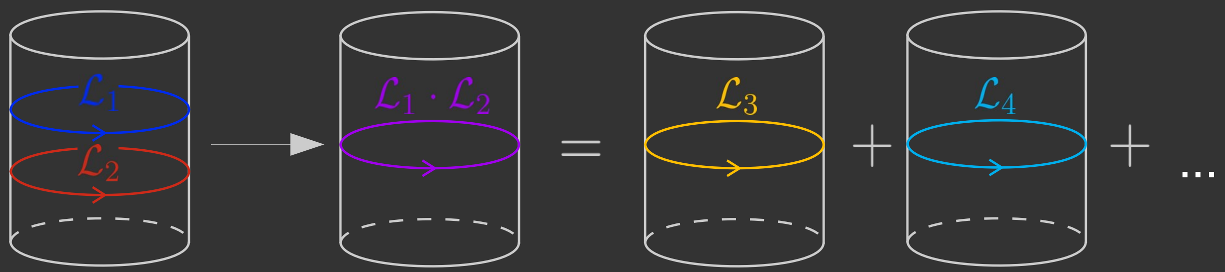


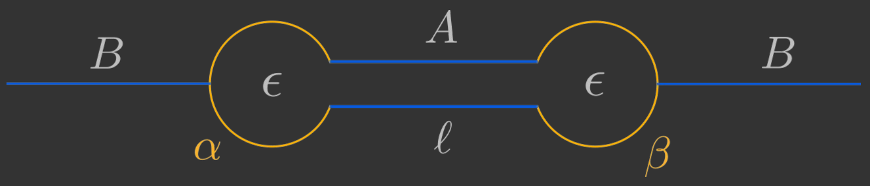
We want to compute Entanglement Entropy of a state in presence of these lines.

Symmetry Resolved EE

Entanglement entropy measures quantum correlations between a region A and its complementary B:

$$\rho_A = \mathrm{Tr}_{\mathcal{H}_B} |\psi\rangle \langle\psi|$$

$$S_A = \lim_{n\to 1} \frac{1}{1-n} \log \mathrm{Tr}\, \rho_A^n$$



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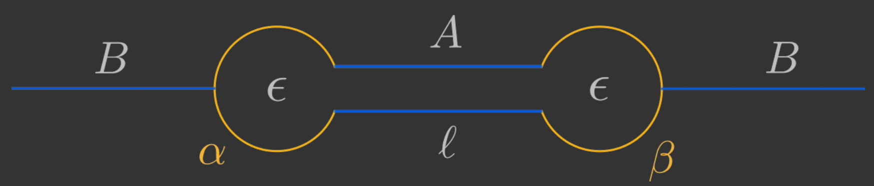

In presence of a global symmetry, Symmetry Resolved Entanglement Entropy accounts for how EE is distributed among the charged sectors of the symmetry.

Goldstein and Sela, 2018

$$\mathcal{Q} = \mathcal{Q}_A \otimes \mathbb{1}_B + \mathbb{1}_A \otimes \mathcal{Q}_B$$

$$\rho_A = \bigoplus_r [P_r \rho_A] = \sum_r p_A[r] \rho_A[r]$$

$$S_A[r] = \lim_{n\to 1} \frac{1}{1-n} \log \mathrm{Tr}\, \rho_A^n[r]$$

$\rho_{A,\mathcal{Q}} =$

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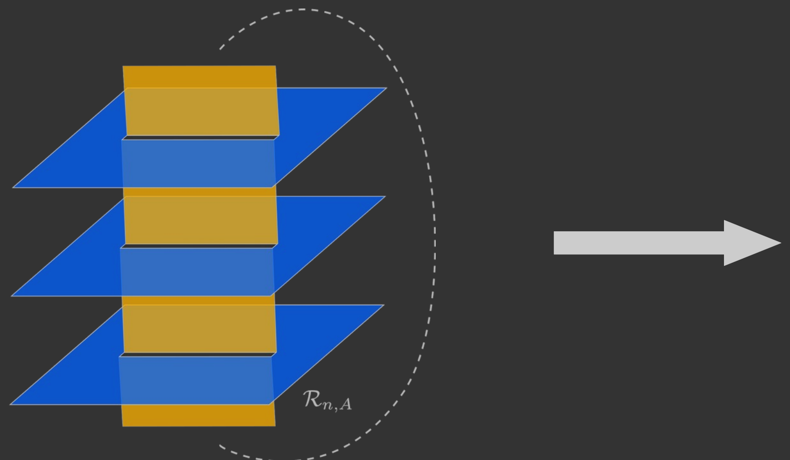
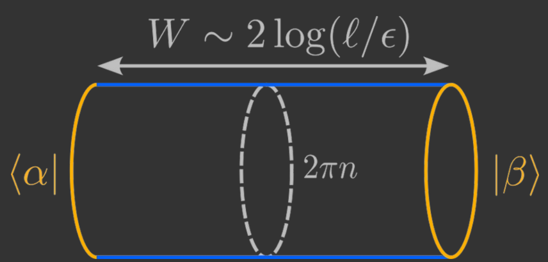
The Replica Trick

We can interpret the replica trick in two ways:

Glue the geometry: Worldsheet approach





Boundary Conformal Field Theory

Kusuki, Murciano, Ooguri, Pal, 2023
PSB, Das, Sierra, Molina-Vilaplana, 2024
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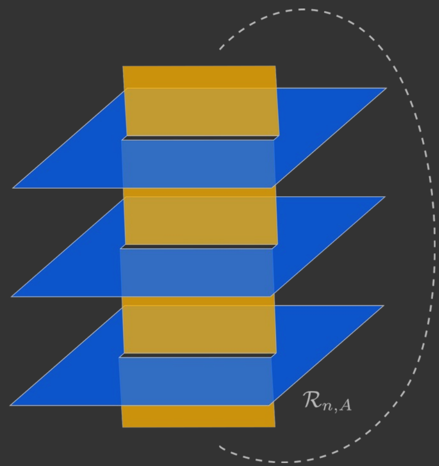

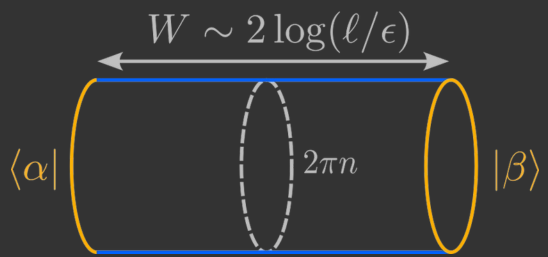

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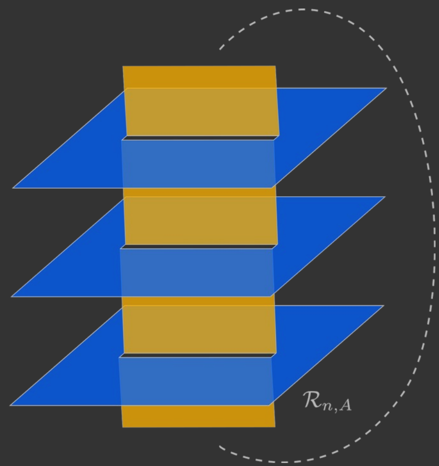

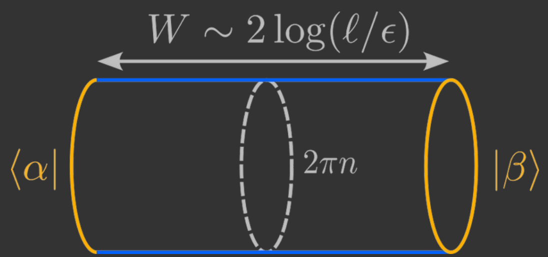

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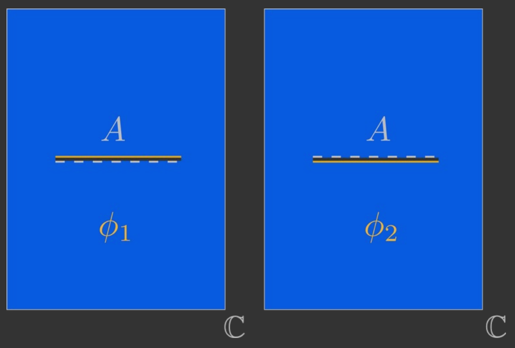
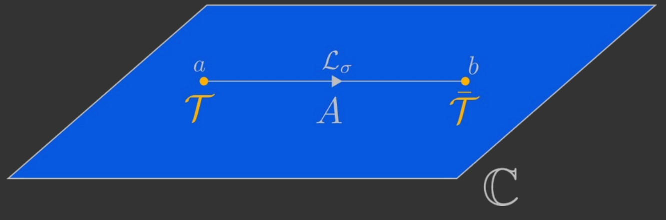
Glue the field content: Target Space approach





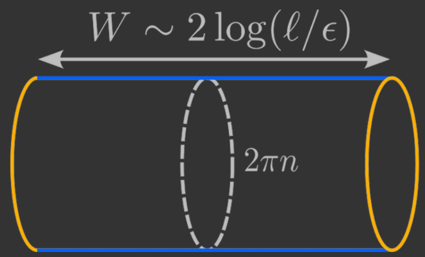
Branch-point Twist Fields

Cardy, Castro-Alvaredo, Doyon, 2007
Goldstein, Sela, 2018

BCFT vs Twist Fields

In the Worldsheet approach the partition function can be written as an amplitude:

$$\mathrm{Tr}[\rho_A^n] = \langle\alpha|$$



$$|\beta\rangle = \mathrm{Tr}\left[q^{n\left(L_0-\frac{c}{24}\right)}\right] = \langle\alpha|\, \tilde{q}^{\frac{1}{n}\left(L_0-\frac{c}{24}\right)}\, |\beta\rangle$$

Kusuki, Murciano, Ooguri, Pal, 2023

With the geometric quantities:

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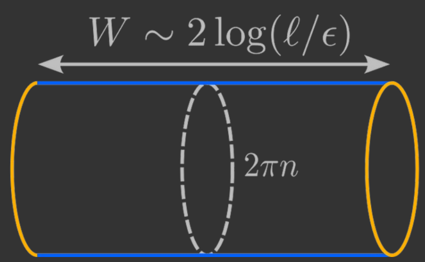

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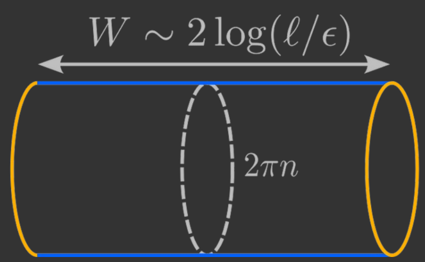

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Which, at leading order in $\varepsilon \ll \ell$ gives the result for entanglement entropy:

$$S_A = \frac{c}{3}\log\frac{\ell}{\epsilon} + \log\langle\alpha|0\rangle + \log\langle 0|\beta\rangle$$

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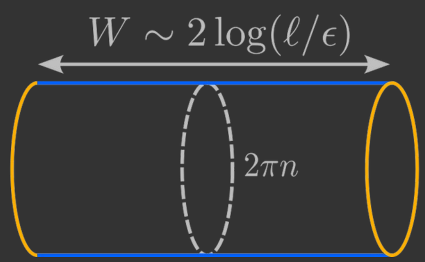

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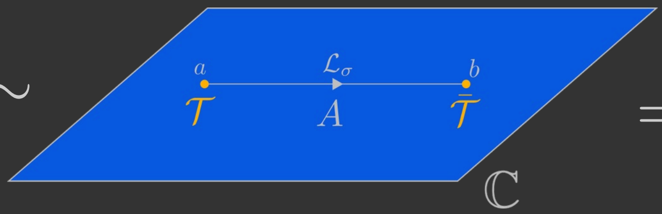
Affleck-Ludwig boundary entropy

Affleck and Ludwig, 1991

In the Target Space approach the partition function takes the form of a conformal correlator:

Cardy, Castro-Alvaredo, Doyon, 2007

$$\mathrm{Tr}[\rho_A^n] \sim$$



$$= \langle \mathcal{T}(0,a)\tilde{\mathcal{T}}(0,b)\rangle_{\mathbb{C}} = \frac{1}{\ell^{2\Delta_{\mathcal{T}}}}$$

Branch-point twist fields are scalar fields of the same conformal dimension

$$\Delta_{\tilde{\mathcal{T}}} = \Delta_{\mathcal{T}} = \frac{c}{12}\left(n - \frac{1}{n}\right)$$

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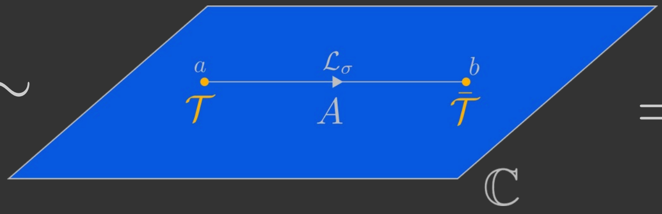

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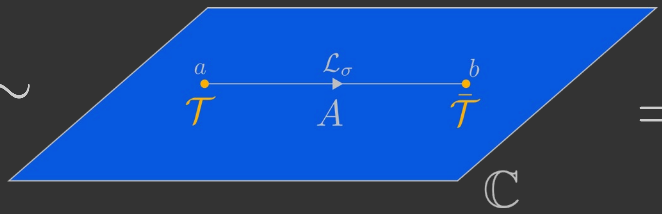

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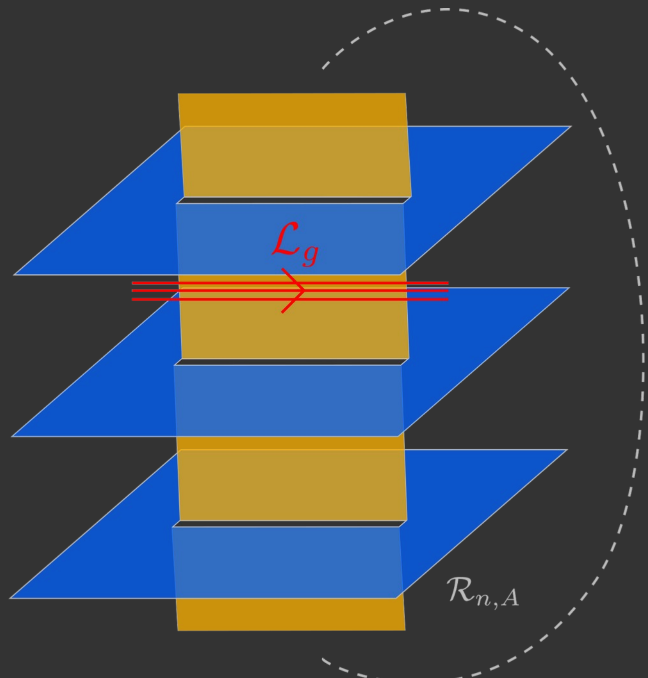
This gives the usual result for entanglement entropy

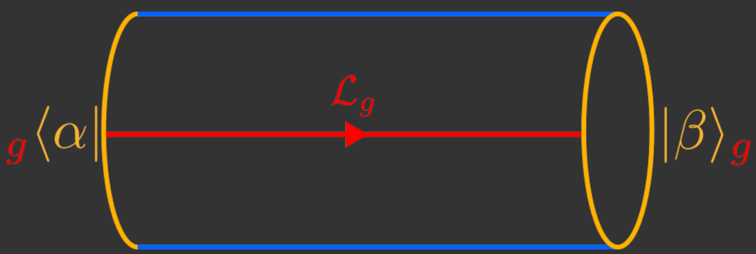
$$S_A^{(n)} = \frac{c}{6}\frac{n+1}{n}\log\frac{\ell}{\epsilon} \quad \xrightarrow[n\to 1]{} \quad \frac{c}{3}\log\frac{\ell}{\epsilon}$$

Twist Fields for SREE

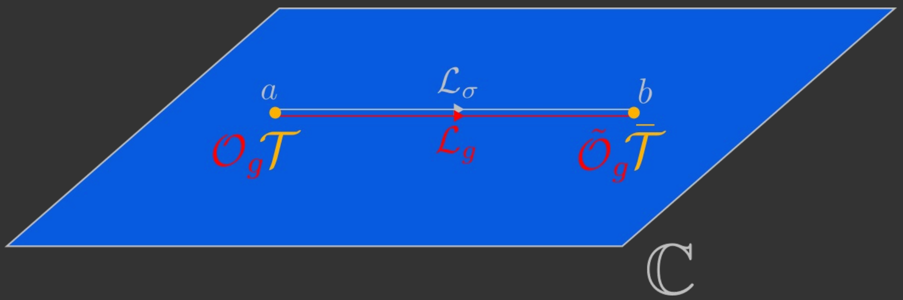
Symmetry resolve involves computing charged moments:

Goldstein, Sela, 2018





Symmetry-invariant boundary states



Symmetry-defect operators dressing twist fields

$$Z^{(n)}[g] = \mathrm{Tr}(\mathcal{L}_g \rho_A^n)$$

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Anyonic Sectors

For a categorical symmetry, generalized charges are associated with the irreps of the tube Algebra $Tub(\mathcal{C})$. From the SymmTFT picture, these irreps are in one to one correspondence with anyons of the Drienfield Center.

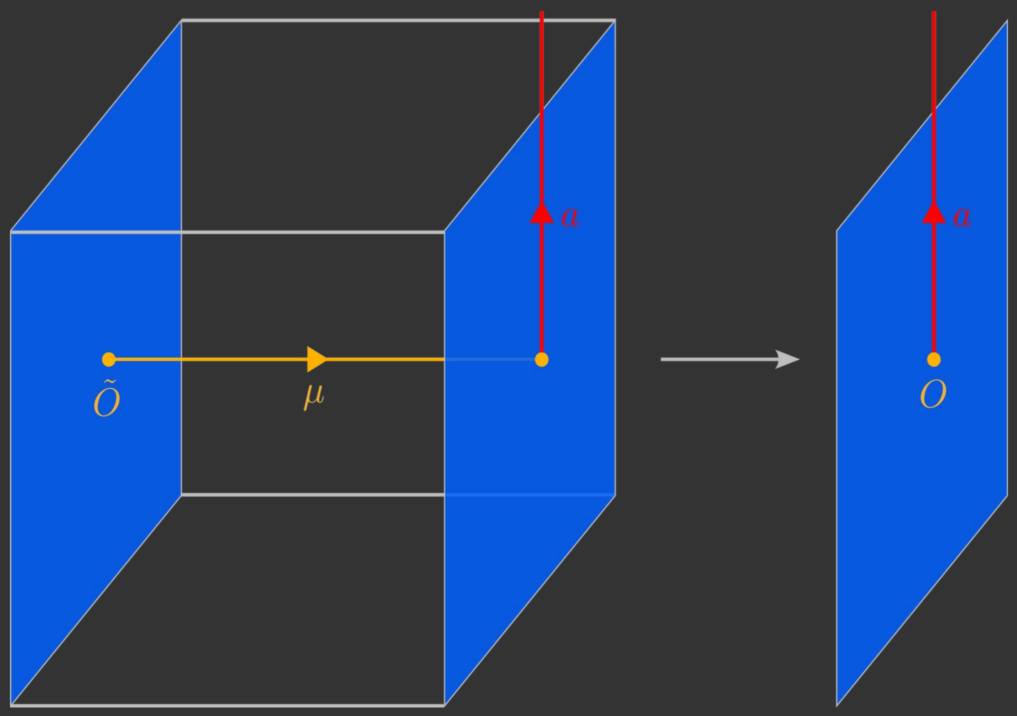
Freed, Moore, Teleman, 2022

In diagonal RCFTs

$$\mathcal{D}(\mathcal{C}) = \mathcal{C} \boxtimes \mathcal{C}$$

$$\mu = c \otimes d$$

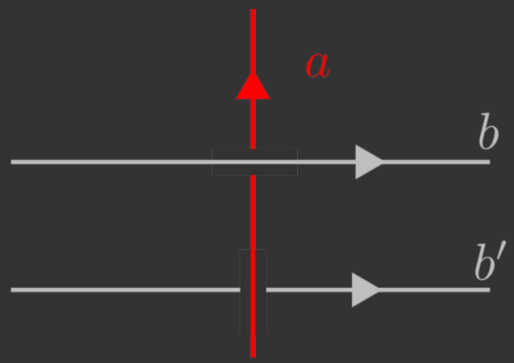
Charged sectors = Anyonic Sectors



The projectors into anyonic sectors can be written in terms of the 2-dimensional category:

Lin, Okada, Seifnashri, Tachikawa, 2022

$$P^{\mu} = \sum_{a} P_a^{(c,d)} = \sum_{a,b,b'} S_{1c} S^*_{bc} S_{1d} S^*_{b'd}$$



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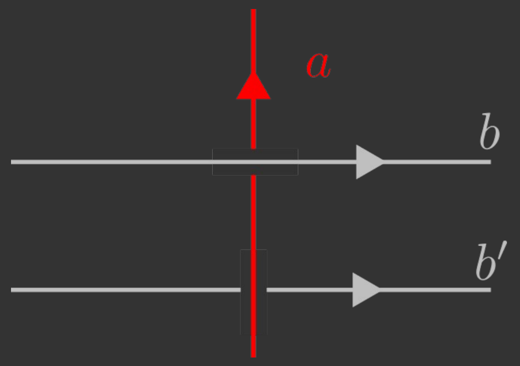
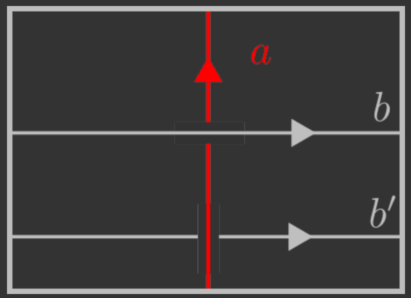
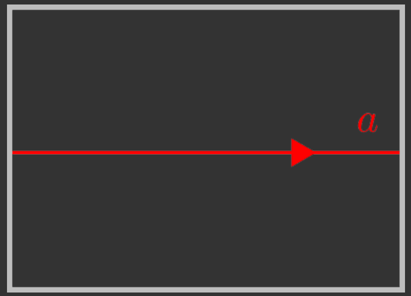


Introducing the projectors on the torus partition function we can simplify the expressions using the modular data of the RCFT and the fusion rules:

$$\mathrm{Tr}[P^{\mu}\rho] = \sum_{a,b,b'} S_{1c} S^*_{bc} S_{1d} S^*_{b'd}$$

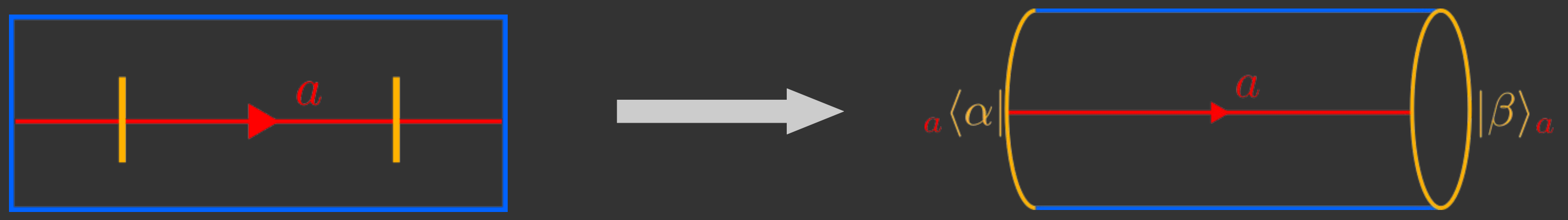


$$\sim \sum_a \frac{N^c_{ad}}{|\mathcal{C}|} \frac{d_c d_d}{d_a}$$



The BCFT Approach

To compute entanglement entropy we have to cut the interval:



Symmetry must be compatible with the cut, we need C-symmetric boundary conditions:

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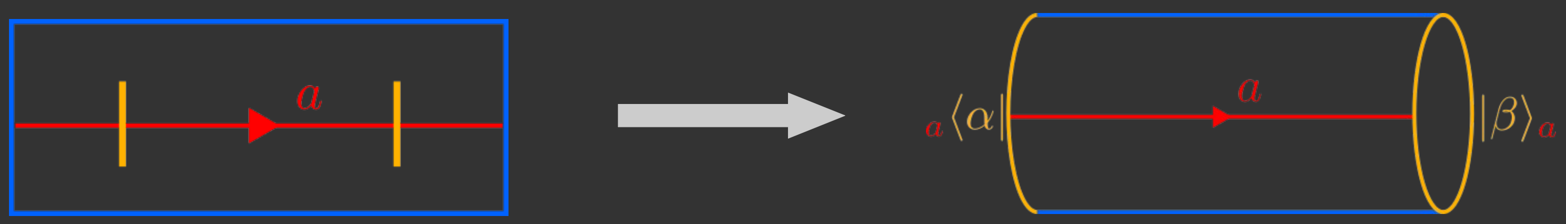

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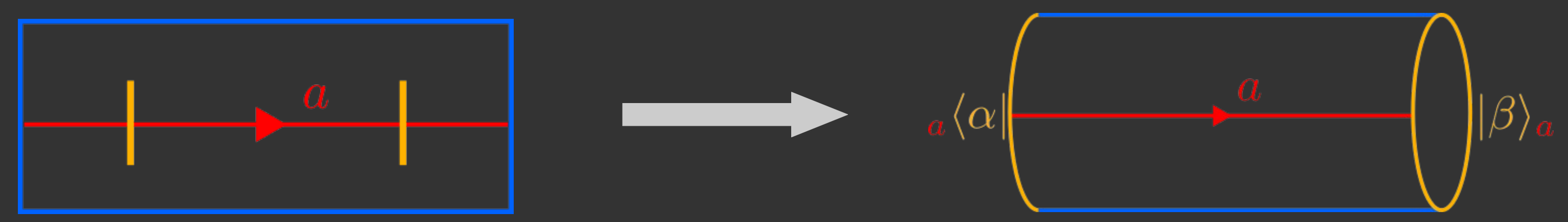

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Choi, Rayhaun, Sanghavi, Shao, 2023

$$\mathcal{L}_a |\mathcal{B}\rangle = \langle \mathcal{L}_a \rangle |\mathcal{B}\rangle$$ Strongly symmetric

$$\mathcal{L}_a |\mathcal{B}\rangle = |\mathcal{B}\rangle + \dots$$ Weakly symmetric

If there are not such conditions we cannot symmetry resolve. This is a signature of an Anomaly.

Each twisted sector contributes as:

$$\frac{d_\mu \langle \mu, a \rangle}{d_a |\mathcal{C}|} g^a_\alpha \bar{g}^a_\beta \tilde{q}^{\frac{1}{n}\left(h^a_0 - \frac{c}{24}\right)}$$

$$d_\mu \langle \mu, a \rangle = N^c_{ad} d_d d_c$$

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And h^0_a is the conformal weight of the lowest primary in the twisted sector, being the smallest $h^{\mathbb{1}}_0 = 0$ the identity operator. $\longrightarrow$ Sum over a is dominated by $\mathbb{1}$

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$$S_A[\mu] = \frac{c}{3}\log\frac{\ell}{\epsilon} + \log\frac{d_\mu\langle \mu, \mathbb{1}\rangle}{|\mathcal{C}|} + \log g_\alpha + \log \bar{g}_\beta$$

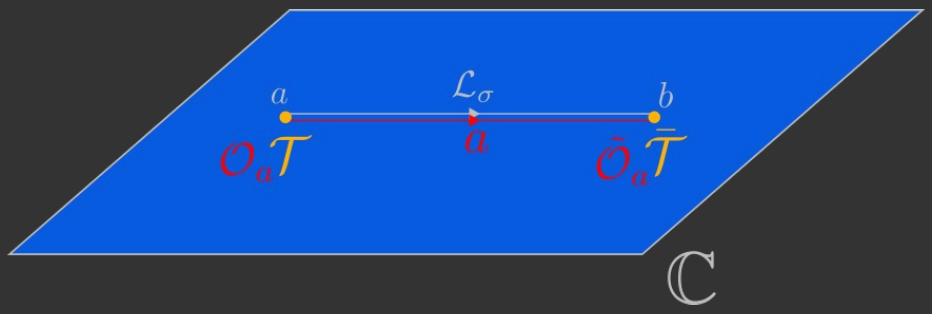
Das, Molina-Vilaplana, PSB, 2024

For abelian group-like symmetries

$$d_\mu \langle \mu, \mathbb{1}\rangle = 1$$ → Entanglement equipartition

Target Space Approach

In the target space approach we have to dress the branch-point twist field with a defect operator.



These are fields on the twisted Hilbert space of the line $\mathcal{O}_a \in \mathcal{H}_a$. Both of them have the same conformal dimension and is the lowest in that Hilbert space. They have to be scalar fields.

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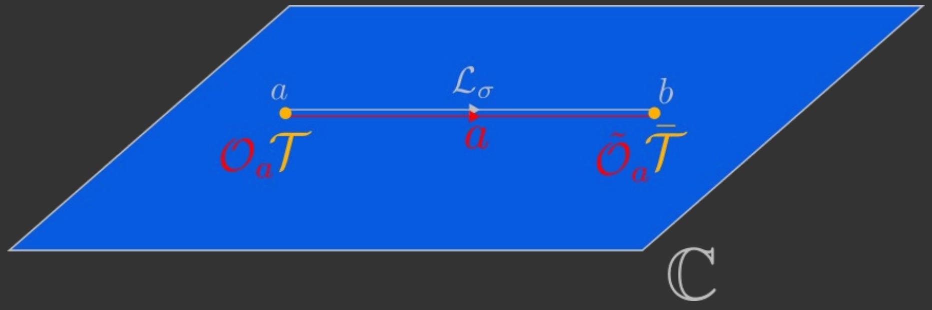

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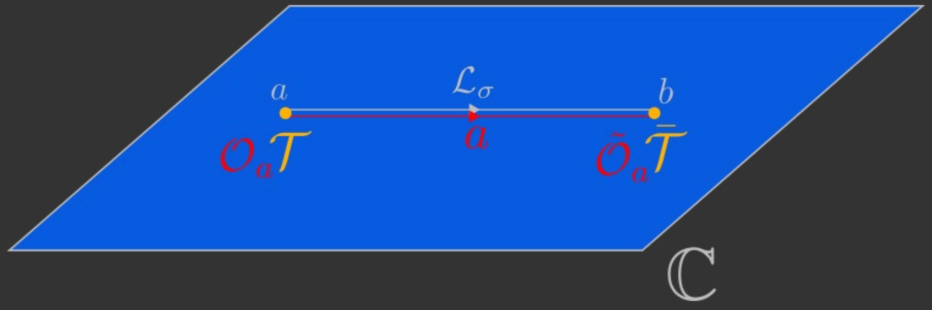

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$$\langle \phi(z_1, \bar{z_1})\phi(z_2, \bar{z_2})\rangle = \frac{1}{|z_{12}|^{2\Delta_\phi}} e^{2i\theta s_\phi}$$

The correlator picks an imaginary part if $s_\phi \neq 0$, and so thus SREE. If there are no scalar defect fields symmetry resolution cannot be performed. This is a signature of an Anomaly.

Each twisted sector then contributes as:

$$\frac{d_\mu \langle \mu, a\rangle}{d_a |\mathcal{C}|}\langle \mathcal{T}_a \tilde{\mathcal{T}}_a\rangle_{\mathbb{C}} \sim \frac{d_\mu \langle \mu, a\rangle}{d_a |\mathcal{C}|}\left(\frac{\ell}{\epsilon}\right)^{-2\Delta_{\mathcal{T}}-2\frac{\Delta_{\mathcal{O}_a}}{n}} \qquad \Delta_{\mathcal{O}_a} = 2h_0^a$$

The sum over a is again dominated by the identity sector, giving the familiar result:

$$S_A[\mu] = \frac{c}{3}\log\frac{\ell}{\epsilon} + \log\frac{d_\mu\langle \mu, \mathbb{1}\rangle}{|\mathcal{C}|}$$

Which is the same as the one obtained with the BCFT approach appart from the Aflleck-Ludwig boundary entropy.

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μ	$d_\mu\langle\mu,\mathbb{1}\rangle$
$\mathbb{1}\otimes\mathbb{1}$	1
$\mathbb{1}\otimes W$	1
$W\otimes\mathbb{1}$	φ
$W\otimes W$	φ

The Ising Category

The Ising Category is contains three elements

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No C-symmetric states

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No C-symmetric states

Twist Fields

$$\mathcal{H}_\eta = \{\psi_{(\frac{1}{2},0)}, \bar{\psi}_{(0,\frac{1}{2})}, \mu_{(\frac{1}{16},\frac{1}{16})}\}$$

$$\mathcal{H}_N = \{s_{(\frac{1}{16},0)}, \bar{s}_{(0,\frac{1}{16})}, \Lambda_{(\frac{1}{2},\frac{1}{16})}, \bar{\Lambda}_{(\frac{1}{16},\frac{1}{2})}\}$$

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The symmetry is anomalous

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Conclussions

- We have generalized composite branch-point twist fields for categorical symmetries and computed SREE both in the worldsheet approach using BCFT and in the target space approach, obtaining the same result.
- Even though one can insert the flux, not every dressed operator or boundary is suitable to symmetry resolve. One must be careful with anomalies.
- Entanglement equipartition is broken by categorical symmetries. Even for non-abelian symmetries we believe the origin is categorical.
- There has been some controversy in the literature regarding SREE for categorical symmetry regarding the BCFT approach. We hope to clarify confussions presenting the paralell twist field approach.

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THANK YOU!