Warm-up: A quick review on superstring theory

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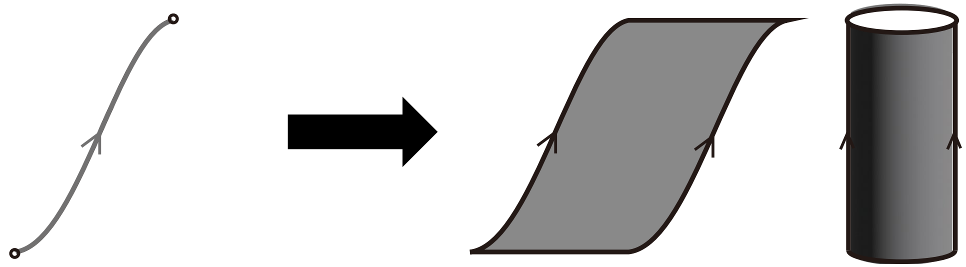

$$S_{\mathrm{pp}} = -m \int d\tau \sqrt{-\eta_{\mu\nu}\dot{X}^{\mu}X^{\nu}} \qquad S_{\mathrm{NG}} = -\frac{1}{2\pi\alpha'}\int_M d\tau d\sigma \sqrt{-\det\left(\eta_{\mu\nu}\partial_a X^{\mu}\partial_b X^{\nu}\right)}$$

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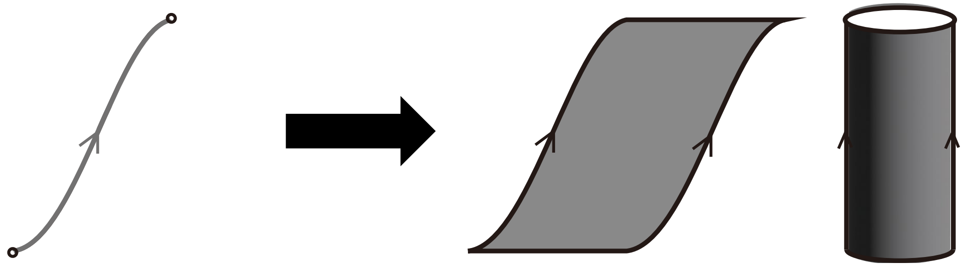

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String Theory is a **sigma model** on the worldsheet. It turns out string theory can be described by a **free CFT** on the worldsheet:

Free Boson

$$S_{\mathrm{P}} = \frac{1}{2\pi\alpha'}\int d^2 z \partial X^{\mu}\bar{\partial}X_{\mu} + \frac{1}{2\pi}\int d^2 z\left(b\bar{\partial}c + \tilde{b}\partial\tilde{c}\right) + \lambda\chi$$

Ghost Fields

Topological Term

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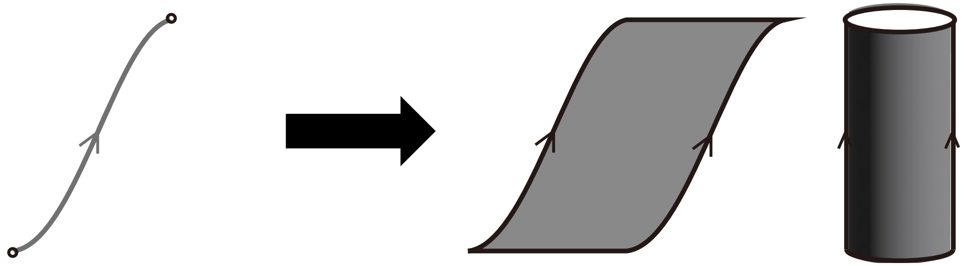

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Ghost Fields

Topological Term

X^{μ}: Rieman surface $\hookrightarrow$ our spacetime

b, c: fix the **diff** $\times$ **weyl** gauge

χ: interactions $\Leftrightarrow$ worldsheet topologies

Unlike QFT, string theory's interactions are **intrinsic** and **unique**.

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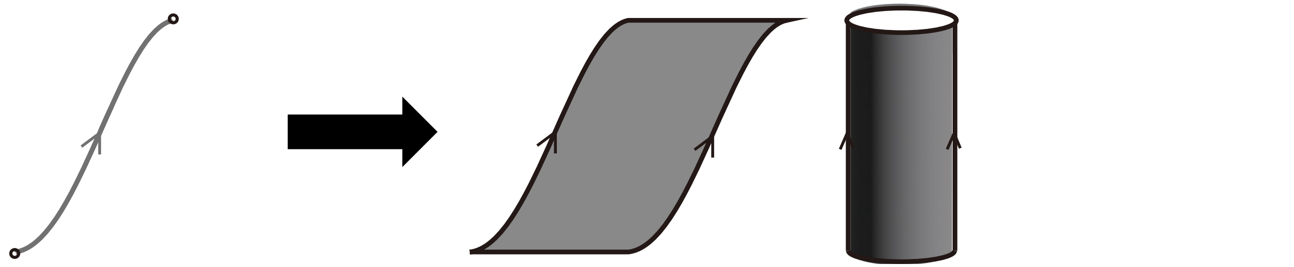

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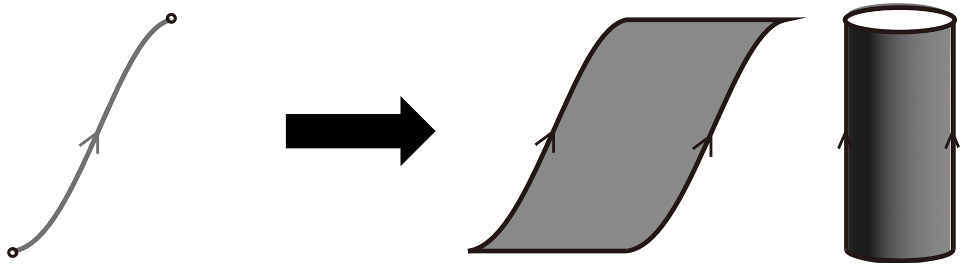

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To avoid conformal anomalies, central charge should be zero, which implies **D=26, 10**

String Amplitudes: Bosonic String

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Tachyon $|0;k\rangle \cong :e^{ik\cdot X(0,0)}:$

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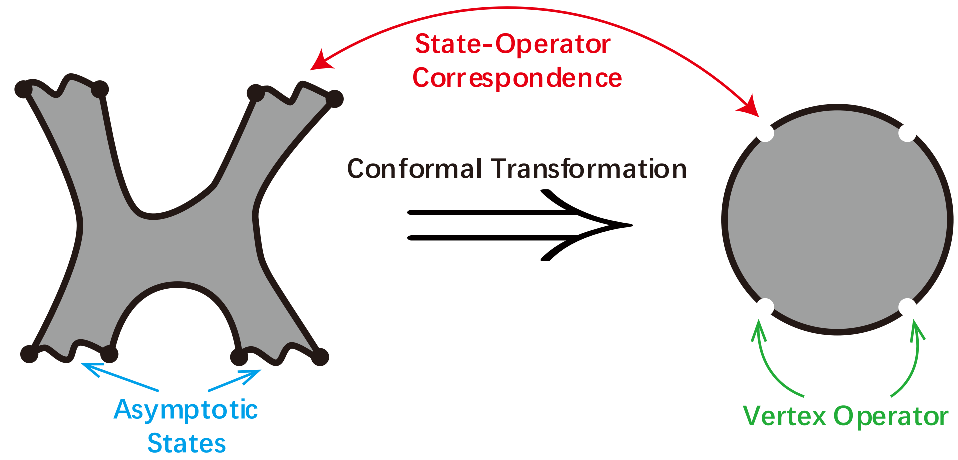
b, c ghosts make the relationship between U and V very simple:

$$V = cU$$



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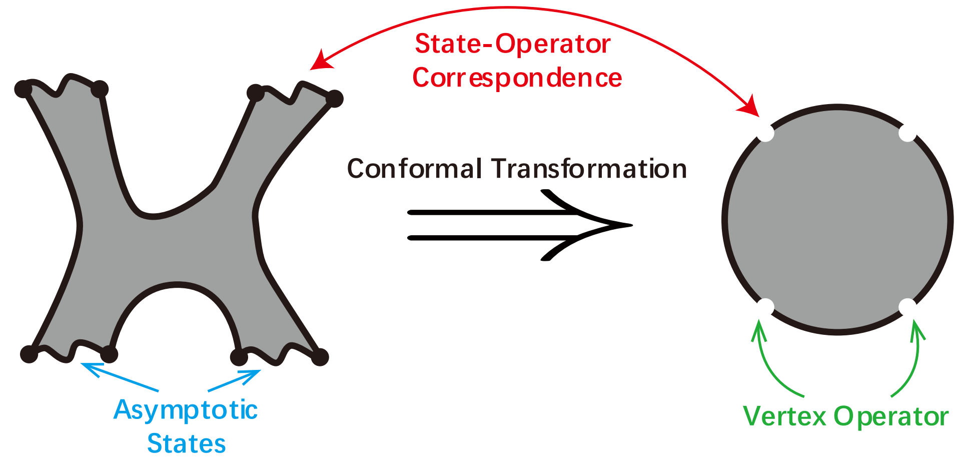

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$$S_{j_1\ldots j_n}(k_1,\ldots,k_n) = \sum_{\substack{\text{compact}\\ \text{topologies}}} \int \frac{[dXdg]}{V_{\text{diff}\times\text{Weyl}}} \exp(-S_X - \lambda\chi) \prod_{i=1}^{n} \int d^2\sigma_i g(\sigma_i)^{1/2} V_{j_i}(k_i,\sigma_i)$$

$$\sim e^{-\lambda\chi} \int_{\mathcal{M}_{g,n}} d^{\mu}t \int \frac{d^2z_1\cdots d^2z_n}{V_{\text{CKG}}} \langle V_1 \, U_2\cdots U_{n-2} \, V_{n-1}V_n \rangle + \cdots$$

Moduli Space

Unintegrated Vertex Operator

Topological Expansion

Fix 3 points on the sphere

Spherical Topology

Integrated Vertex Operator

non-tivial Topologies

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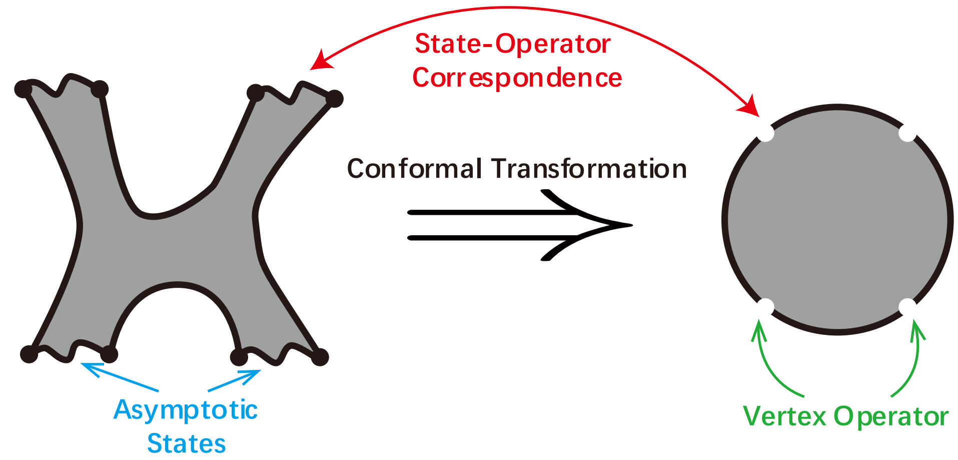

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$\int_{\mathcal{M}_{g,n}} d^{\mu}\, t$: integrate over all complex structures

$e^{\lambda\chi}$: sum over worldsheet topologies

$\int d^2 z$: Amplitudes independent of worldsheet coordinates

V_{CKG} : Conformal symmetries help us fix some points

V: inserted at fixed punctures

U: integrated over the worldsheet

$\langle\cdots\rangle$: Tree-level correlation functions can be computed using the OPE

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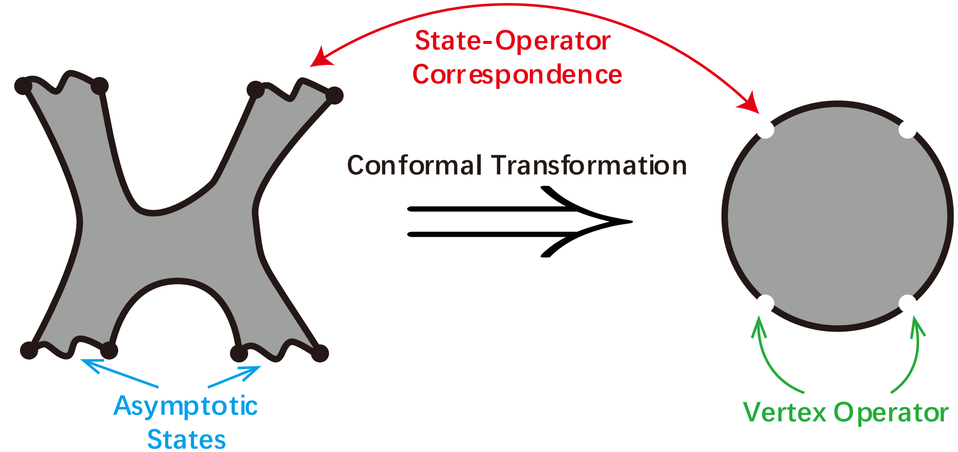

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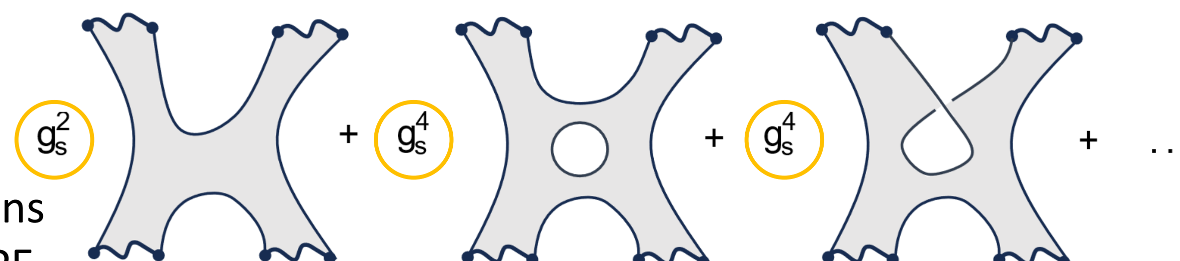

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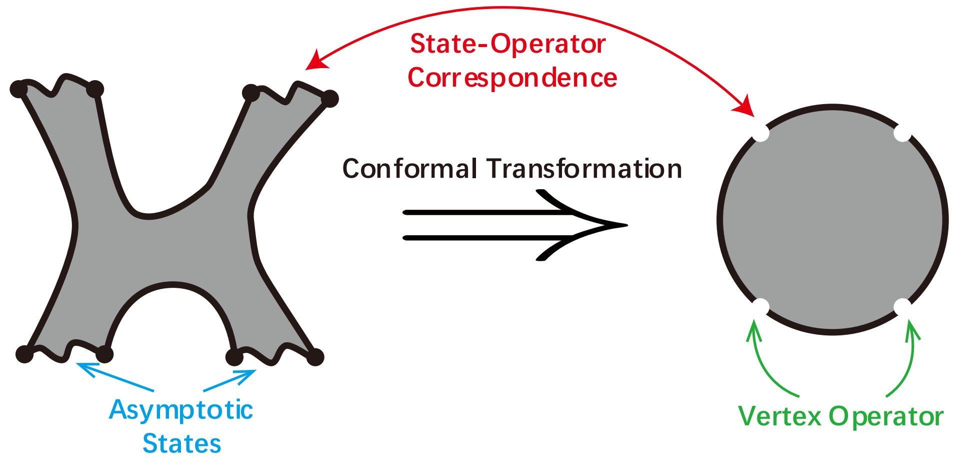

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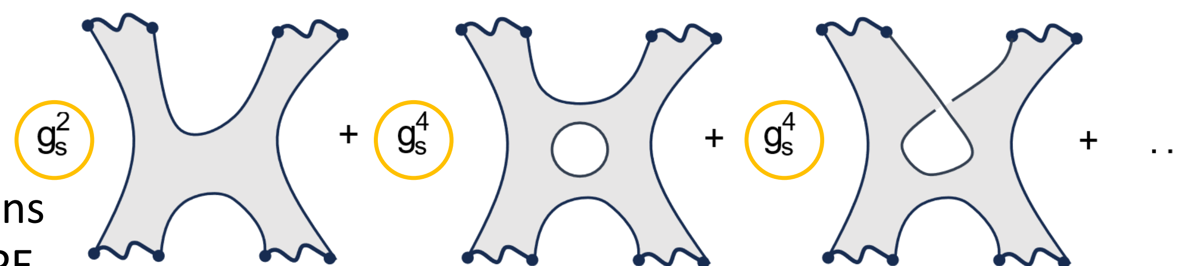
Moduli Space; Unintegrated Vertex Operator; Topological Expansion; Fix 3 points on the sphere; Spherical Topology; Integrated Vertex Operator; non-tivial Topologies



QFT: off-shell correlation function —LSZ Formula→ on-shell amplitudes

String Theory: we only know how to define the on-shell amplitudes directly!

Superstring Theory

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Bosonic String

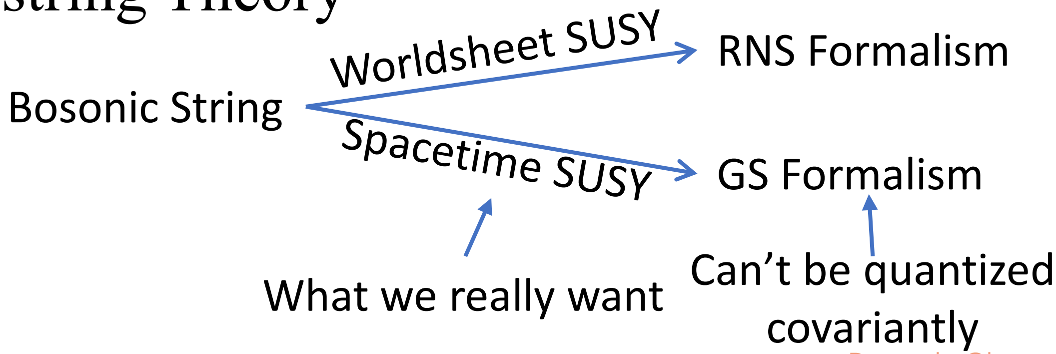
Worldsheet SUSY → RNS Formalism

Spacetime SUSY → GS Formalism

What we really want

Can't be quantized covariantly

Superstring Theory



$$S_{\mathrm{RNS}} = \frac{1}{2\pi}\int \mathrm{d}^2 z\left(\frac{2}{\alpha'}\partial X^{\mu}\overline{\partial} X_{\mu} + \psi^{\mu}\overline{\partial}\psi_{\mu} + b\overline{\partial}c + \beta\overline{\partial}\gamma\right) + \mathrm{c.c.}$$

Free Boson

Free Fermion

Fermionic Ghost

Bosonic Ghost

Superstring Theory

Bosonic String → (Worldsheet SUSY) → RNS Formalism

Bosonic String → (Spacetime SUSY) → GS Formalism

Spacetime SUSY: What we really want

GS Formalism: Can't be quantized covariantly

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- $\frac{2}{\alpha'}\partial X^\mu \bar{\partial} X_\mu$: Free Boson
- $\psi^\mu \bar{\partial}\psi_\mu$: Free Fermion
- $b\bar{\partial}c$: Fermionic Ghost
- $\beta\bar{\partial}\gamma$: Bosonic Ghost

ψ: spinor on the **worldsheet**

NS sector: $\psi(\sigma + 2\pi) = -\psi(\sigma)$

R sector: $\psi(\sigma + 2\pi) = \psi(\sigma)$

β, γ: fix **Super diff** $\times$ **weyl** gauge

But $\mathcal{H}_{\mathrm{CQ}}$ is non-SUSY!

1-loop modular invariance

$\Downarrow$

We need **GSO projection**

$\Downarrow$

Project $\mathcal{H}_{\mathrm{CQ}}$ to SUSY part

$\Downarrow$

Type IIA\B superstring

SUSY is hidden, not broken!

Superstring Theory

Bosonic String — Worldsheet SUSY → RNS Formalism

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What we really want (→ Spacetime SUSY)

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$m^2 = 0$	Type IIA	Type IIB
R-R gauge fields IIA: $\Omega_1 \oplus \Omega_3, 8 \oplus 56$ IIB: $\Omega_0 \oplus \Omega_2 \oplus \Omega_4, 1 \oplus 28 \oplus 35$	$\lvert\dot{\alpha}; -\rangle_{\mathrm{R}} \otimes \lvert\alpha; +\rangle_{\mathrm{R}}$	$\lvert\alpha; +\rangle_{\mathrm{R}} \otimes \lvert\alpha; +\rangle_{\mathrm{R}}$
dilaton, B-field, graviton $1 \oplus 28 \oplus 35$	$\tilde{\psi}^i_{-1/2}\lvert 0\rangle_{\mathrm{NS}} \otimes \psi^j_{-1/2}\lvert 0\rangle_{\mathrm{NS}}$	$\tilde{\psi}^i_{-1/2}\lvert 0\rangle_{\mathrm{NS}} \otimes \psi^j_{-1/2}\lvert 0\rangle_{\mathrm{NS}}$
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The definition of amplitudes is analogous to the bosonic string

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Superstring Theory

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What we really want → Spacetime SUSY

Can't be quantized covariantly → GS Formalism

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GS Formalism: Manifest spacetime SUSY | Light-cone quantization only

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