Introduction to AdS/CFT research

YSW Ringberg 2014

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take home message

AdS/CFT is a duality between a gravity theory and a quantum field theory • it can be used to study strongly coupled phenomena

holographic principle

’t Hooft, Susskind ‘90s

. ordinary system without gravity in d-dim. space-time

$$S_{\max} \sim \text{volume} \sim L^{d-1}$$

. this is not the case in a gravitating system, because they contain black holes!

↳ the maximal entropy in a region of volume V is given by the entropy of the biggest black hole that fits in V

holographic principle

't Hooft, Susskind '90s

. the black hole's entropy scales with the area of its event horizon

$$S_{\rm bh} = \frac{\text{area of horizon}}{4G_{\rm N}}$$

. therefore in a gravitating system

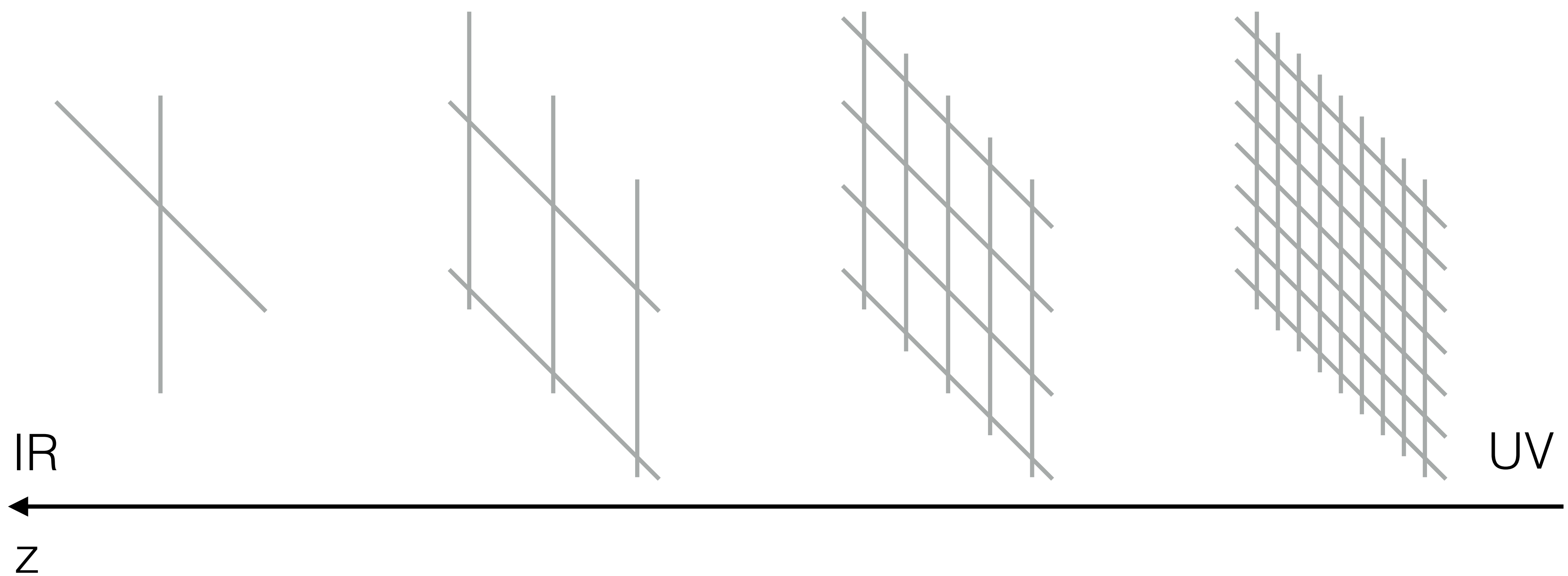
$$S_{\max} \sim \text{area} \sim L^{d-2}$$

the information contained in a d+1 dimensional gravitating system can be encoded in its d dimensional boundary described by an ordinary quantum field theory

QFT with an extra dimension

what is the extra dimension from a QFT perspective?

energy scale of the system



renormalization group flow $$\frac{\mathrm{d}g(z)}{\mathrm{d}z} = -\beta_g(g(z))$$

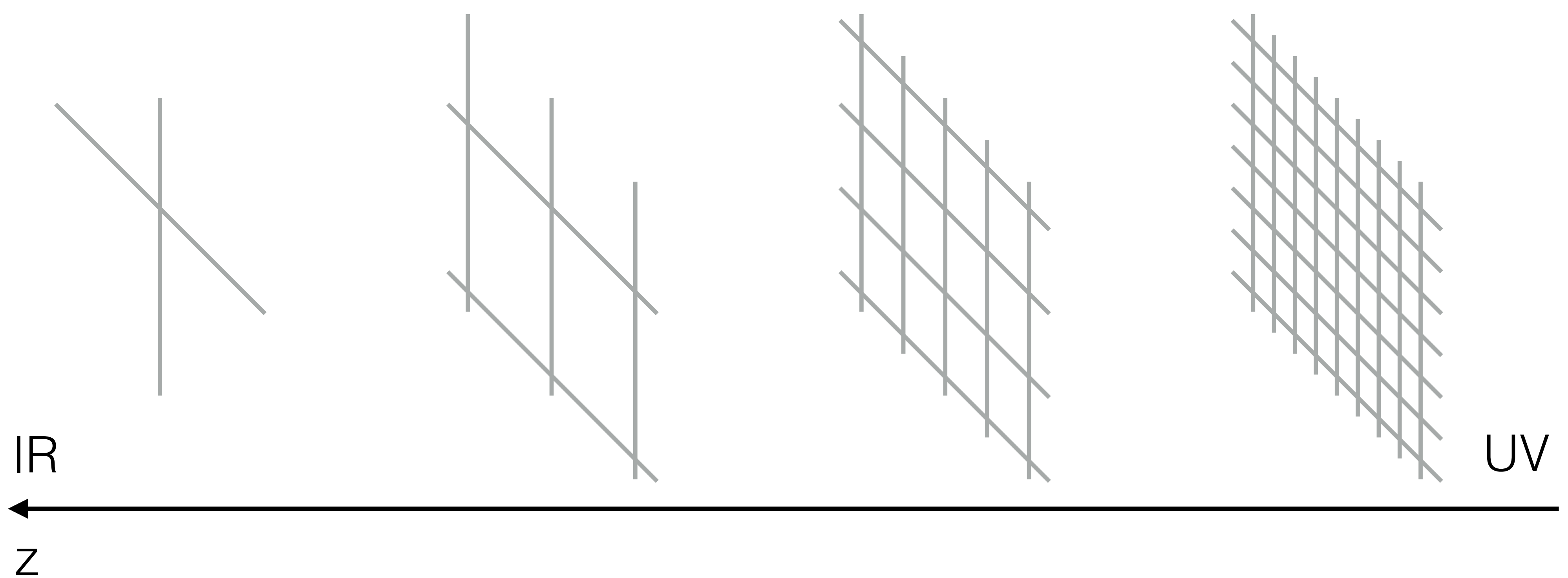
explicit realisation: AdS/CFT

. what is a conformal field theory? a field theory with conformal symmetry!

. translation • boost • special conformal transf.• scaling

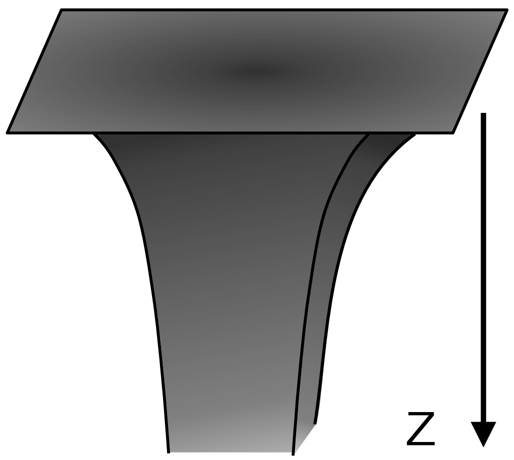
$$\frac{\mathrm{d}g(z)}{\mathrm{d}z} = -\beta_g(g(z)) \equiv 0$$

. associated symmetry group is SO(d,2)



explicit realisation: AdS/CFT

. Anti-de-Sitter space-time



. embedding of AdS_{d+1} in $\mathbb{R}^{d+2}$

$$L^2 = X_0^2 + X_{d+1}^2 - \sum_{i=1}^{d} X_i^2$$

→ isometry group: SO(d,2)

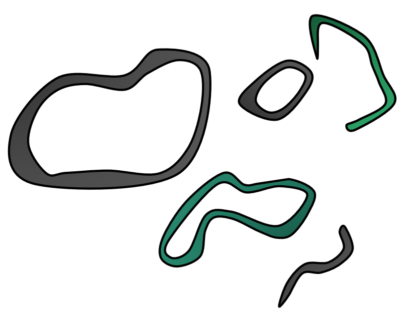
. the metric of AdS_{d+1} is given by

$$\mathrm{d}s^2 = \frac{L^2}{z^2}\left(-\mathrm{d}t^2 + \mathrm{d}x_1^2 + ... + \mathrm{d}x_{d-1}^2 + \mathrm{d}z^2\right)$$

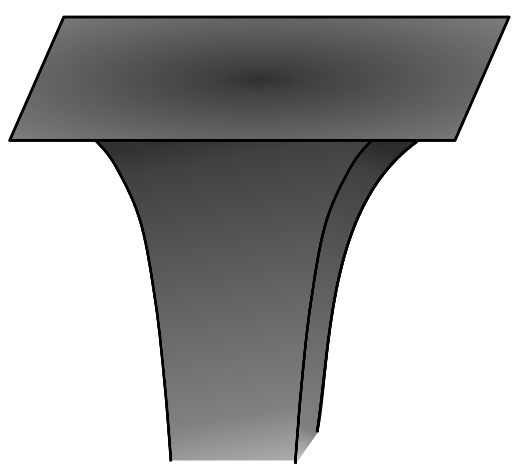
. ‘sequence of Minkowski space-times at different scales’

explicit realisation: AdS/CFT

Maldacena '97



2 interpretations of D-Branes → special limit



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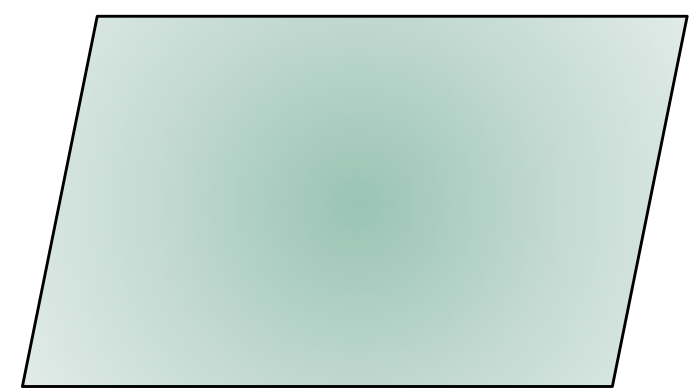


Anti-de-Sitter space-time

weakly coupled, 5 dim

IIB supergravity on AdS

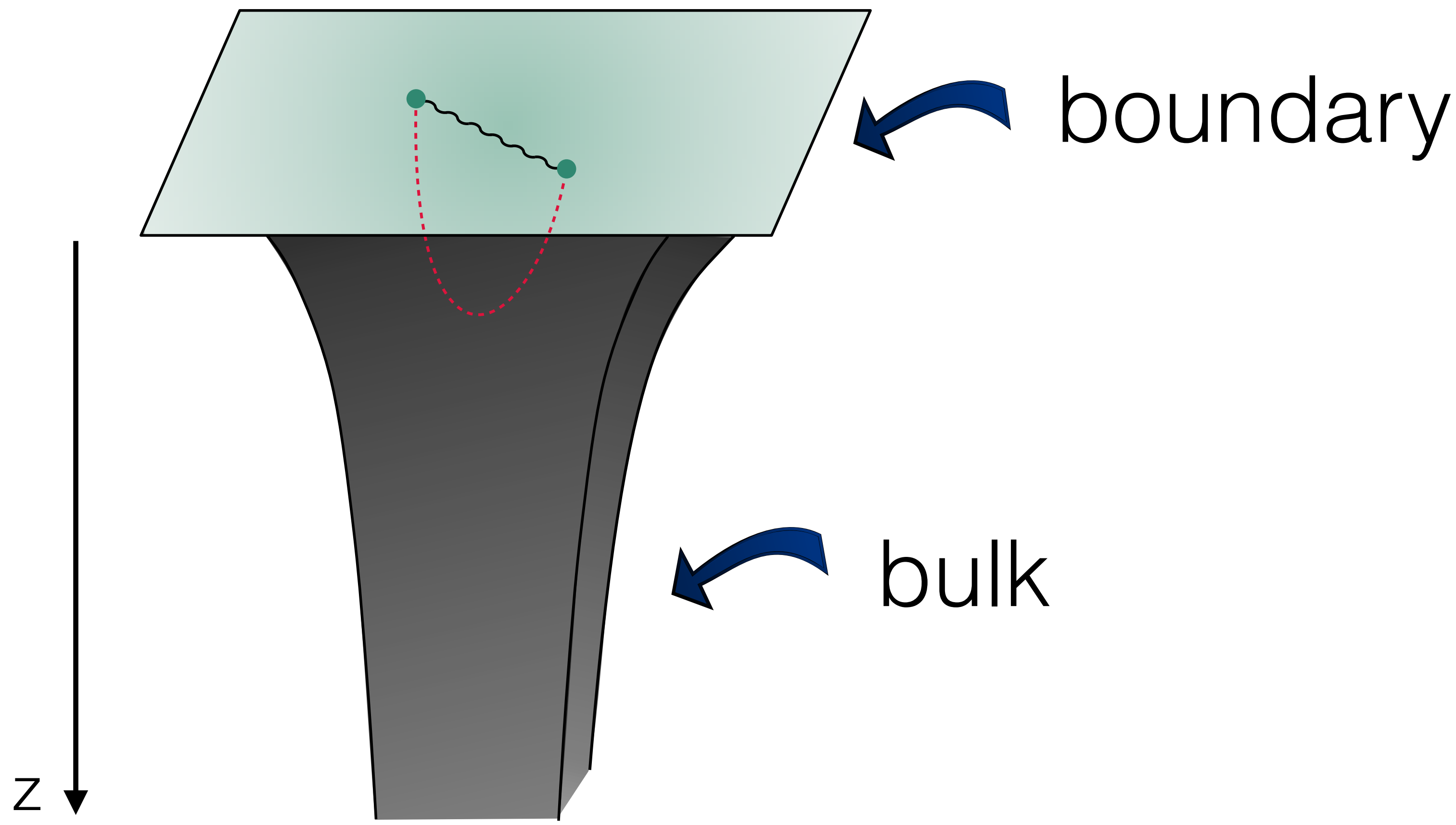
conformal field theory

$\mathcal{N} = 4$ SYM, gauge group SU(N)

strongly coupled, 4 dim

explicit realisation: AdS/CFT

Maldacena '97



. isometry group of AdS = conformal symmetry group

. identify the two partition functions

$$\exp(iS_{\mathrm{AdS}}) = Z_{\mathrm{AdS}} \equiv Z_{\mathrm{CFT}} = \int \mathcal{D}\phi \, \exp(iS_{\mathrm{CFT}})$$

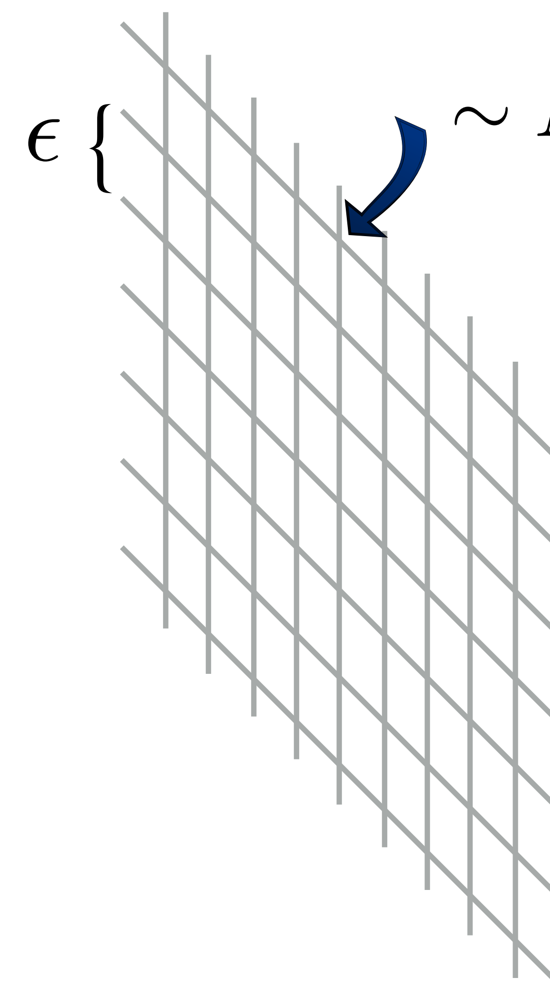
degrees of freedom

CFT in $\mathbb{R}^{1,d-1}$

. SU(N) gauge theory has N^2-1 dof's at each point

. introduce cutoff ϵ

. entropy as a measure of dof's



$$S_{\max} \sim N^2 \left(\frac{R}{\epsilon}\right)^{d-1}$$

degrees of freedom

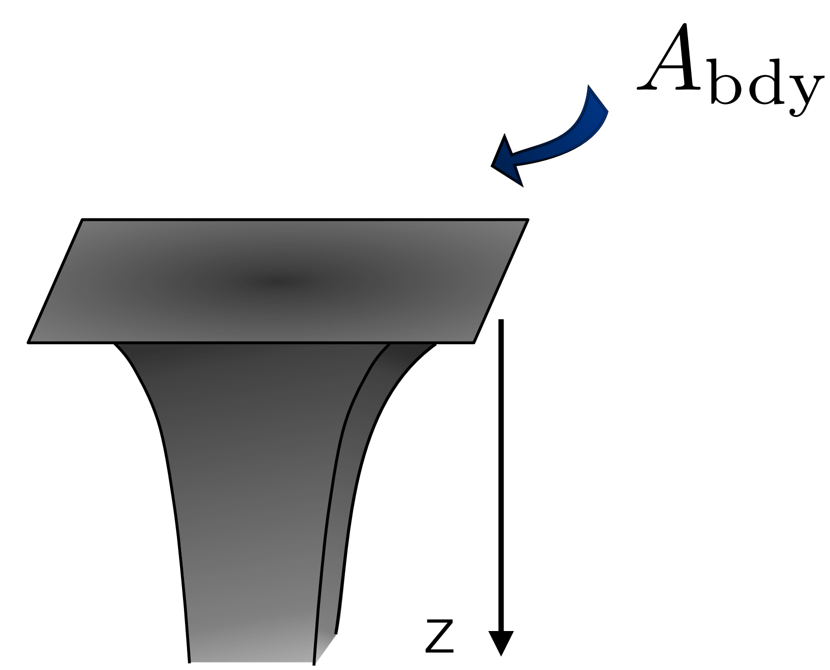
gravity in AdS_{d+1}

. entropy of a gravitating system is proportional to A_{bdy}

$$A_{\mathrm{bdy}} = \int_{\mathrm{bdy}} \mathrm{d}x^{d-1} \sqrt{-g} = \lim_{z \to 0} \left(\frac{LR}{z} \right)^{d-1} \sim \left(\frac{LR}{\epsilon} \right)^{d-1}$$

. cutoff ϵ

$$S_{\mathrm{max}} \sim \frac{L^{d-1}}{4G_{\mathrm{N}}} \left(\frac{R}{\epsilon} \right)^{d-1}$$



degrees of freedom

$$S_{\text{max, AdS}} \sim \frac{L^{d-1}}{4G_{\text{N}}} \left(\frac{R}{\epsilon}\right)^{d-1}$$

$$S_{\text{max, CFT}} \sim N^2 \left(\frac{R}{\epsilon}\right)^{d-1}$$

$$\frac{L^{d-1}}{4G_{\text{N}}} \sim N^2$$

. curvature of AdS_{d+1} is $R_{\text{AdS}} = -\frac{d(d+1)}{L^2}$

gravity is classical ~ large N CFT

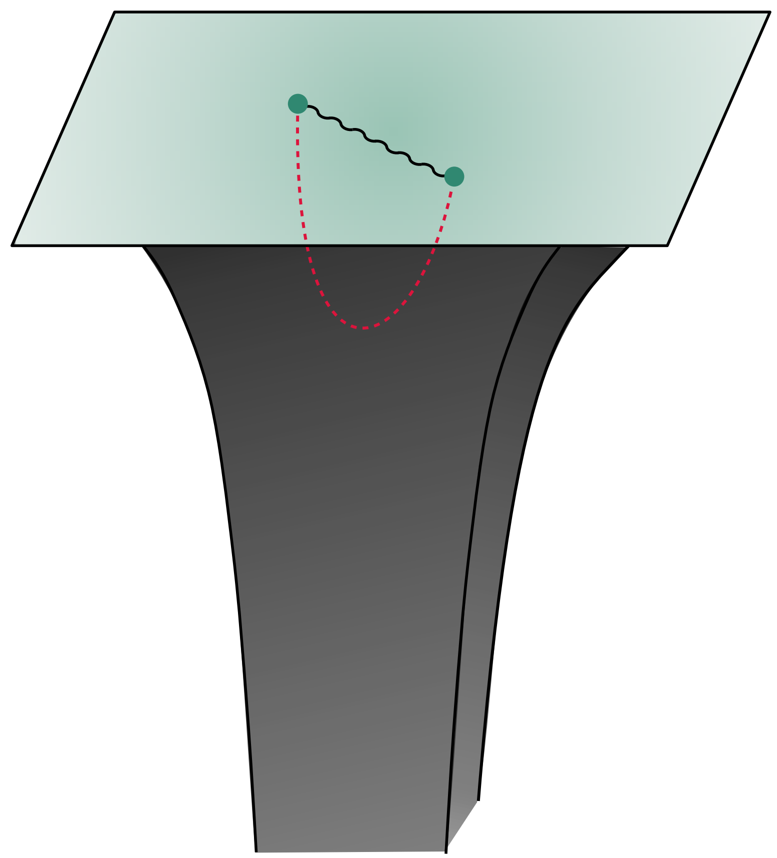
gauge/gravity duality

gravity theory

fields

quantum field theory

operators

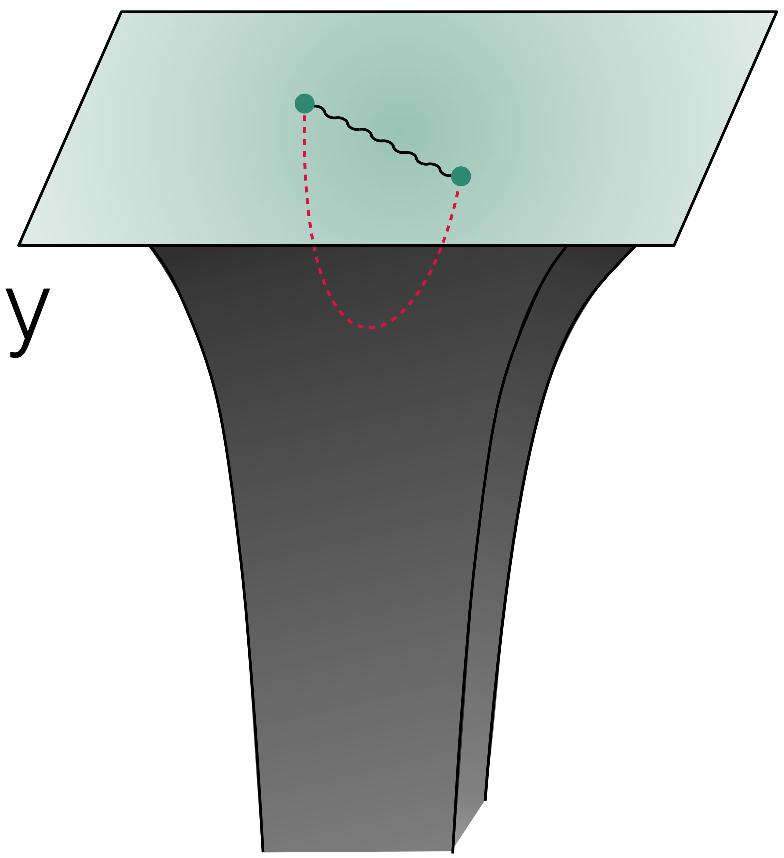


gauge/gravity duality

gravity theory

quantum field theory

fields



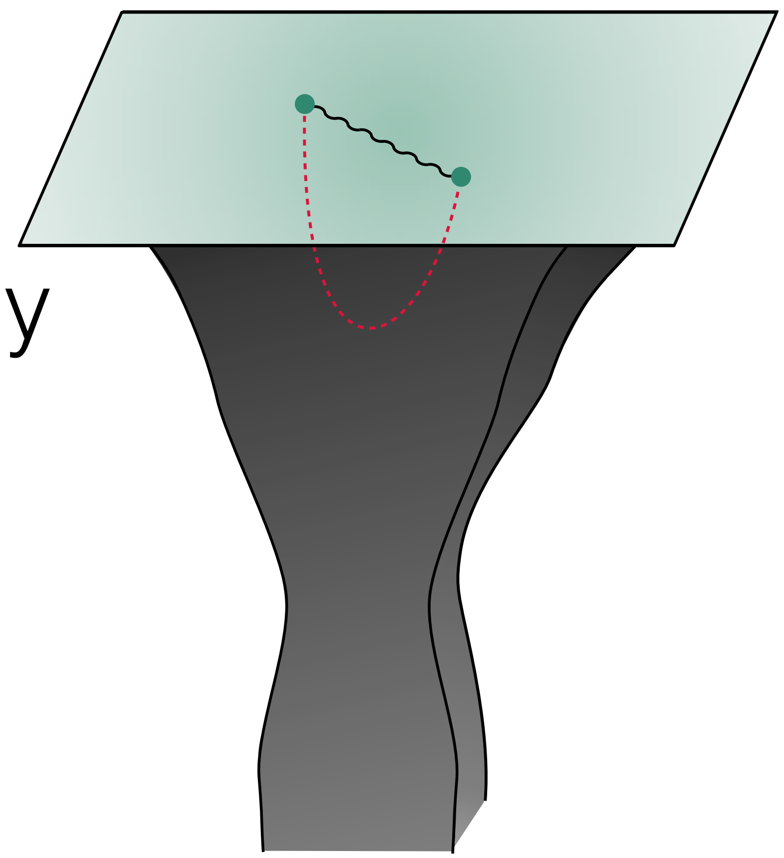
operators

gauge symmetry

global symmetry

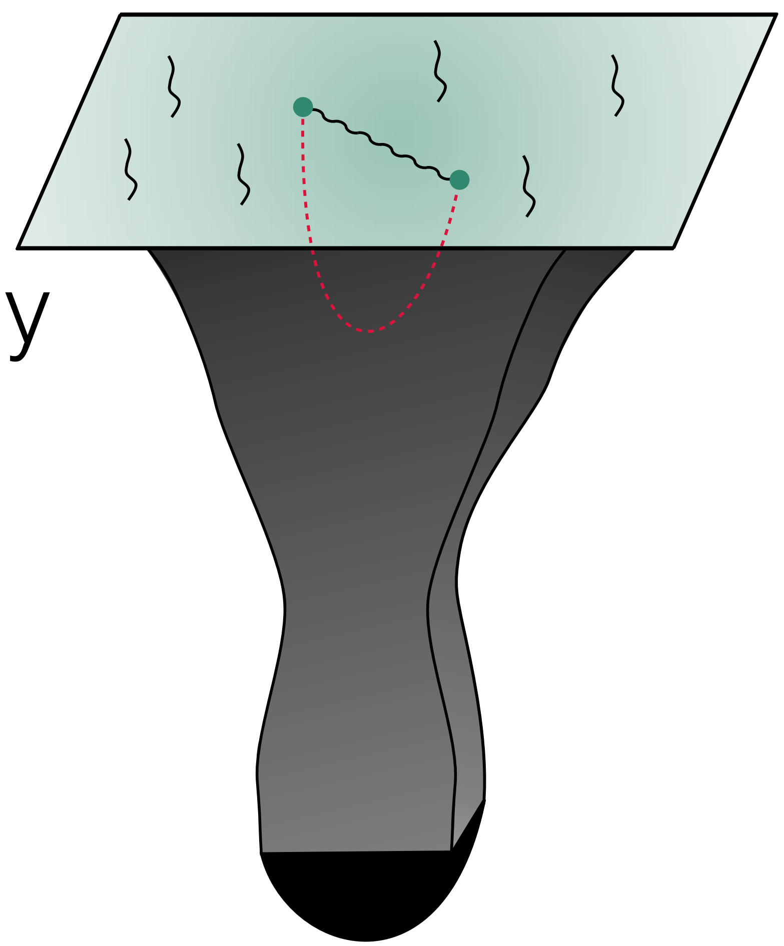
gauge/gravity duality

gravity theory	quantum field theory
fields	operators
gauge symmetry	global symmetry
deformation	less symmetry



gauge/gravity duality

gravity theory	quantum field theory
fields	operators
gauge symmetry	global symmetry
deformation	less symmetry
black hole	temperature



gauge/gravity duality

gravity theory	quantum field theory
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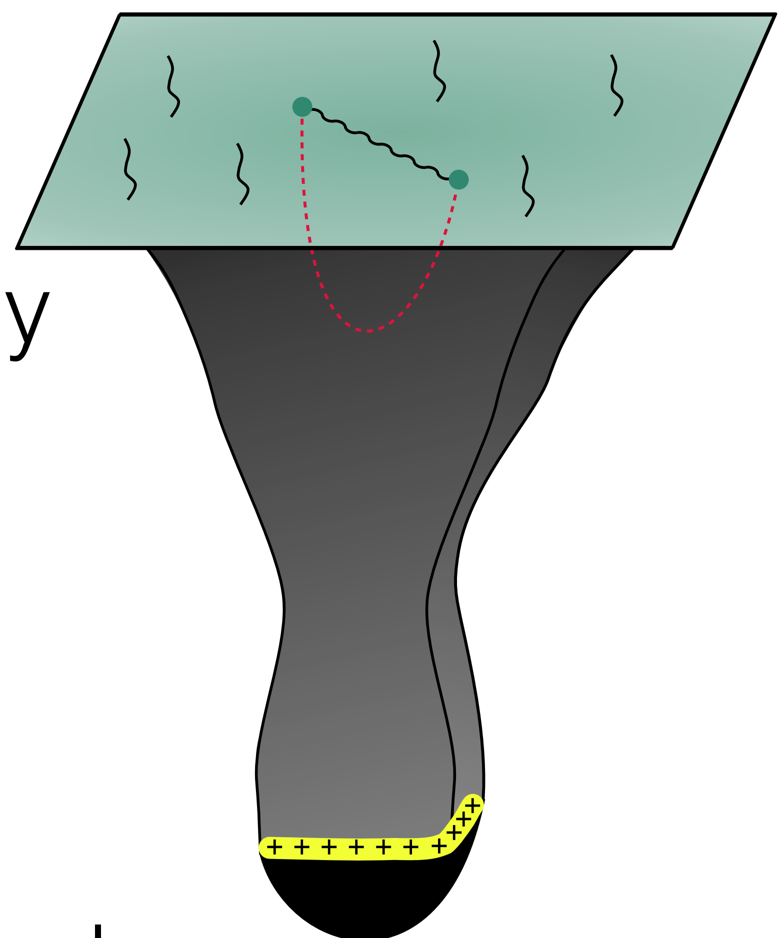
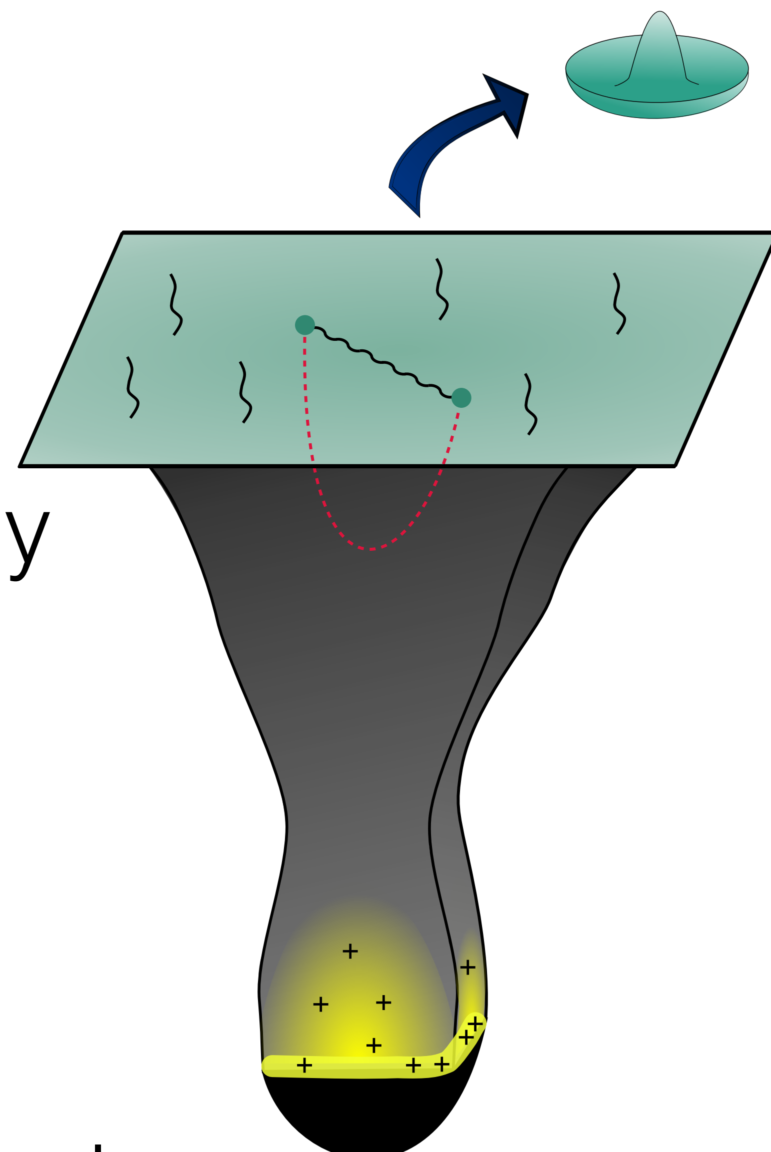
gauge symmetry	global symmetry
deformation	less symmetry
black hole	temperature
charged black hole	charge density



gauge/gravity duality



gravity theory	quantum field theory
fields	operators
gauge symmetry	global symmetry
deformation	less symmetry
black hole	temperature
charged black hole	charge density
black hole ‘hair’	SSB

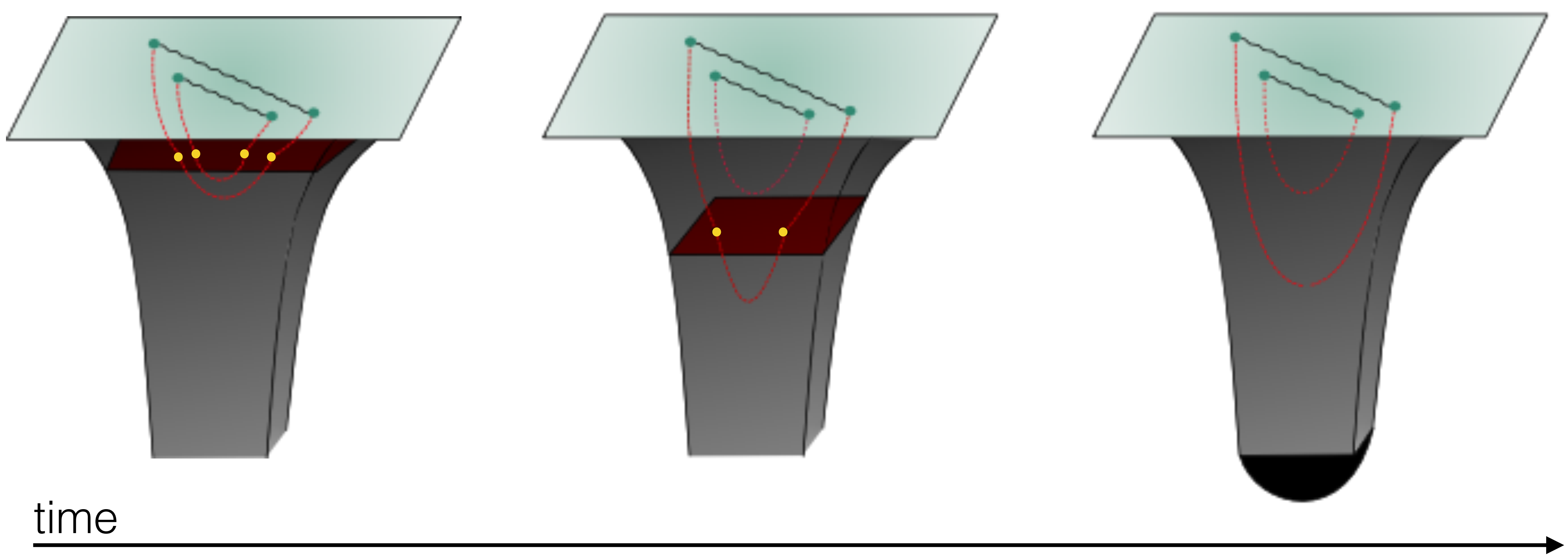
example: thermalization

gravity theory

black hole formation

quantum field theory

thermalization



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