HOLOGRAPHIC PRINCIPLE

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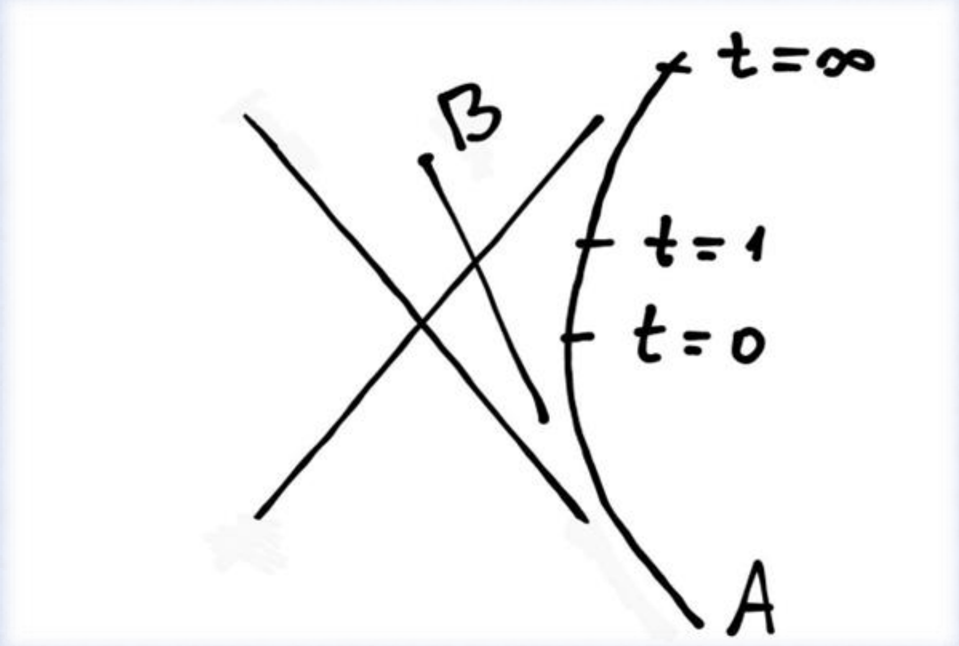
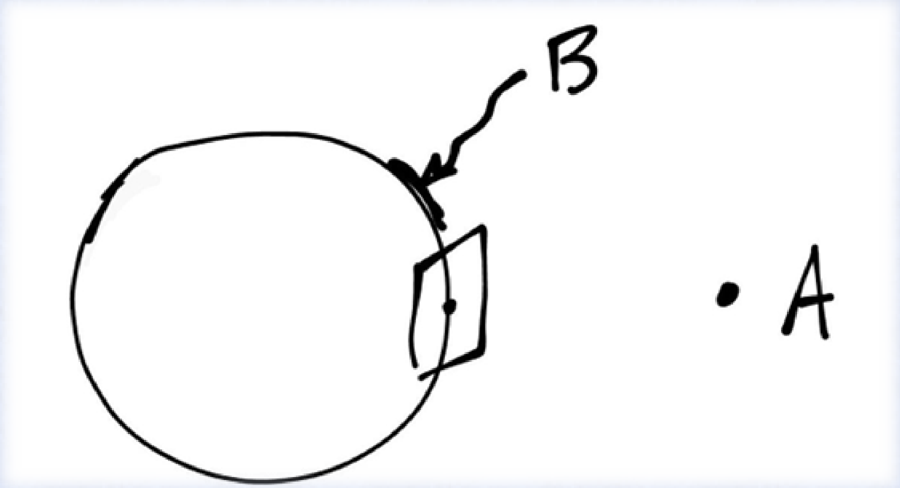
Plan of the talk:

- Equivalence principle – 2 different descriptions
- Black hole entropy and Bekenstein bound
- Holographic Principle
- Realization of Holographic Principle – Anti de-Sitter space
- References

Equivalence principle – 2 different descriptions



A – uniformly accelerated RF (hyperbolic trajectory)
B – not accelerated observer (linear trajectory) crossing the horizon.



A observes B but never actually sees it falling into the black hole. B is experiencing the fall in the gravitational field of a black hole (locally field is assumed to be uniform)

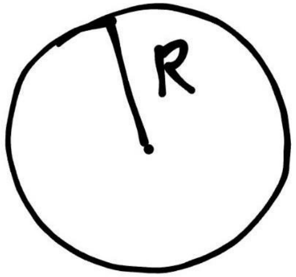
There is a discrepancy between how they perceive the world – A thinks B got stuck at the horizon, but B in his frame, goes inside the black hole. Which of these descriptions is correct?

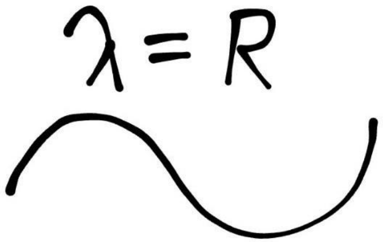
Black hole entropy and Bekenstein bound

From the example of A and B observers, we saw that in one scenario all information got stuck at the horizon. Having information means having entropy. The concept of black hole entropy originated from the work of physicists Jacob Bekenstein and Stephen Hawking in the 1970s.

- How much entropy can be stored in a black hole?

We want to throw 1 bit of information at a time in a small black hole and see how its horizon changes each time.





R – radius of a black hole
c – speed of light
M – mass of a black hole
G – newtons constant
λ – photons wavelength

Photons energy: $E = \frac{hc}{\lambda} \approx \frac{\hbar c}{R}$

Energy of a black hole has changed: $\delta E \approx \frac{\hbar c}{R}$

Change in mass: $E = Mc^2 \rightarrow \delta M \approx \frac{\hbar}{Rc}$

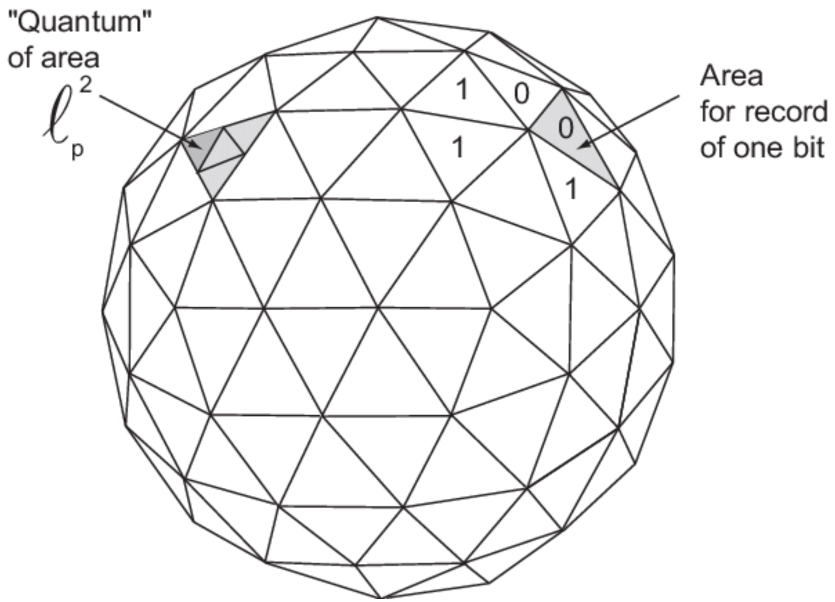
$$R \approx \frac{MG}{c^2} \rightarrow \delta R \approx \frac{\hbar G}{Rc^3}$$

$R\delta R \approx l_p^2$ hence $\delta A \approx l_p^2$ this is called Planck Area

Black hole entropy and Bekenstein bound

After some time, area of the black hole should be the number of bits that we threw (entropy) in times the Planck area:

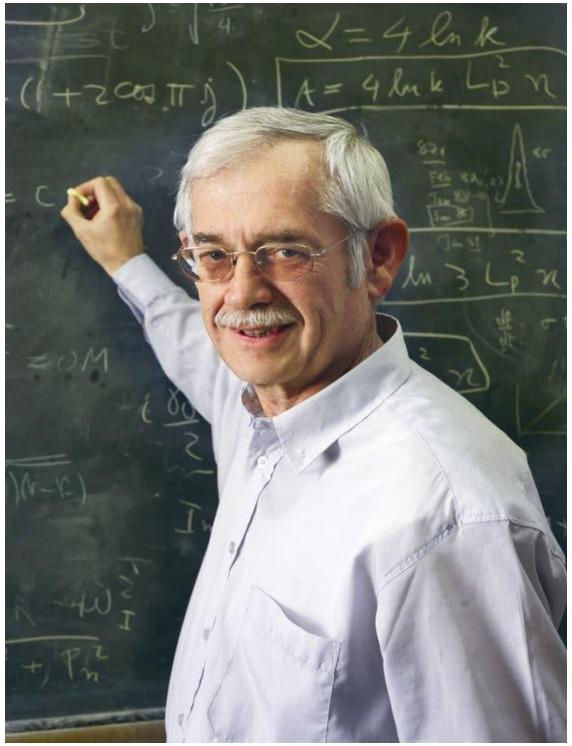
$$A = S \times \delta A \quad \rightarrow \quad S \sim \frac{A}{l_p^2}$$ entropy (information) is proportional to the area.



what falls into a black hole can be fully encoded on the surface area of the event horizon (unusual result for the system that includes gravity).

↓

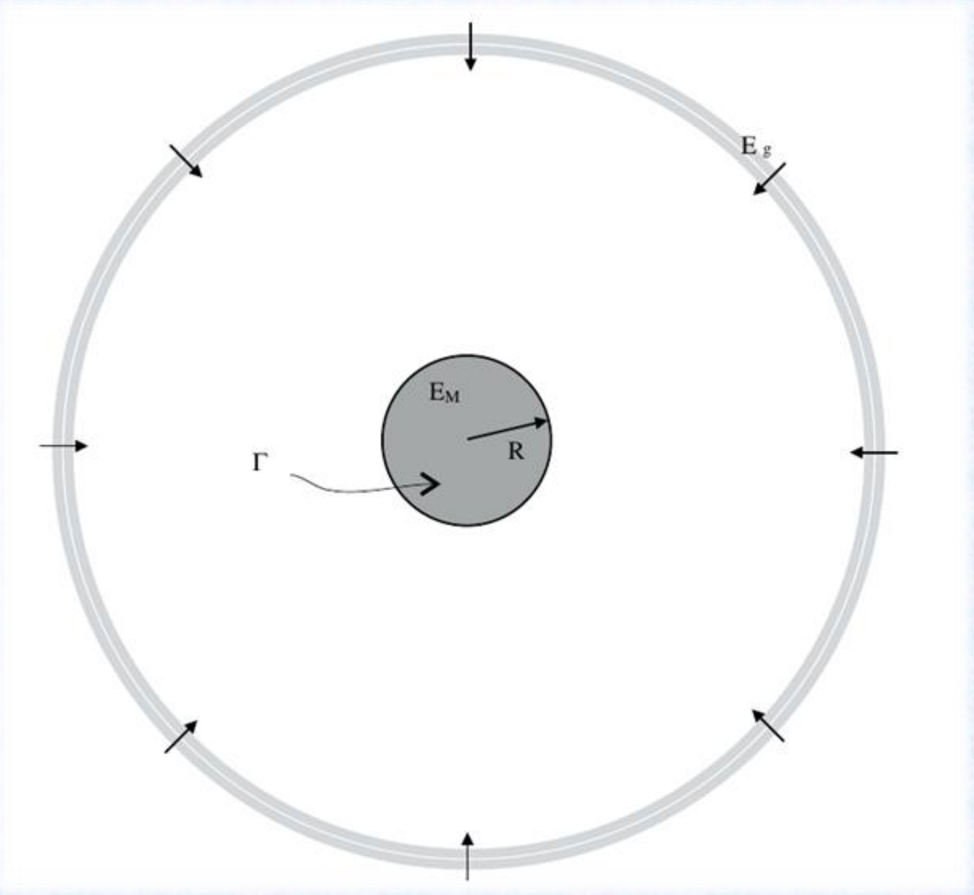
Logical consequence – holographic principle. This is how the general idea was born.



Jacob Bekenstein
1947 - 2015

Black hole entropy and Bekenstein bound

Holographic principle has to do with where information is really stored and how much information can be stored.



Γ region of space with large shell of material around it

thought experiment - what is the maximum amount of entropy or maximum amount of hidden information, that is in this region. We have Γ region of space – thermodynamical system with entropy S and surface A.

We consider collapsing a spherically symmetric shell of matter so that it forms a black hole which fills the region.

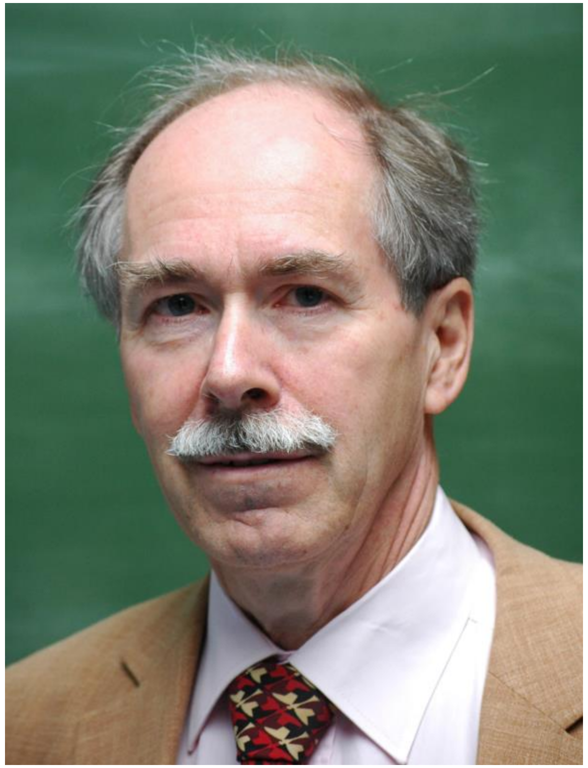
According to the second law of thermodynamics:

$$S \leq \frac{A}{l_p^2}$$

entropy in a certain region of space can not be bigger than the area of that region in Planck units.

Holographic Principle

the holographic principle asserts that the information stored in a volume V_{d+1}, is encoded in its boundary area A_d, measured in units of the Planck area l_p^d.

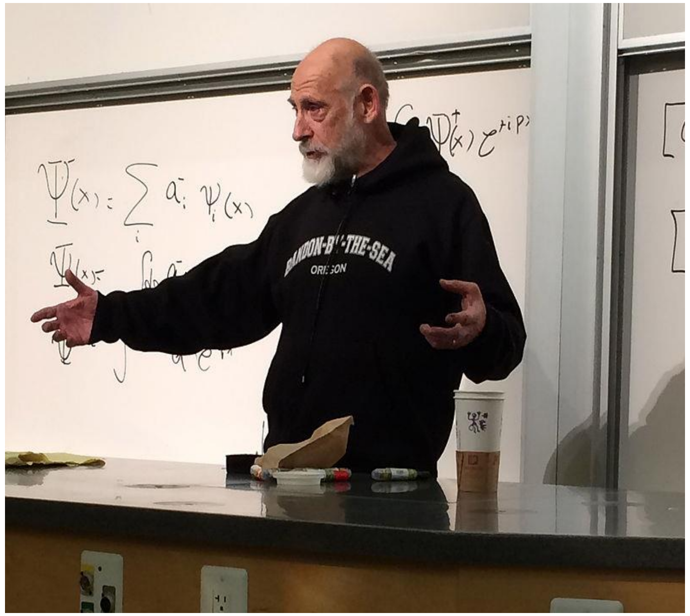


Gerard ’t Hooft, Nobel Prize laureate in Physics

- ’t Hooft has made the analogy with a hologram which stores a three dimensional image on a two dimensional film.
- As in the case of the hologram the flat two dimensional image must be rich enough to code the full rotationally invariant description of three dimensional objects.
- MAYBE - entire universe has a horizon out at very large distances, much like a black hole horizon and we are kind of inside it, so we here in the interior must have another representation as a hologram out at the boundary of the universe

→ Who knows

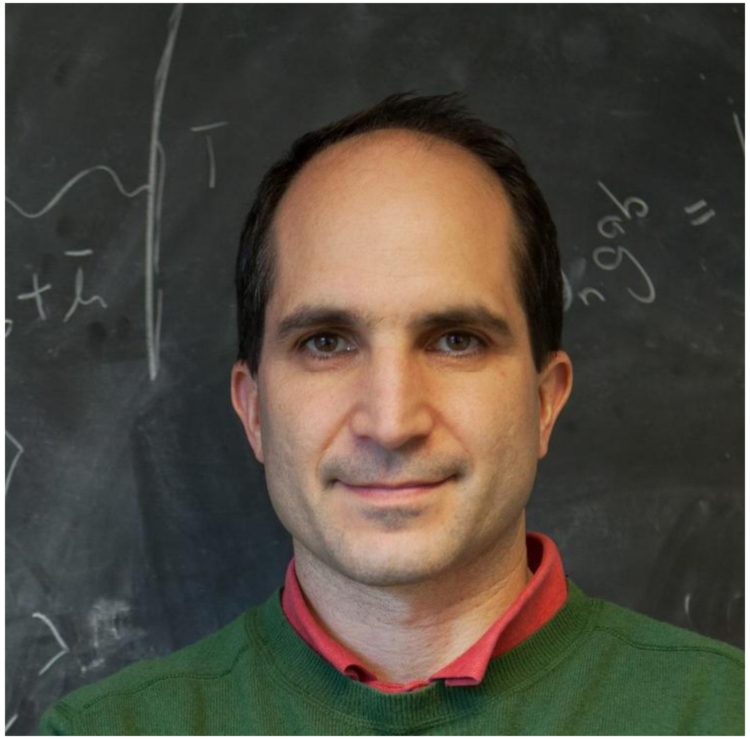
Leonard Susskind, Stanford University



Holographic Principle

't Hooft and Susskind - the basic idea is that suppose we have a spacetime, we consider quantum gravity in the interior of this spacetime and this should be equal to a certain QFT that lives on the boundary of that spacetime.

Juan Maldacena, Princeton University



Bekenstein formula prompted t' Hooft and Susskind to say that in a theory of gravity the basic fundamental degrees of freedom that we should use to describe any region of spacetime should scale like the area of this region and not a volume.

basically we describe a volume in terms of DoF that live on the area.

Juan Maldacena made a concrete version of this idea, called AdS/CFT correspondence – a realization of holographic principle in string theory.

Realization of Holographic Principle – Anti de-Sitter space

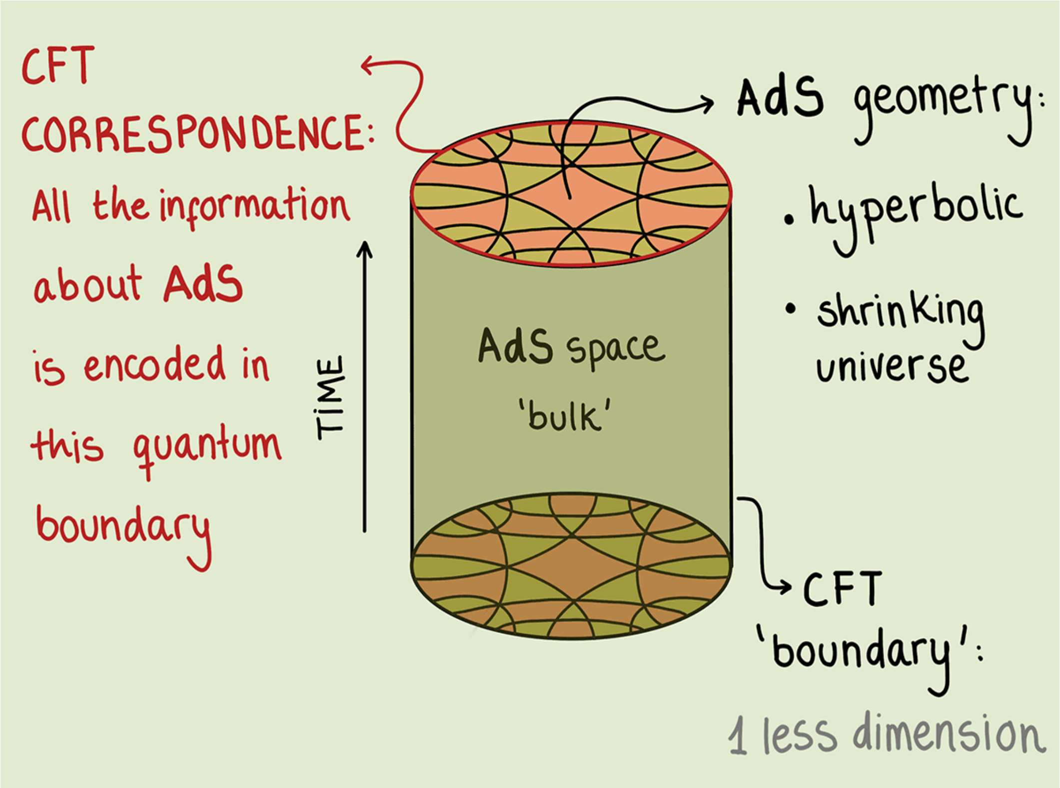
- de Sitter space holds special interest because of its close connection with observational cosmology. It has entered cosmology as the likely candidate for the final fate of the universe.

Space	Matter?	4D Spacetime Curvature	3D Space Acceleration	Other Dimension Spaces Curvature
De Sitter (dS)	no	positive, constant	accelerates	positive, constant
Anti de Sitter (AdS)	no	negative, constant	decelerates	negative, constant

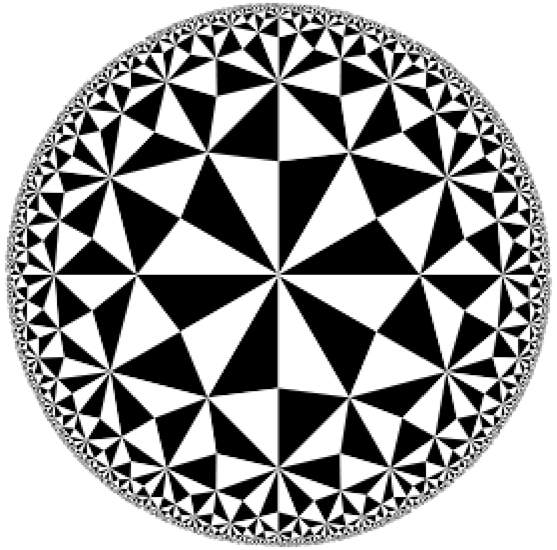
- Anti de Sitter space, on the other hand, is important for an entirely different reason. As it turns out, It is the background in which the holographic principle is best understood.
- Hologram analogy is obvious - three-dimensional space described by a two-dimensional hologram at its boundary and Anti de-Sitter space is the solution of Einstein’s equations, that offers a natural framework in which the Holographic Principle can be studied.

Realization of Holographic Principle – Anti de-Sitter space

- Anti de-Sitter space has negative curvature, it is a hyperbolic space. To talk about its surface/boundary we need to compactify it.
- 2D hyperbolic surface (saddle shape) can be represented as Poincare disk.



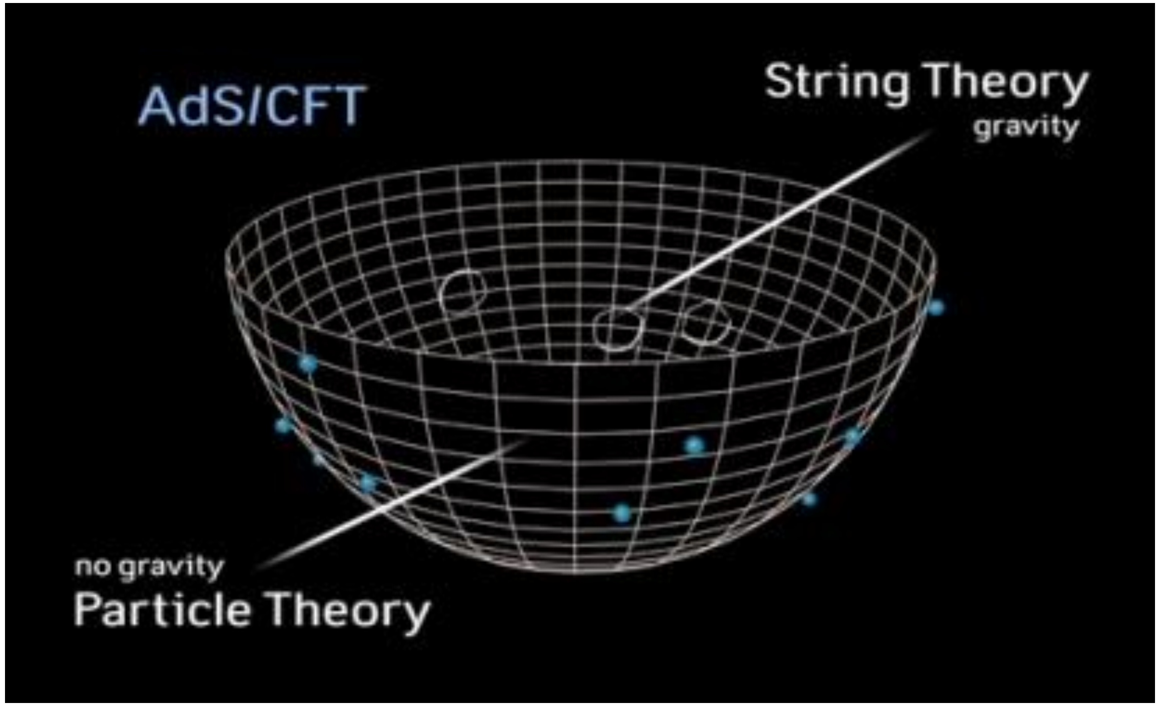
- Circumference of the cylinder is (1 + 1) and it is a Minkowski space, also conformally compactified.
- In 1997, Maldacena discovered that defining a CFT in a (3+1) Minkowski space corresponded to (4+1) Anti de-Sitter space.



String theoretical construction

Realization of Holographic Principle – Anti de-Sitter space

- the basic idea - suppose we have a spacetime and we consider quantum gravity in the interior of this spacetime. Then through holographic description, this should be equivalent to a certain QFT that is defined on the boundary of that spacetime (basically, there is a dimensional reduction in the sense of where degrees of freedom are).
- we think of the QFT as having degrees of freedom per point in spacetime, so number should be proportional to the volume, but in a theory with gravity it changes and is not point by point but on the surface.



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Thank you