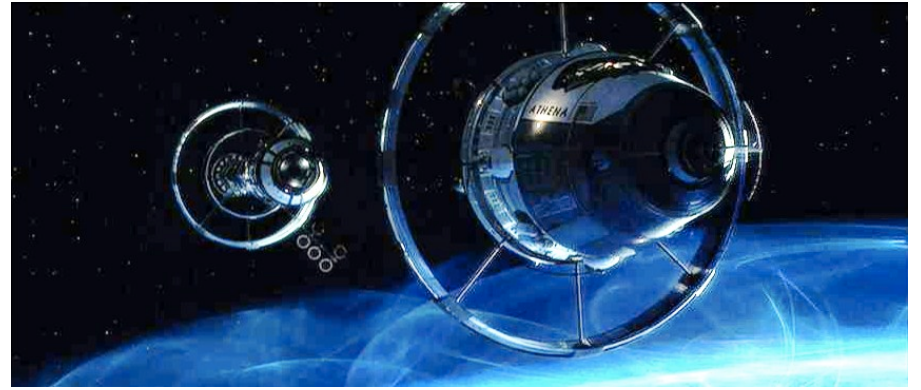
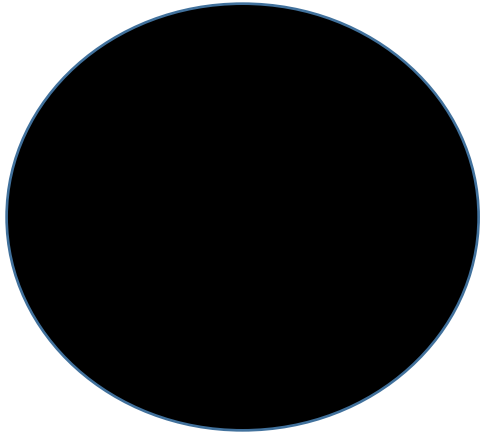


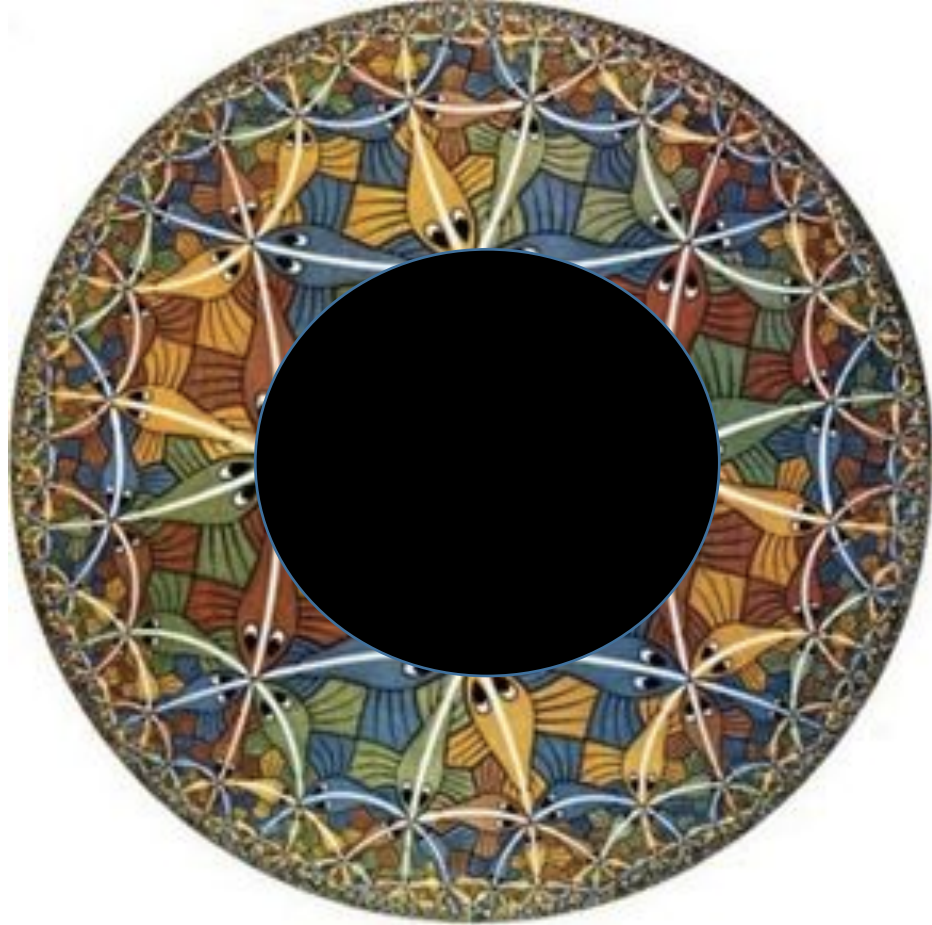
# Towards Wholeography

Strings 2017

Israel

Session on the 20<sup>th</sup> anniversary of AdS/CFT





# Black holes

- Are ordinary quantum systems with finite entropy, as seen from the outside.
- We think that this is a definite and general prediction of quantum gravity (or string theory).

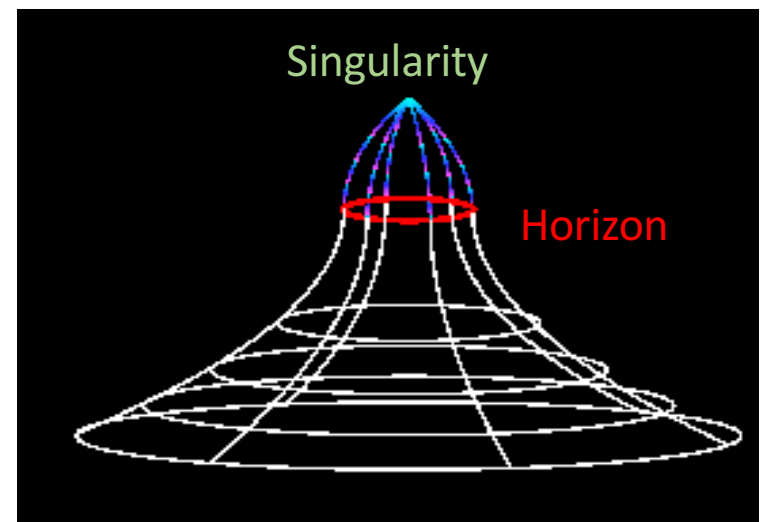
- How do we reconcile this with the gravity description ?
- How do we calculate the small corrections,  $e^{-S}$ , to simple boundary observables that are required by boundary unitarity.
- Or the  $o(1)$  corrections to very complex observables.

Shenker's talk

Raju's talk

# Leaving the boundary

- Is dangerous...
  - ...but with a potentially high payoff!
  - Interior? Approximate,  $e^{-S}$
  - When does the interior exist/fail to exist?
  - Singularity?
  - Beyond the singularity ?
- 
- Lessons for cosmology ? At least big crunch cosmology ?



# AdS/CFT as an experiment in need of theory

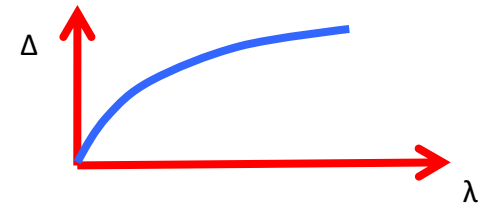
- We have seen, through somewhat indirect arguments, that certain very strongly interacting quantum systems behave as if they had a local bulk dual.
- Emergence vs equivalence.
- Should we view it as a new “phase of matter” ? Or theory of everything.
  
- Analogy: Superconductivity  $\rightarrow$  BCS ,
  - $\rightarrow$  high  $T_c$  superconductivity.
  - TFD = Energy superconductor  $\rightarrow$  “phase” = time =  $t_L - t_R$  .

D-branes  
Polchinski

# Metamorphosis



Challenge: Extract the general lesson.



Vieira's talk

Eg: Onsager's solution of the Ising model vs. the renormalization group.



- Bulk locality requires very strong interactions

$$\Delta_{S>2} \gg 1$$

Caron Huot's talk

- Obvious from the bulk:  $M_s R_{\text{AdS}} \gg 1$ .
- What should we tune in the quantum system to get here ? How generic is it ?
- Need bulk locality to talk about the interior (proper time to the singularity  $< R_{\text{AdS}}$  ).
- Need bulk locality to explore the interior. (Proper time to the singularity  $< R_{\text{AdS}}$

Bulk locality as a critical phenomenon:

Bulk locality implies certain singularities in correlation functions. These singularities only develop as the coupling goes to infinity (and  $N$  goes to infinity).

Into the bulk

Renormalization group

HKLL / Rehren

Tensor networks

Quantum error correction

Chaos

Complexity

Modular Hamiltonians

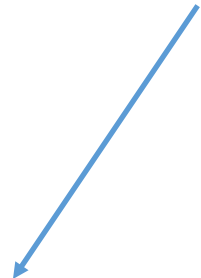
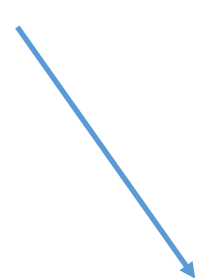
# Into the relativistic bulk

- Local special relativity is “hard wired” to gravity. Equivalence principle.
- We are not using this enough !
- Tensor networks capture some aspects of the bulk, but not this local special relativity.
- Bootstrap  $\rightarrow$  global conformal symmetry, but not enough bulk locality.
- Subalgebras & modular Hamiltonians. Exact boost symmetry.
- Essential for gravity/thermodynamics connection.

MERA  
Tensor networks

CFT  
bootstrap

?



What will happen in the future ?



**Start with the Bible...**



God created the universe ...

Genesis 1 ,...

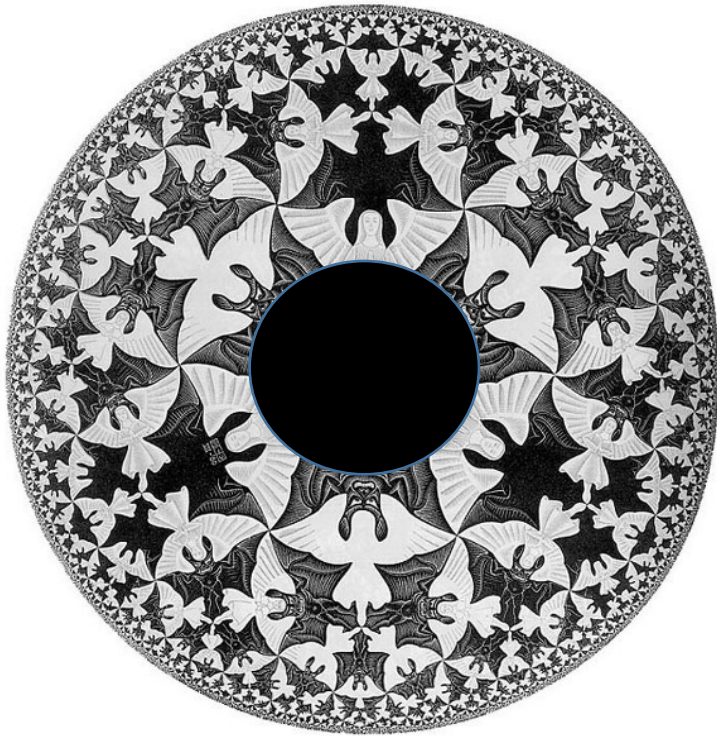
God created man in his own image...

Genesis 1, 27.



We should be creative !

We can now create certain universes

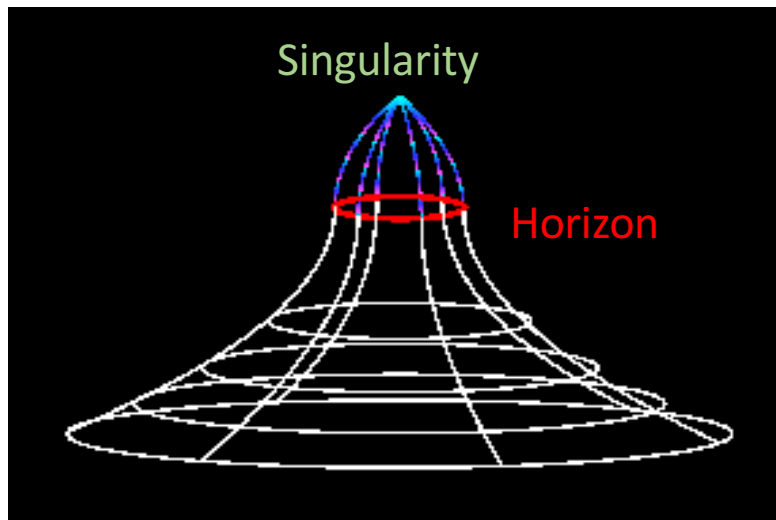


# Some of our universes are useful

- With a purpose:
- Black holes as sources of information. (For strongly coupled systems).
- We have “Universal” computers.

## But our universes have a dark side

- Our universes are not nice to bulk observers → singularity



# Cosmology

- How do we build a more comfortable universe, with growing space for everybody ?



# Wild speculations

Renormalization group

HKLL/Reheren

Tensor networks

Error correction

Chaos

Complexity

Modular Hamiltonians

.....

## Wholeography

Whole bulk theory

Quantum equivalence principle

Universal quantum computer



# Wilder speculations

Renormalization group

HKLL/Reheren

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Complexity

Modular Hamiltonians

.....

## Wholeography

Powerful computer ! → replace artificial neural networks

# Wholeography

- Find it before the end of time !



*My time is up !*

*Thank you !*

