Gong Show

The preview session by the poster presenters today

#1

Strings, warped AdS and irrelevant deformations

Luis Apolo

YMSC, Tsinghua University

in collaboration with Wei Song

(arxiv:1806.10127, 190x.xxxxx)

Goal: construct a tractable toy model of the Kerr/CFT correspondence in string theory

string theory on $\text{WAdS}_3 \ltimes S^3$ ⟷ $S_{CFT_2} + \delta S_{CFT_2}$

$\frac{\lambda}{\ell} \int d^2z \, j^- k^3$ ↑ TsT $\qquad\qquad$ $\lambda \int d^2x \, J\bar{T}$

string theory on $\text{AdS}_3 \times S^3$ ⟷ CFT_2

#2

Complexity for Quantum Fields: From Quenches to Path Integrals

Hugo A. Camargo

Max Planck Institute for Gravitational Physics (AEI)
Freie Universität Berlin

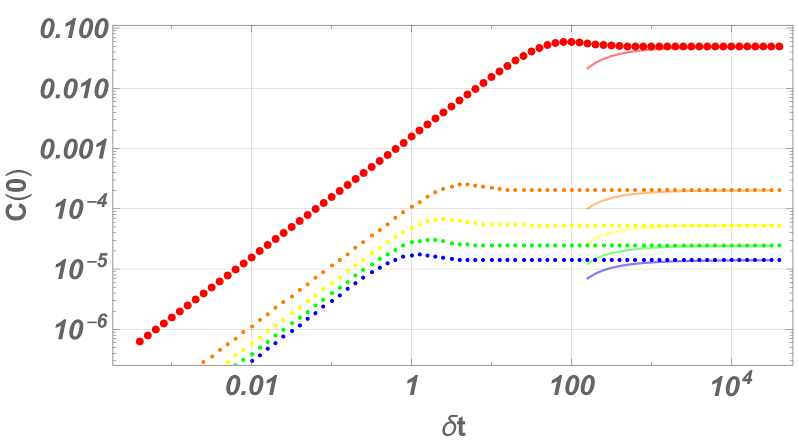
I. Complexity as a Novel Probe of Quantum Quenches

1807.07075
(with P. Caputa, D. Das, M. P. Heller, and R. Jefferson)

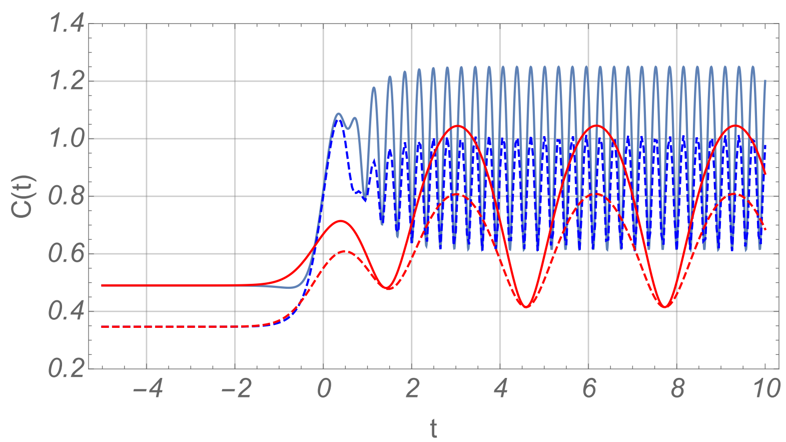
II. Path-integral Optimization as Circuit Complexity

1904.02713
(with M. P. Heller, R. Jefferson, and J. Knaute)

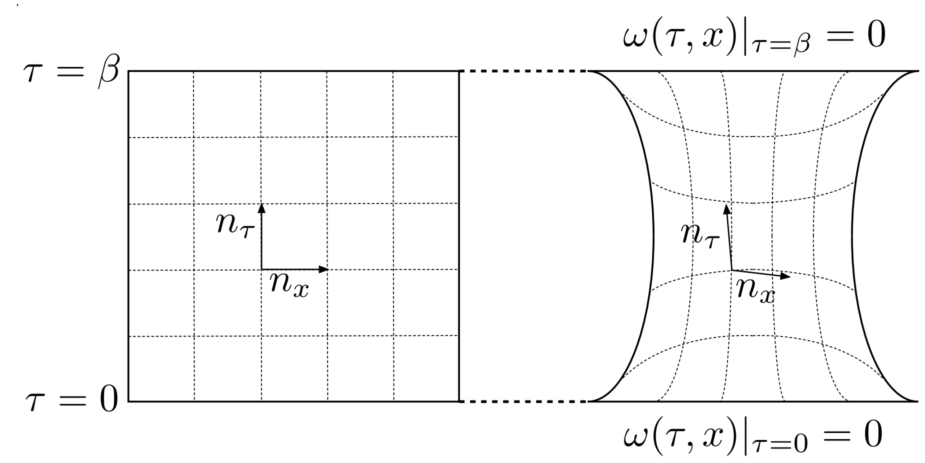
Universal Scalings



Purifications



Liouville Action from Gate-Counting

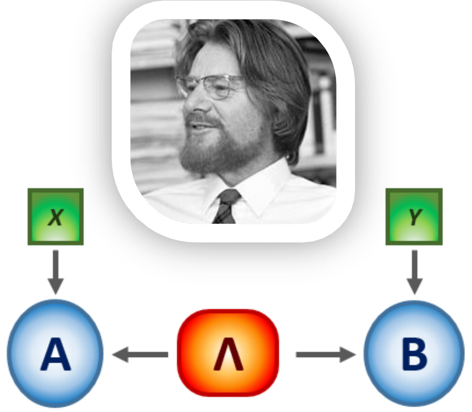


Poster #2 @ Maskawa Hall

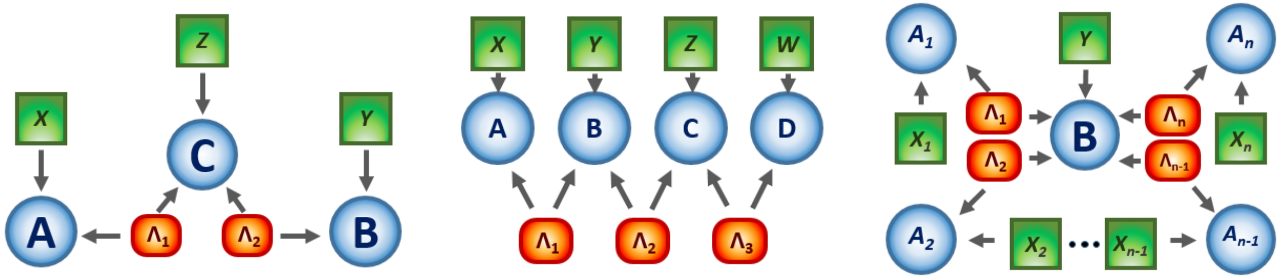
#3

Experimental quantum tests of causal structures

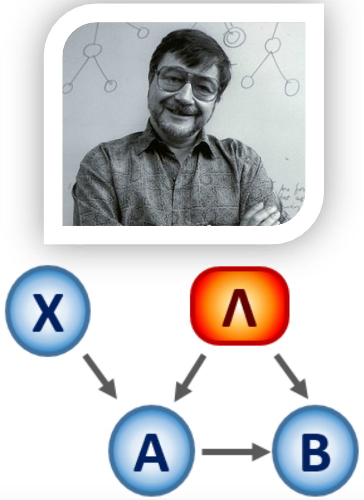
Bell Causal Structure

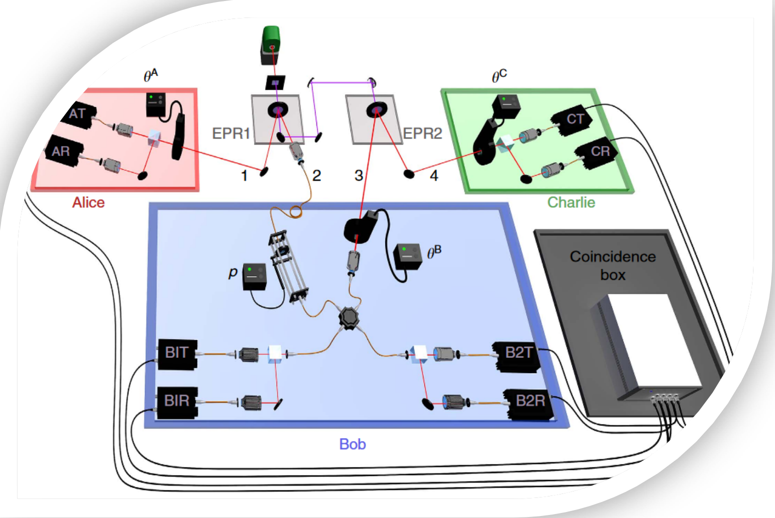


Complex Causal Structures

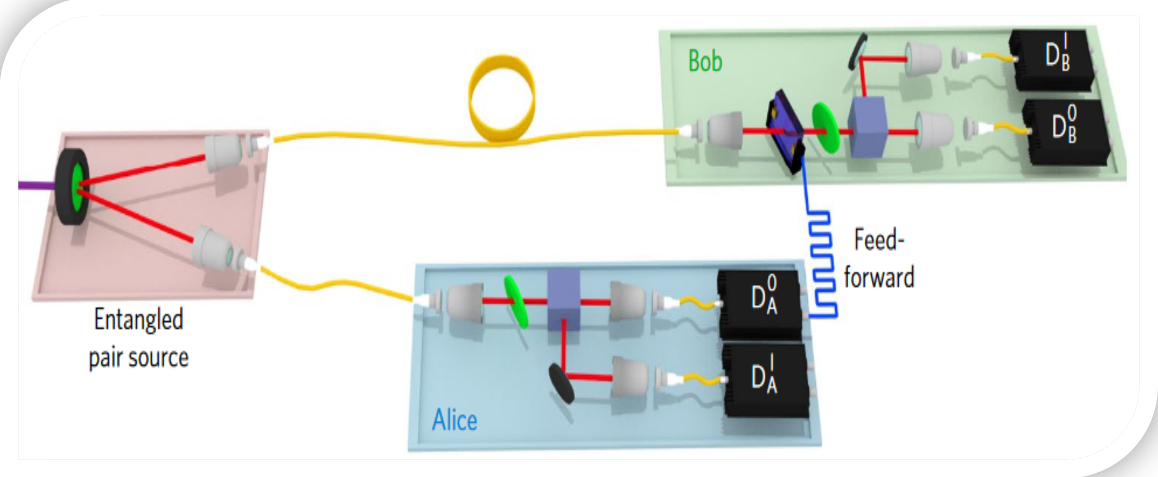


Instrumental Causal Structure



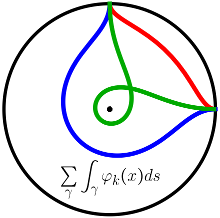


See you at the poster session



#4

OPE blocks give the contribution to the OPE from the conformal family of a primary $\mathcal{O}_k$:
$\mathcal{O}_i(x_1)\,\mathcal{O}_i(x_2) = |x_1 - x_2|^{-2\Delta_i} \sum_k C_{iik} \mathcal{B}_k(x_1, x_2)$.



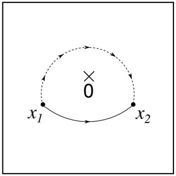
Dual to geodesic integrated field [CLMMS 1604.03110]

$\mathcal{B}_k(x_1, x_2) \sim \sum_\gamma \int_{\gamma(x_1,x_2)} \varphi_k(x) ds$, $\quad$ (φ_k dual to $\mathcal{O}_k$).

For non-pure AdS_3, sum over geodesics.

We constructed a class of CFT observables $\mathcal{B}_{k,m}$ that distinguish terms in the sum.

Each partial OPE block $\mathcal{B}_{k,m}$ is dual to a bulk field integrated over a single geodesic, minimal or non-minimal, giving access to information deep in the bulk.



In CFT excited states created by a heavy operator insertion, OPE paths around the insertion differ by monodromy.

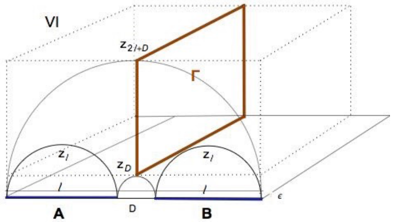
$\mathcal{B}_{k,m}$ decomposition of OPE block induced from monodromy around insertion in the same way that non-minimal geodesics arise.

#5

The connection between holographic entanglement and complexity of purification

Mahdis Ghodrati, Xiao-Mei Kuang , Bin Wang , Cheng-Yong Zhang, Yu-Ting Zhou

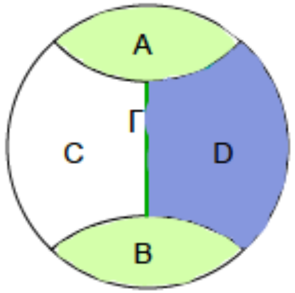
There are various kinds of correlations among mixed states, mainly **entanglement Entropy** and **classical correlations**. Other forms of quantum correlations such as **quantum discord** could also exist.



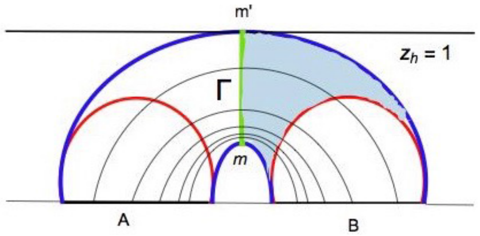
1. Can we examine the contribution for each of these kinds of correlations from holography by comparing various subregion volumes?

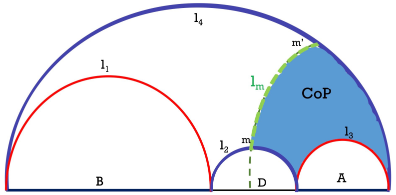
2. If we assume the Ep=EW conjecture, can we also define a notion of **complexity of purification** which is dual to the number of gates needed to purify mixed states? What is the corresponding subregion volume in the bulk? Hint: →

$$CoP(A,B) = \frac{V_D}{8\pi G} = \frac{1}{8\pi G}\left(\frac{V_{ABCD} - V_A - V_B}{2}\right).$$



3. Where are the qubits and gates are actually located? Do they behave locally or in a non-local way? How changing the mass or charge in the bulk region could be connected to correlations among qubits? Can we use **LOCC** and **bit thread** to study this problem?





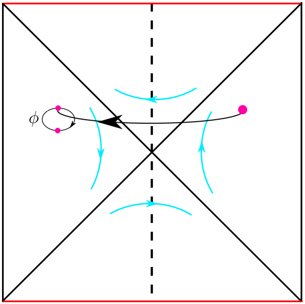
Maskawa Hall #5

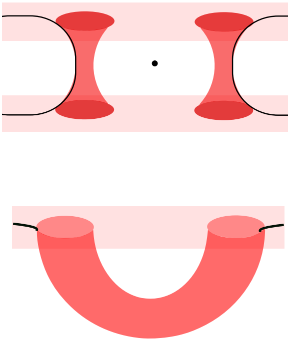
#6

UNIVERSITY OF CALIFORNIA
SANTA BARBARA

A Perturbative Perspective on Self-Supporting Wormholes

Brianna Grado-White
brianna@physics.ucsb.edu
With Donald Marolf & Zicao Fu





#7

Complexity=Action-CA 2.0

Considering the physical relevance to the holographic duals of quantum complexity, we propose that the ''complexity=action 2.0'' or CA-2 duality:

$$\mathcal{C} = \frac{I_\Lambda}{\pi \hbar}$$

which implies complexity duals the thermodynamic volume.

We have

$$\dot{S}_{\Lambda_+} \equiv PV = -\frac{1}{16\pi G}\int_{\mathcal{A}_{n-2}} \mathrm{d}x^1 \mathrm{d}x^2 \cdots \mathrm{d}x^{n-2} \int_{r_i}^{r_+} \mathrm{d}r \sqrt{-g}\, U_\Lambda \,.$$

For the black holes without an inner horizon, we have $r_i = 0$. Otherwise, we can define S_{Λ_-} for the inner horizon and find

$$\begin{aligned}\dot{S}_\Lambda &\equiv \dot{S}_{\Lambda_+} - \dot{S}_{\Lambda_-} = P\left(V_+ - V_-\right) \\ &= -\frac{1}{16\pi G}\int_{\mathcal{A}_{n-2}} \mathrm{d}x^1 \mathrm{d}x^2 \cdots \mathrm{d}x^{n-2} \int_{r_-}^{r_+} \mathrm{d}r \sqrt{-g}\, U_\Lambda \,,\end{aligned}$$

#8

Anomalous Gravitation and its Positivity from Entanglement

Hongliang Jiang

University of Bern

Topologically Massive Gravity with CS term in AdS_3 ⟷ CFT_2 with gravitational anomaly ($c_L \neq c_R$)

Goal: understand the emergence of spacetime from entanglement in CFT generally

Tool: 1st law of entanglement + Wald-Tachikawa formalism + HEE in TMG

- Holographic dictionary of stress tensor

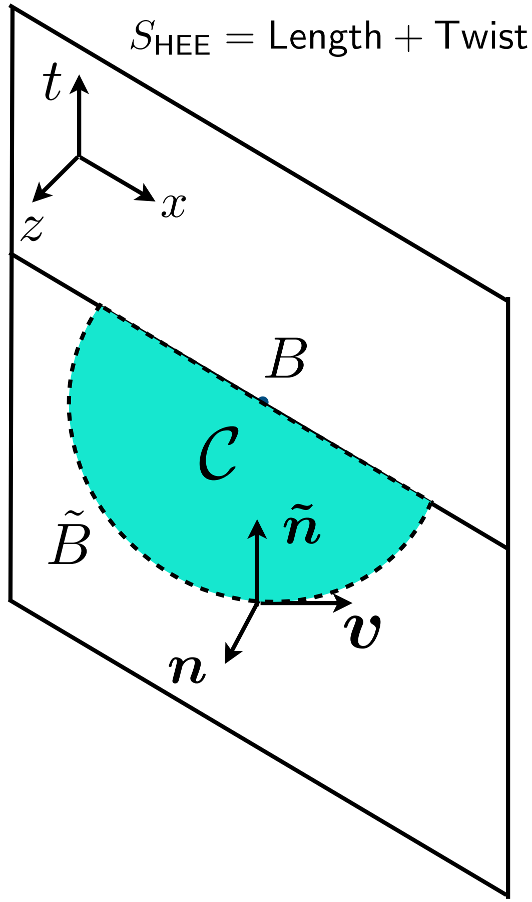
$$T_{tt} = \frac{1}{8\pi G_N}\left(H_{tt} + \frac{1}{\mu}H_{tx} + 2B_{tx}\delta_{\mu,1}\right)$$

- Linearized equation of motion in TMG

$$\delta\mathcal{E}_{\mu\nu} = 0$$

- Holographic relative entropy

$$S(\rho_B||\sigma_B^{vac}) = H_{\xi_B}(M) - H_{\xi_B}(\mathrm{AdS}) > 0$$



#9

Probing nonperturbative structures in gravity with SYK

Mikhail Khramtsov — Steklov Mathematical Institute

1. Replica-nondiagonal large N saddle points in the SYK model
   - Integrable case $q = 2$: analytic solutions
   - Chaotic case $q = 4$: numerical solutions
2. Physics of replica-nondiagonal saddle points in 2-replica SYK:
   $S[\psi, \mathbf{j}] = S_{\mathrm{SYK}}[\psi^L, \mathbf{j}] + S_{\mathrm{SYK}}[\psi^R, \mathbf{j}] + S_{\mathrm{int}}[\psi]$,

$$S_{\mathrm{int}}[\psi] = \int_0^\beta \int_0^\beta d\tau_1 d\tau_2 \sum_{i=1}^{N} \psi_i^L(\tau_1) \frac{\nu}{\beta \sin \frac{\pi}{\beta}(\tau_1 - \tau_2)} \psi_i^R(\tau_2)$$

   - Integrable case $q = 2$: phase diagram
   - Chaotic case $q = 4$: phase structure
   - Spontaneous symmetry breaking in SYK
3. Towards gravity interpretation of nontrivial saddle points in SYK

SYK large N saddle point expansion VS $2D$ Gravity genus expansion

$$\langle Z_{\mathrm{SYK}}(\beta)^M \rangle = \sum_{\text{saddles}} \mathrm{e}^{-NI[G_0, \Sigma_0]} \sum_{k=0}^{\infty} \frac{\zeta^{(k)}(G_0, \Sigma_0)}{N^k}; \quad Z_{\mathrm{gravity}}(\beta; M) = \sum_{g=0}^{\infty} \mathrm{e}^{-S_0(M-2+2g)} Z_{g,M}(\beta)$$

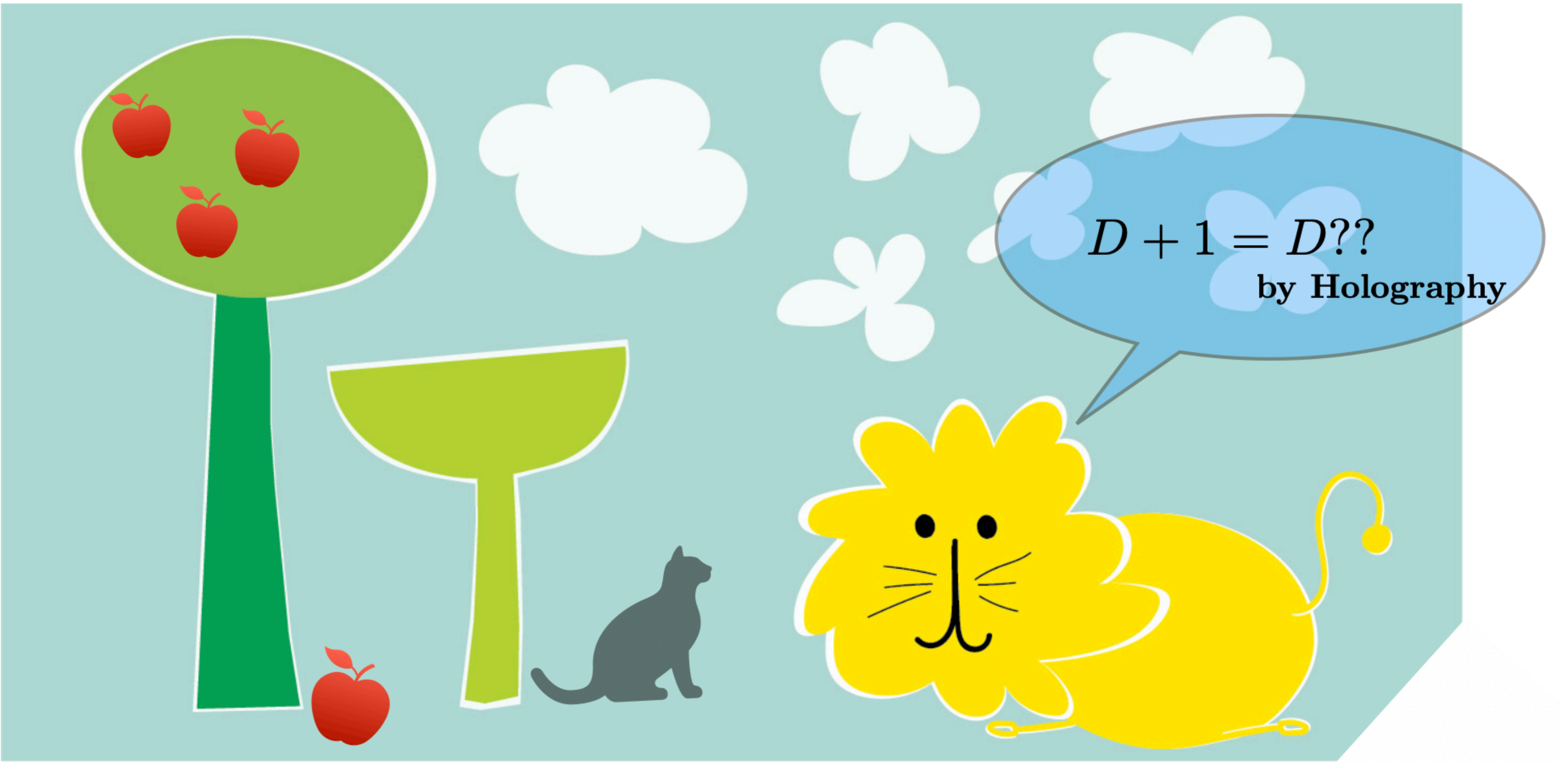
#10

Holographic c-theorem of the Entanglement Entropy

Beyond standard RG flows

Chanyoung Park & **Jung Hun Lee**
Department of Physics and Photon Science, Gwangju Institute of Science and Technology (GIST), Korea

- **How an *aAdS* deformed by a scalar field is connected to a *RG flow (c-function of E.E)*.**
- **What kind of the *RG flow* (*sRG*, *cRG* and *bRG*) can occur depending on the value of parameters.**



Thank you for listening :)

#11

The Entanglement Contour as a Fine-Grained Probe of Entanglement Spreading

Ian MacCormack, University of Chicago

J. Kudler-Flam, IM and S. Ryu, *Holographic entanglement contour, bit threads, and the entanglement tsunami*, 1902.04654

IM, M.T. Tan, J. Kudler-Flam and S.Ryu, *Probing entanglement spreading after quantum quenches in non-thermalizing systems,* 18XX.XXXXX *(In Preparation)*

$$\mathrm{S}_{VN}(A) = \int_A dx s_A(x)$$

↓

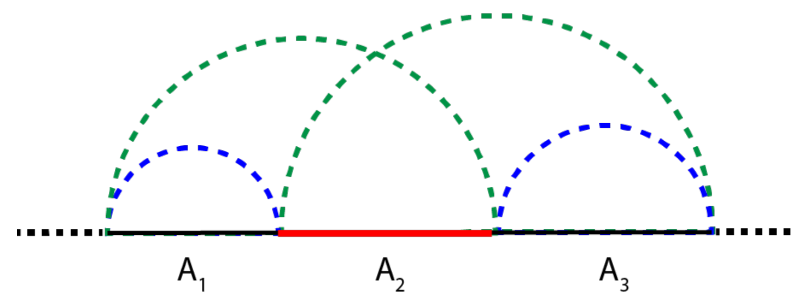
$$S(A) = \frac{1}{2}\sum_{i=1}^{n}\Big[S(A_i|A_1\cup\cdots\cup A_{i-1}) + S(A_i|A_{i+1}\cup\cdots\cup A_n)\Big]$$

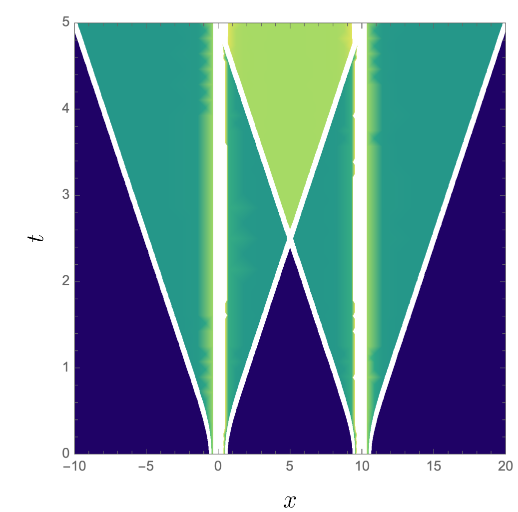
↓

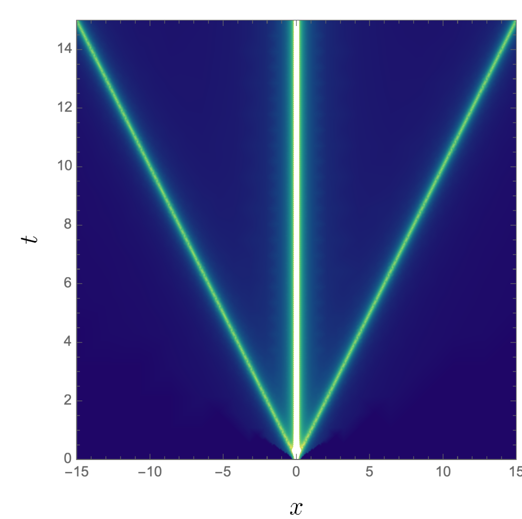
$$s_A(A_i) = \frac{1}{2}\Big[S(A_i|A_1\cup\cdots\cup A_{i-1}) + S(A_i|A_{i+1}\cup\cdots\cup A_n)\Big]$$

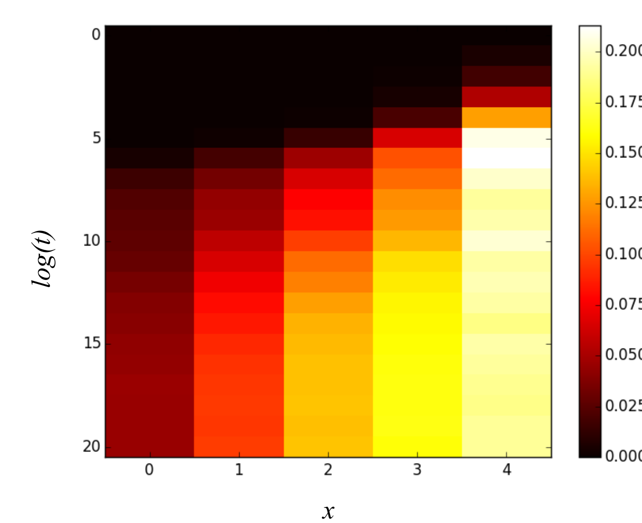
↓

$$s_A(A_2) = \frac{1}{2}\left[S(A_1\cup A_2) + S(A_2\cup A_3) - S(A_1) - S(A_3)\right]$$









#12

Holographic BCFT with Dirichlet Boundary Condition

In general, there are more than one consistent BCs for a theory. It is found that Dirichlet BC works as well as Neumann BC for holographic BCFT.

- Variation of the gravitational action

$$\delta I|_Q = -\int_Q \sqrt{h}\left(K^{\alpha\beta} - (K - T)h^{\alpha\beta}\right)\delta h_{\alpha\beta}. \tag{1}$$

- Takayanagi's proposal: Neumann BC

$$\left(K^{\alpha\beta} - (K - T)h^{\alpha\beta}\right)|_Q = 0, \tag{2}$$

- My proposal: Dirichlet BC

$$\delta h_{\alpha\beta}|_Q = 0. \tag{3}$$

- They both give the correct one point functions

$$\langle T_{ij}\rangle = -2\alpha_d \frac{\bar{k}_{ij}}{x^{d-1}}, \quad x \sim 0. \tag{4}$$

#13

It from Qubit School / Workshop, Quantum Information and String Theory 2019

Jackiw-Teitelboim Gravity and Rotating Black Holes

Upamanyu Moitra
Department of Theoretical Physics
Tata Institute Fundamental Research
India

Based on arXiv:1905.10378 [hep-th]: U. M., S. K. Sake, S. P. Trivedi, V. Vishal

Key Results:

- Demonstration of how the Jackiw-Teitelboim model correctly captures the leading thermodynamic behaviour of nearly extremal black holes, including rotating ones
- Verification with explicit calculations for rotating black holes in five-dimensional AdS and rotating, dyonic black holes in four-dimensional AdS; comment on possible applications to black holes in the sky

YUKAWA INSTITUTE FOR THEORETICAL PHYSICS

Supported by the Department of Atomic Energy, Government of India and the Infosys Endowment for Research on the Quantum Structure of Spacetime

Additional Support (Towards Participation) from the Organisers of the Workshop

tata institute of fundamental research

#14

Holographic description of the operator size and complexity growth

- There is the correspondence between momentum of probe(particle or something else) and the operator size(Susskind)
- Chemical potential disrupts chaos - we show how the holography describes this. Critical charge in terms of local butterfly velocities(1806.05574)
- We calculate the holographic complexity of operator growing at finite temperature 2d CFT (1902.03632)
- What this correspondence can tell us about the thermalization: collapsing black hole momentum(work in progress)
- Can we observe the operator support(size) decay somehow?(work in progress)

#15

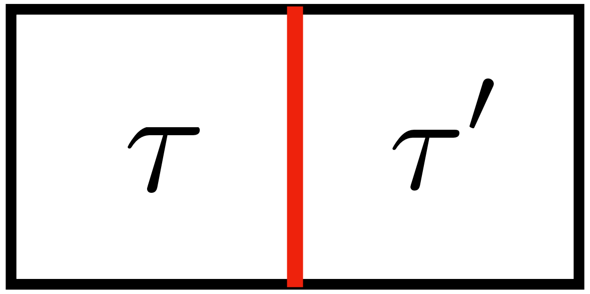
Interface Entropy in 4d N=2 SCFTs

Lento Nagano (Univ. of Tokyo)

based on a work in progress
with K. Goto, T. Nishioka, and T. Okuda

- construct a Janus interface in a 4d N=2 SCFT
- define its entropy by an entanglement entropy
- compute this entropy via SUSY localization

Interface entropy ∝ Calabi's diastasis



(a particular linear combination of analytically continued Kahler potentials)

#16

#17

Kento Osuga (17) : Super Airy Structures

UNIVERSITY OF ALBERTA

2d Gravity

- Kontsevich-Witten
- JT Gravity
- Topological String
- Matrix Models
- Topological Recursion

Airy Structure

⬇

recursive formalism for many interesting quantities!!

Algebraic Geometry

- Gromov-Witten
- Mirror Symmetry
- Chern-Simons
- CohFT
- KdV Hierarchy

⇩?

Supersymmetric 2d Gravity ??

Supersymmetry ✓

Super Airy Structures !!

⇩?

Supersymmetric Algebraic Geometry ??

#18

#19

Entropy and modular Hamiltonian for a free chiral scalar in two intervals

R. Arias, H. Casini, M. Huerta, D. Pontello
Centro Atómico Bariloche and Instituto Balseiro

The problem studied

$$A = (a_1, b_1) \cup (a_2, b_2)\,.$$

- The theory of (derivatives) of the free chiral scalar field $j(x^+) \stackrel{\text{def}}{=} \partial_+ \phi(x^+)$, with commutator

$$[j(x), j(y)] = i\,\delta'(x-y)\,,$$

Hamiltonian

$$H = \int_{-\infty}^{-\infty} T(x)\,dx\,, \qquad T(x) = \frac{1}{2} j^2(x)\,,$$

and vacuum state defined through (+ Wick theorem)

$$F(x-y) = \langle j(x) j(y) \rangle = -\frac{1}{2\pi} \frac{1}{(x-y-i\,0^+)^2}\,.$$

- For CCR algebra and a gaussian state, the modular Hamiltonian can be expressed as

$$K_A = \int_{A\times A} j(x)\,\mathcal{K}_A(x,y)\,j(y)\,dx\,dy\,,$$

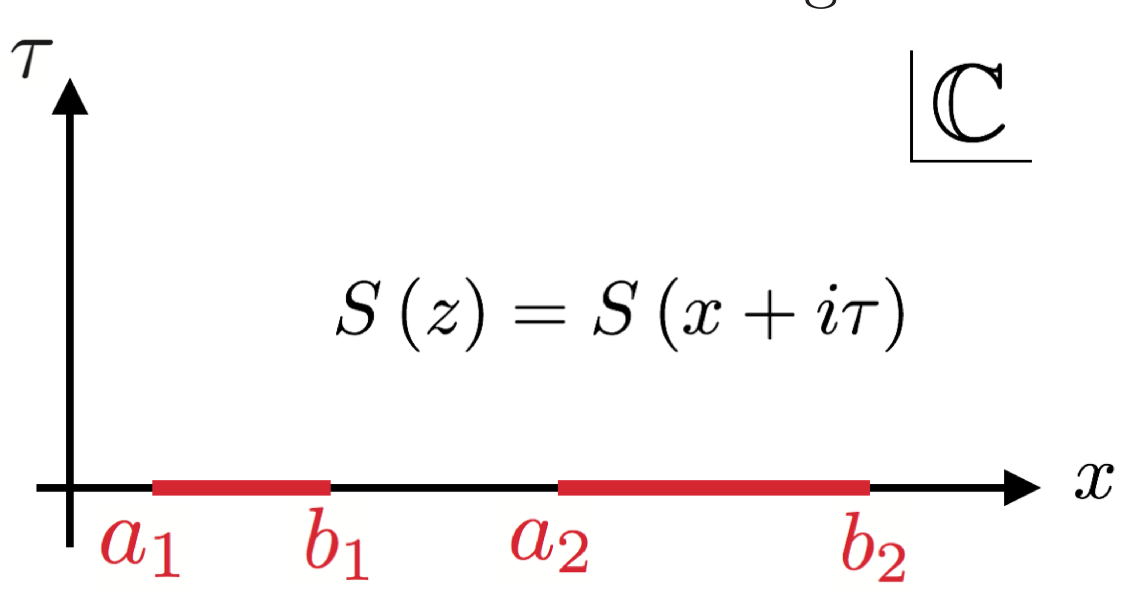
and the eigenvectors of the kernel $\mathcal{K}_A(x,y)$ coincides with the eigenvectors of $(\delta')^{-1} \circ F$.

The method

eigenvectors of $(\delta')^{-1} \circ F$

$\updownarrow$

holomorphic functions $S(z)$ on the complex plane with some specific boundary conditions on the region A.



The results

- **For single interval** $A = (a, b)$

$$K_A = 2\pi \int_a^b dx\, \frac{(b-x)(x-a)}{b-a} T(x)\,, \qquad S(A) = \frac{1}{6} \log\left(\frac{b-a}{\epsilon}\right).$$

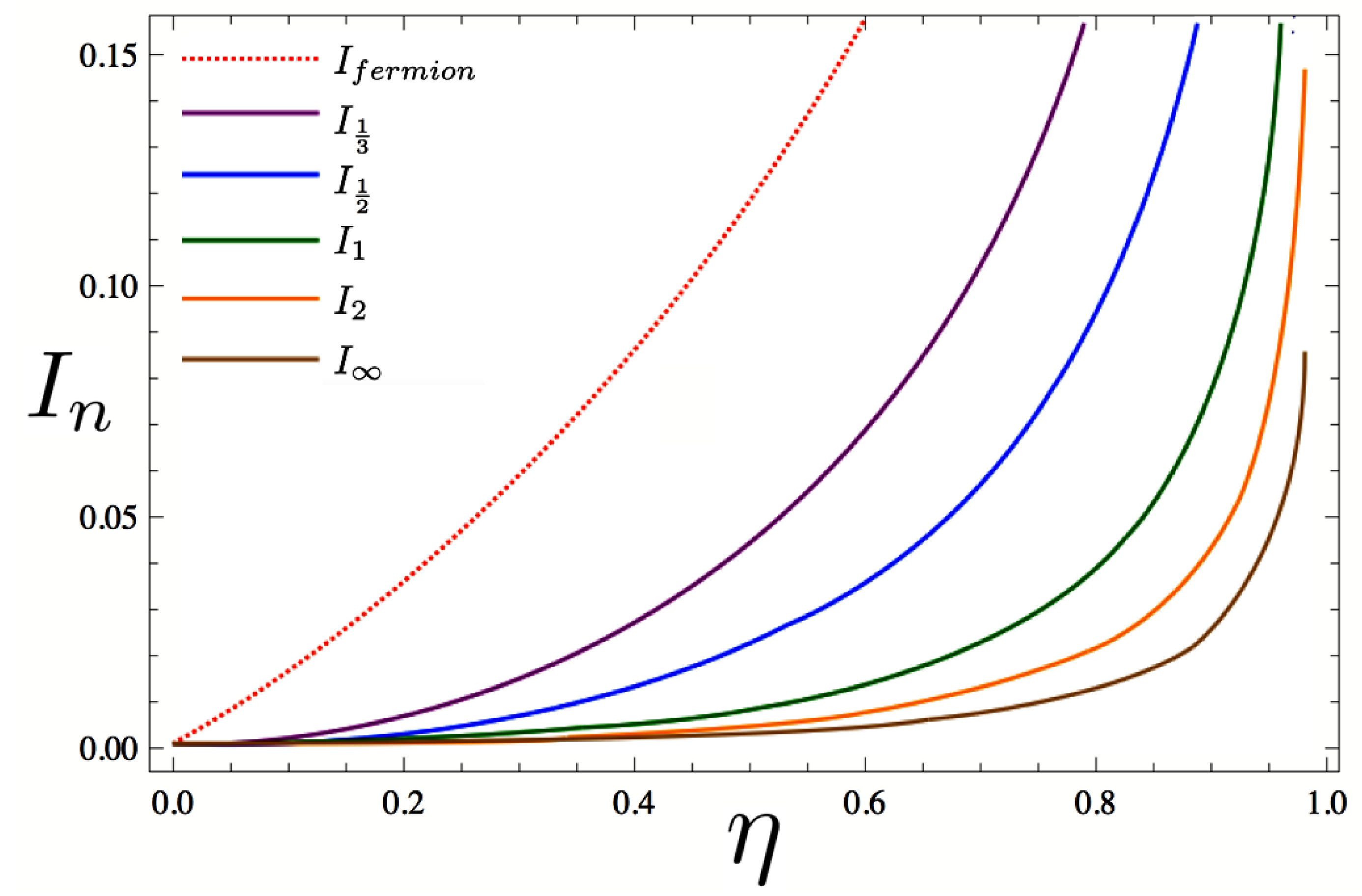
- **For two intervals** $A = A_1 \cup A_2 = (a_1, b_1) \cup (a_2, b_2)$

$$I_1(A_1, A_2) = \frac{1}{6} \log\left(\frac{1}{1-\eta}\right) - \frac{i\,\pi}{2} \int_0^\infty ds \frac{s}{\sinh^2(\pi s)} \log\left(\alpha(s,\eta)\right),$$

$$I_n(A_1, A_2) = \frac{n+1}{12n} \log\left(\frac{1}{1-\eta}\right) + \frac{i\,n}{2} \int_0^\infty ds \frac{\coth(n\pi s) - \coth(\pi s)}{n-1} \log\left(\alpha(s,\eta)\right).$$

where

$$\eta = \frac{(b_1-a_1)(b_2-a_2)}{(a_2-a_1)(b_2-b_1)} \in (0,1), \qquad \alpha(s,\eta) = \frac{{}_2F_1\left(1+is, -is; 1; \eta\right)}{{}_2F_1\left(1-is, is; 1; \eta\right)}.$$



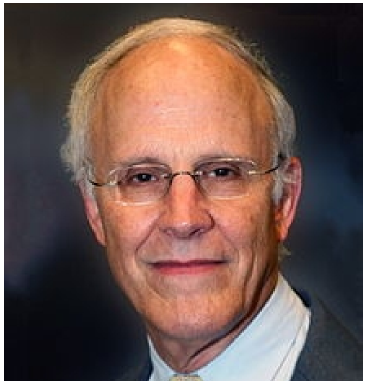
We also found a analytic expression (up to numerical integration) for the modular Hamiltonian kernel $\mathcal{K}_A$ which is completely non-local.

Discussion

Failure of the equality of the vacuum entanglement entropy for complementary regions

$$S(A) \neq S(A')\,.$$

#20



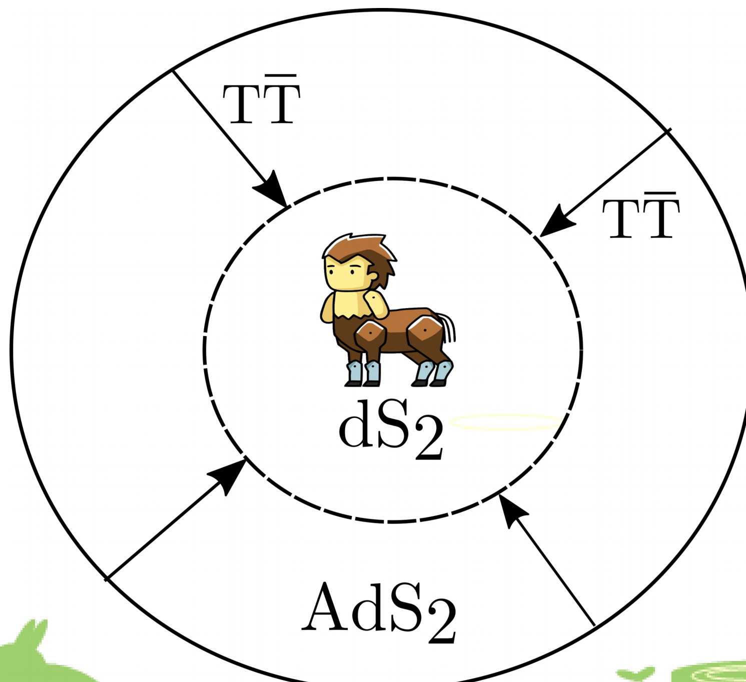
David Gross

Jorrit Kruthoff

Andrew Rolph

Edgar Shaghoulian

$T\bar{T}$, AdS_2 and Quantum Mechanics

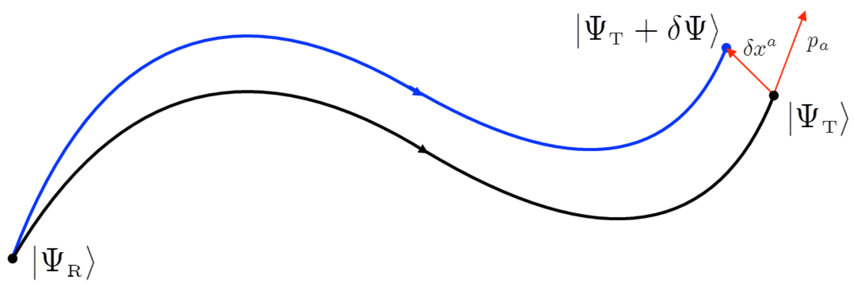


#21

#22

The First Law of Complexity

with A.Bernamonti, F.Galli, J.Hernandez, R.Myers, J.Sim´on



Circuit Complexity

$$\mathbf{C}\left(|\Psi_T\rangle\right) = \text{Min}\int_0^1 ds\; F\left(U(s), Y^I(s)\right)$$

$$\delta\mathbf{C} = p_a\,\delta x^a\Big|_{s=1} + \frac{1}{2}\,\delta p_a\,\delta x^a\Big|_{s=1} \qquad \text{with} \quad p_a = \frac{\partial F}{\partial \dot{x}^a}$$

AdS/CFT $\quad \mathscr{H}_{AdS} = \mathscr{H}_{\partial AdS}$

Semi-Classical gravity theory

AdS + Scalar

Vacuum State → Coherent State

Holographic Complexity

$$\mathbf{C}_A(\Sigma) = I_{WDW}/\pi\,.$$

$$\delta\mathbf{C}_A(\Sigma) = I_{mat}/\pi\,.$$

#23

“Bulk Reconstruction and Cosmological Singularities”

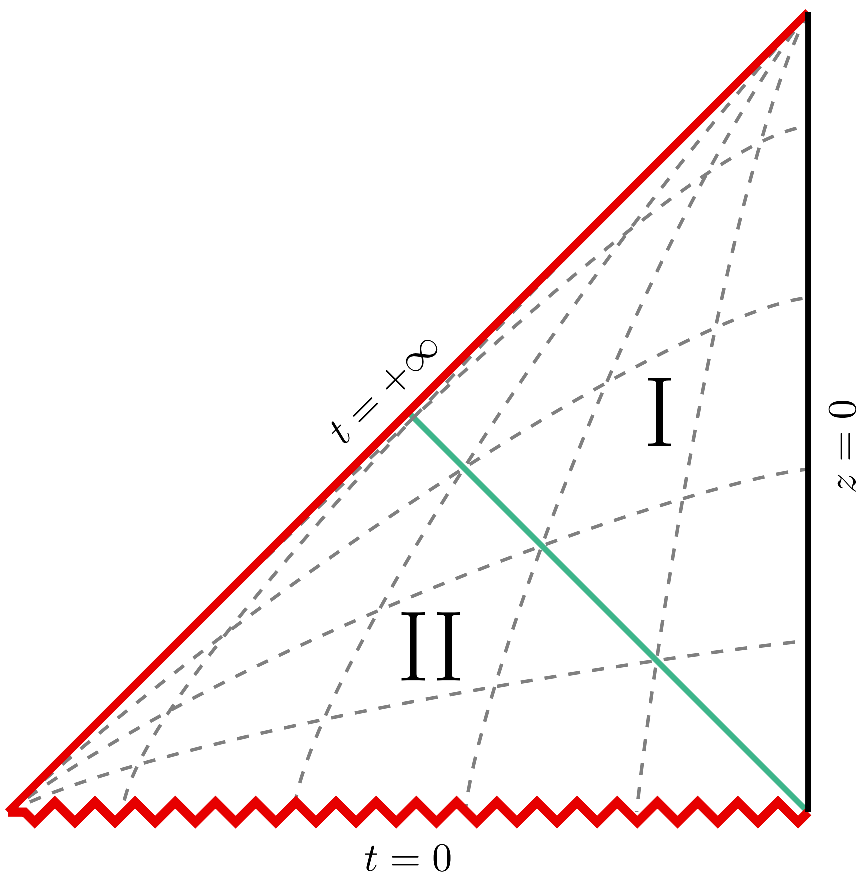
José L.F. Barbón, Martin Sasieta

arXiV:1906.04745

Kasner-AdS state

$$ds^2_{\mathrm{CFT}} = -dt^2 + \sum_{j=1}^{d-1} t^{\,2p_j}\, dx_j^2$$

$$ds^2 = \frac{dz^2 + ds^2_{\mathrm{CFT}}}{z^2}$$



I. Causal Reconstruction

- The singularity limits causal reconstruction to region I.
- Cannot solve bulk dynamics due to tidal singularities.

II. Modular Supremacy

- For specific subregions, the entanglement wedges enter arbitrarily deep into region II.
- Modular flow of a proper subalgebra is more powerful than the Hamiltonian flow of the whole algebra.

Instituto de Física Teórica UAM-CSIC

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#24

#25

㉕ Ryoto Tange, June 26, 2019

Survey on quantum algorithms for Jones polynomials from knot theory

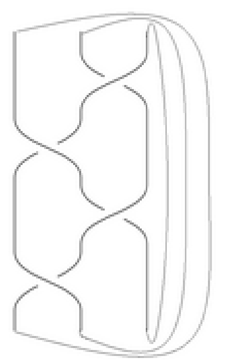
$\langle \bigcirc \rangle = 1,$

$\langle \times \rangle = a \langle)(\rangle + a^{-1} \langle \asymp \rangle,$

$\langle \mid \cup \bigcirc \rangle = (-a^{-2} - a^{2}) \langle \mid \rangle.$

$\langle \times \rangle = a^{-1} \langle)(\rangle + a \langle \asymp \rangle,$

knot → braid



$B_3 \to \mathrm{U}(2)$

$\sigma_1 \mapsto A_1$

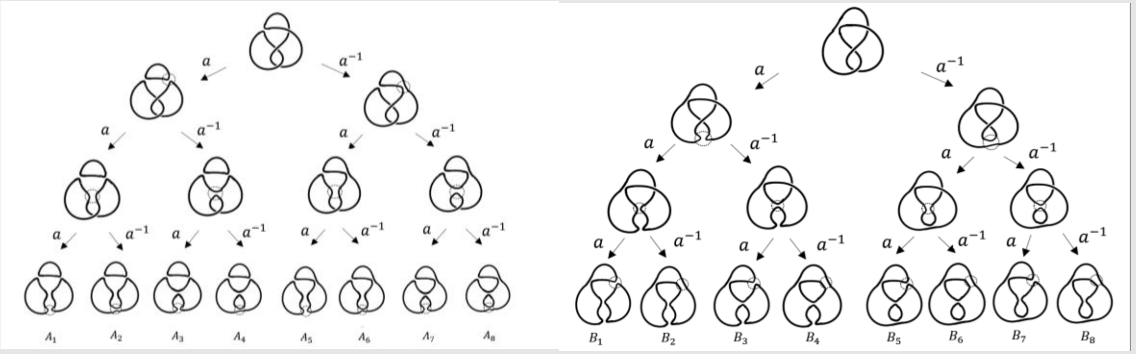
$\sigma_2 \mapsto A_2$

B_3 : 3-strand braid group

$\mathrm{U}(2)$: unitary group of deg. 2

$\sigma_2^{-1}\sigma_1\sigma_2^{-1}\sigma_1 \longmapsto A_2^{\dagger}A_1A_2^{\dagger}A_1$

Kauffman bracket



Jones polynomial

classical algorithm

$$J(q) = q^{-2} - q^{-1} + 1 - q + q^{2}$$

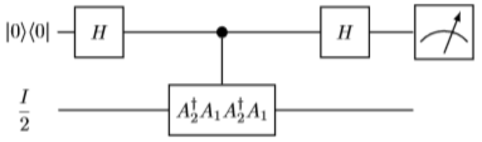
n-th root of unity $q = e^{\frac{2\pi\sqrt{-1}}{n}}$

$$J\left(e^{\frac{2\pi\sqrt{-1}}{n}}\right)$$

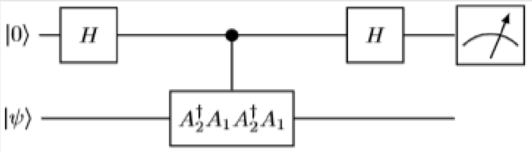
Markov trace

quantum algorithm

Hadamard test

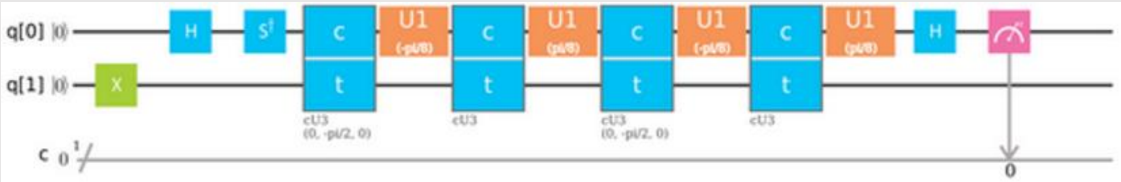


DQC1 (in Q#)



$|\psi\rangle = |0\rangle, |1\rangle$

||



IBM Q

braid index, Arf invarint (n=4),
volume conjecture, topological quantum computing (n=5), etc.

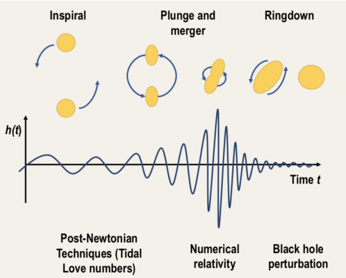
#26

Exploring strong-field deviations from general relativity via gravitational waves

Gabriel Treviño Verástegui

University of California Santa Barbara

- LIGO/Virgo: **Strong-field in GR**
- Are nature's black holes the black holes of general relativity?
- We use a **toy model** and a **tidal Love number analysis** to constraint possible **quantum** deviations from GR, in the description of **BHs**, using observations from gravitational waves



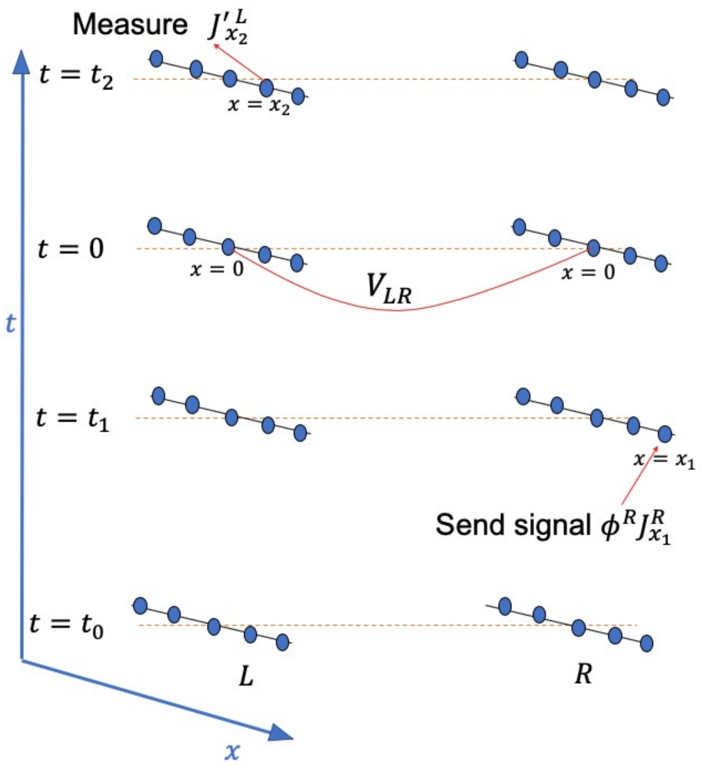
#27

Regenesis in Random Unitary Circuits

Shreya Vardhan, MIT
Work with Hong Liu

The phenomenon of regenesis

- Holographic dual of traversable wormhole, argued to exist in generic chaotic systems.
- Two copies of system, in initial state which evolves to thermofield double at $t = 0$.

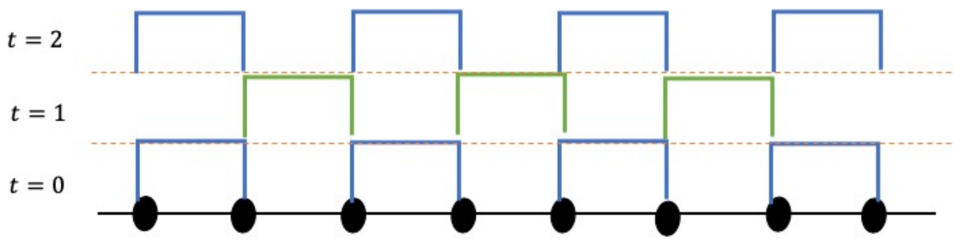


- $\langle J'^{L}_{x_2} \rangle = G_{LR}(t_2, x_2; t_1, x_1)\, \phi^R$

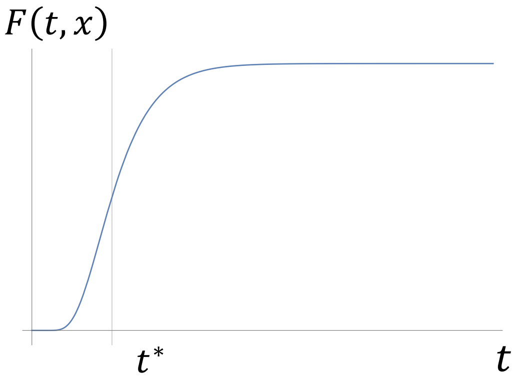
When $t \gg t^*$, $G_{LR}(t, x; -t, x)$ is $O(1)$. **Signal can be recovered in L long after it has been lost due to scrambling in R.**

Setup and results

Within each system, evolution by local random unitaries from Haar measure. Unitaries in the two systems are correlated.



- $\overline{G_{LR}}(t, x; -t, x) = C(g)\, F(t, x)$ for all t, where $F(t, x) = 1 - f(t, x)$, and $f(t, x)$ is the out-of-time-ordered correlator for any two operators. With fixed x,



- Matches general expectation at early and late times.
- Different from chaotic CFT result at intermediate times.
- $C(g)$ takes variety of forms depending on the coupling V_{LR}.

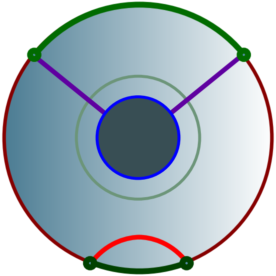
#28

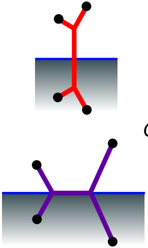
Black holes and large-c BCFTs

David Wakeham (UBC)

- **AdS/BCFT**: CFT_2 with boundary $=$ AdS_3 with brane
  $+$ Euclidean time evolution $=$ BTZ with brane

bulk EE
geodesic lengths





CFT EE
twist correlators

- **Matching EE**: (1) gives microscopic evidence for AdS/BCFT and (2) constrains holographic BCFTs.

#29

Qiang Wen， **Shing-Tung Yau Center of Southeast University**

- Entanglement contour function quantifies the contribution from the degrees of freedom in any subset to the total entanglement entropy
- Entanglement contour read from a natural slicing of the entanglement wedge.
- Entanglement contour from the subset entanglement entropies
- Entanglement contour for annuli and spherical shells

#30

Covariant Phase space with Boundaries

Jie-qiang Wu (MIT CTP)

- In this work, we study the covariant phase space formalism with more careful treatment of the boundary effect
- We keep the boundary terms in Lagrangian density, symplectic potential and symplectic form
- We derive the Hamiltonian from $\Omega[\cdot, \delta_\xi \phi] = \delta H_\xi$
- In our formalism, the left hand side is automatically a total derivative only assuming that the configurations satisfy the equations of motion and boundary conditions
- We study our formalism in different examples and the results are consistent with previous result obtained by non-covariant formalism
- One interesting example is the Jackiw-Teitelboim gravity, where we can explicitly solve the phase space and compute the symplectic form which captures all of the classical effect
- Open question: edge mode, gravity dressing

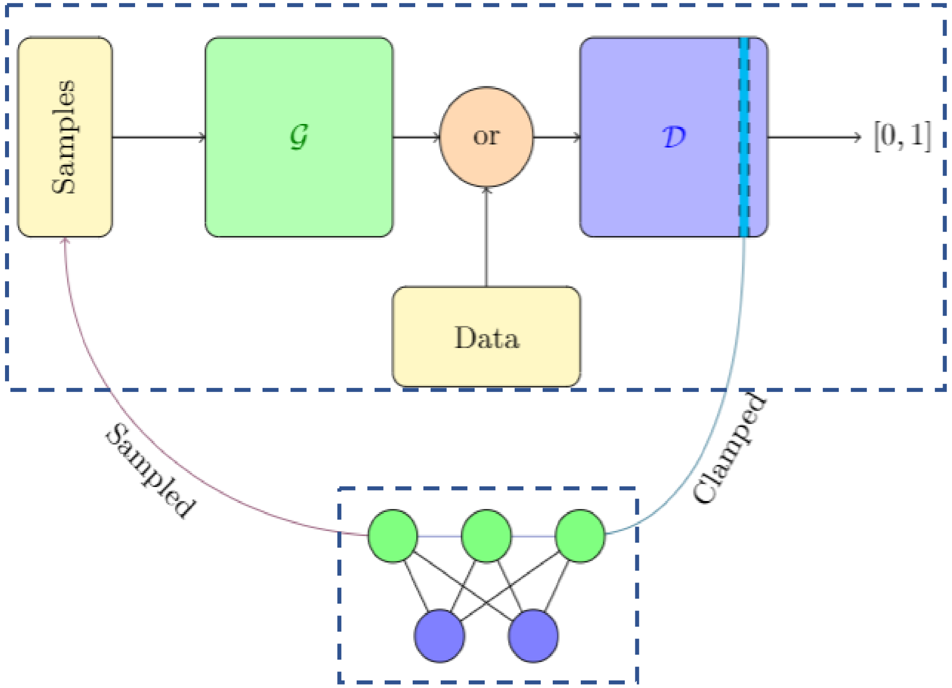
#31

Quantum-Classical Associative Adversarial Networks

Cristian Zanoci and Eric R. Anschuetz, *MIT*

Model

Generative Adversarial Network



Quantum Boltzmann Machine

Data

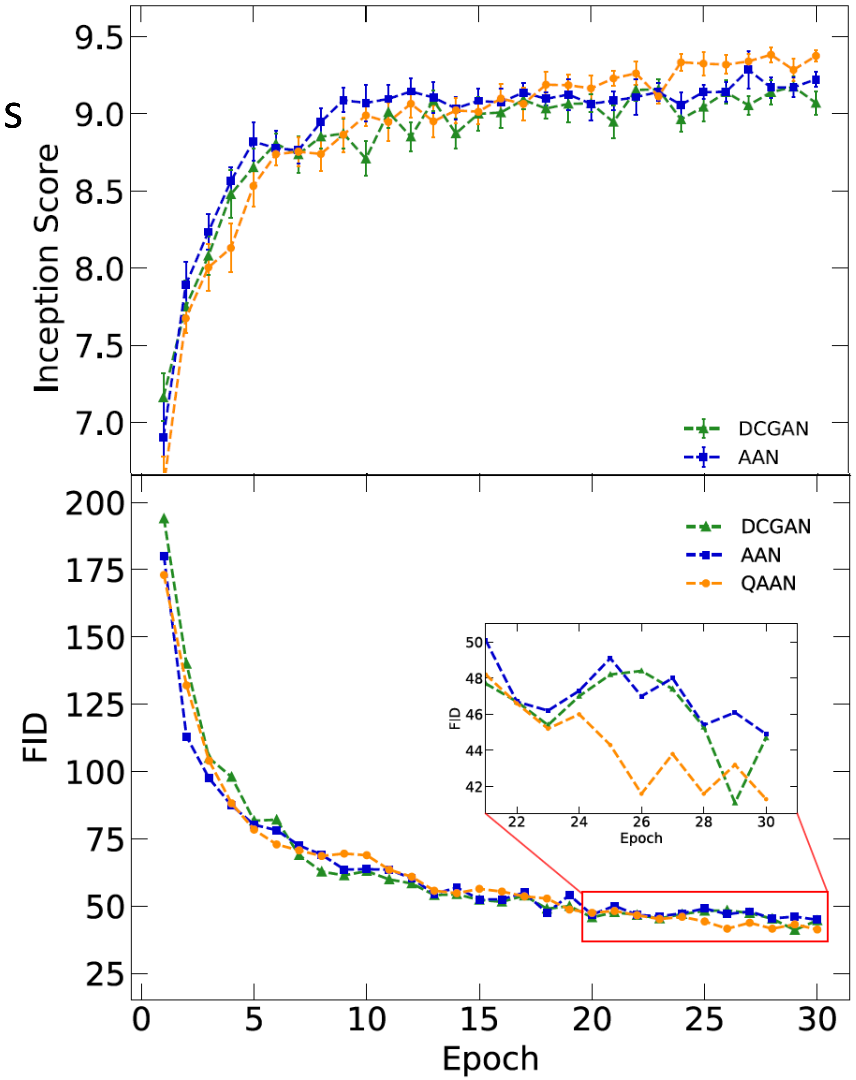
MNIST handwritten digits:

- 28x28 pixel grayscale images

CIFAR-10 nature pictures:

- 32x32 pixel colored images

Results



- Implementable on near-term quantum devices
- Outperforms its classical counterpart