What is String Theory?
- a Visually Challenged Perspective

Rajesh Gopakumar, ICTS-TIFR, Bengaluru;

Strings 2022, Vienna

Perspectives and Prospects Session

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Ways of (not) Seeing

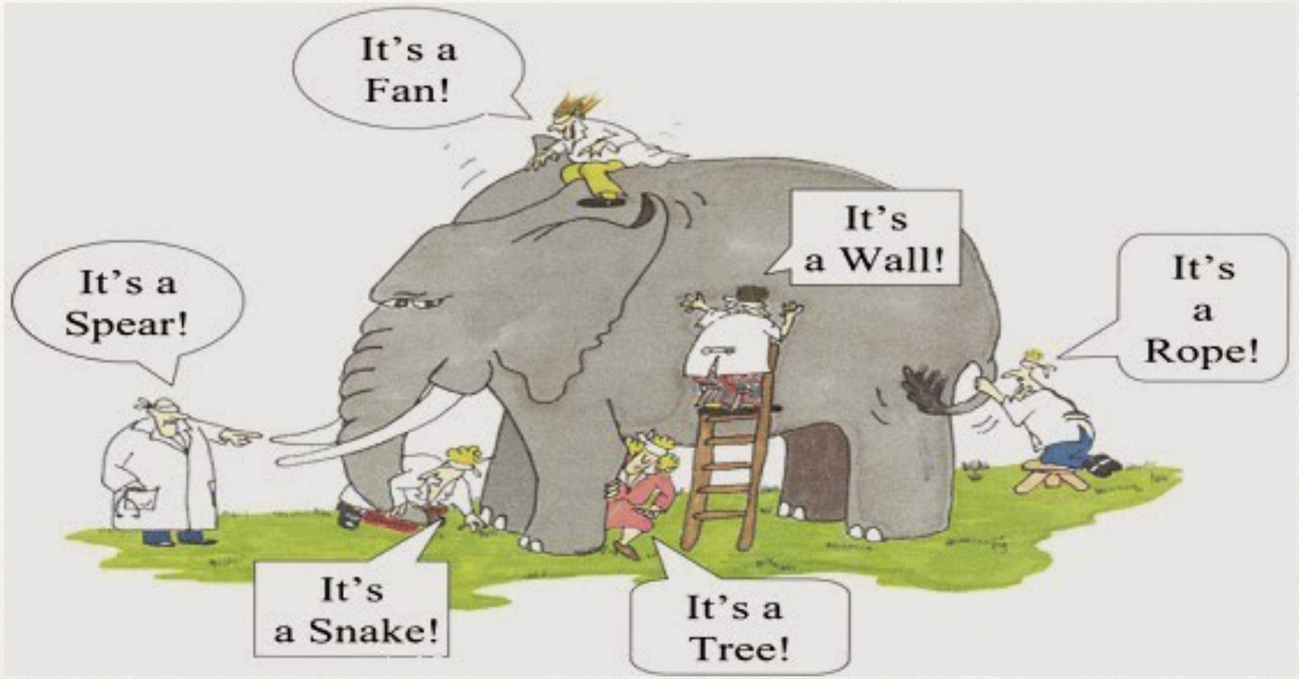
- What is the elephant (in this room!) that we have all been grappling with?

- It was six men of Indostan
  To learning much inclined,
  Who went to see the Elephant
  (Though all of them were blind),
  That each by observation
  Might satisfy his mind

  .....

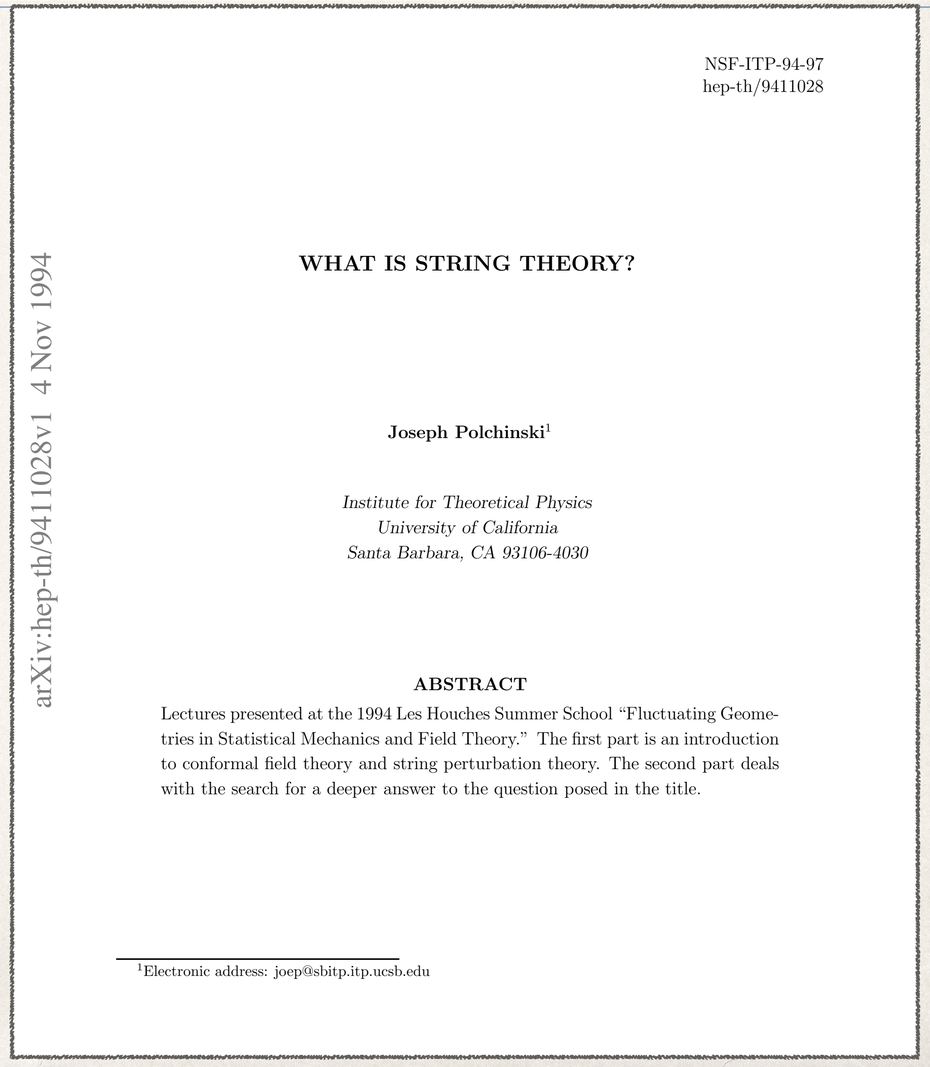
  And so these men of Indostan
  Disputed loud and long,
  Each in his own opinion
  Exceeding stiff and strong,
  Though each was partly in the right
  And all were in the wrong!

John Godfrey Saxe (1872)



What is String Theory? - Redux

- Nearly 30 years ago, Polchinski posed the question.
- *`I think there is good reason to expect that an equally powerful organizing principle remains to be found….The nature of the organizing principle is at this point quite open, and may be very different from what we are used to in quantum field theory.'*
- KITP Program (Jan. 8- Apr.19, 2024) :`What is String theory? Weaving Perspectives Together'.
- *Organisers*: Lara Anderson, R.G., Mukund Rangamani & Xi Yin; *Advisers*: J. Maldacena, A. Sen & E. Witten.



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WHAT IS STRING THEORY?

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ABSTRACT

Lectures presented at the 1994 Les Houches Summer School "Fluctuating Geometries in Statistical Mechanics and Field Theory." The first part is an introduction to conformal field theory and string perturbation theory. The second part deals with the search for a deeper answer to the question posed in the title.

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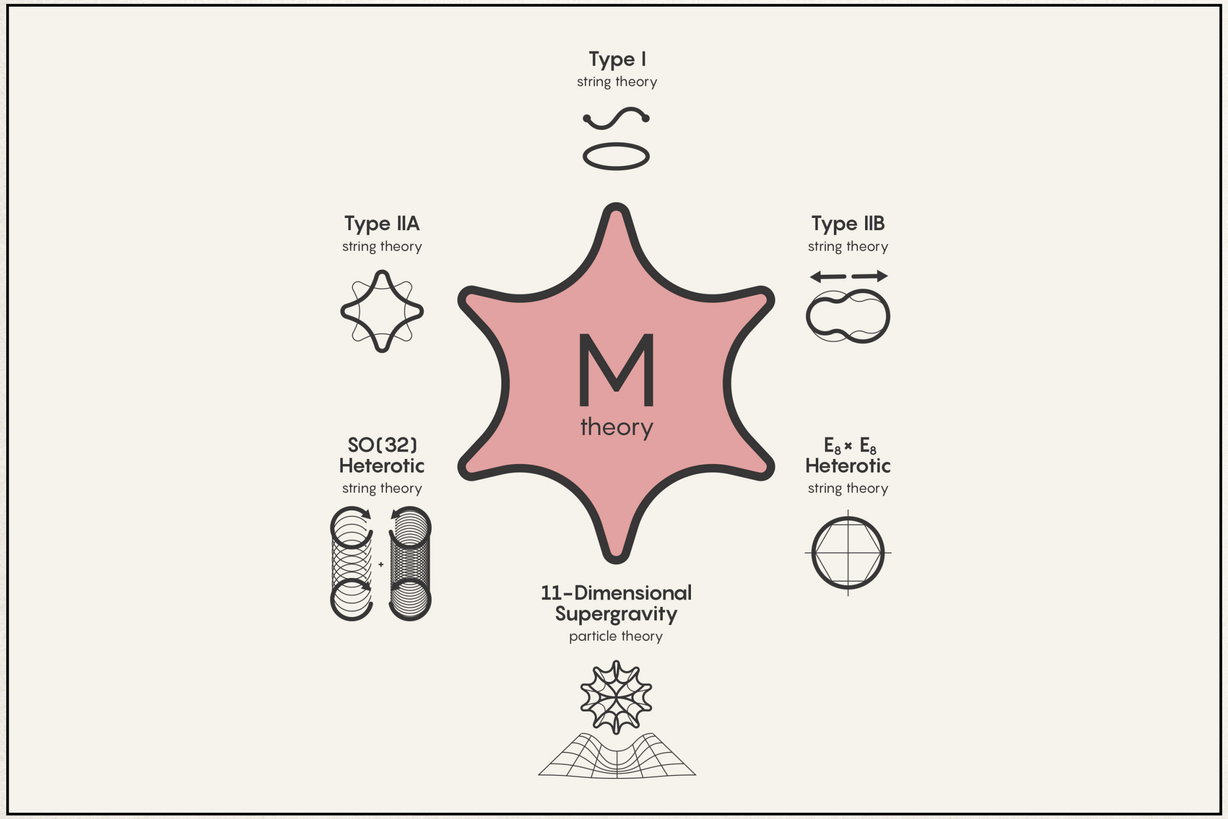
Joe's Elephant



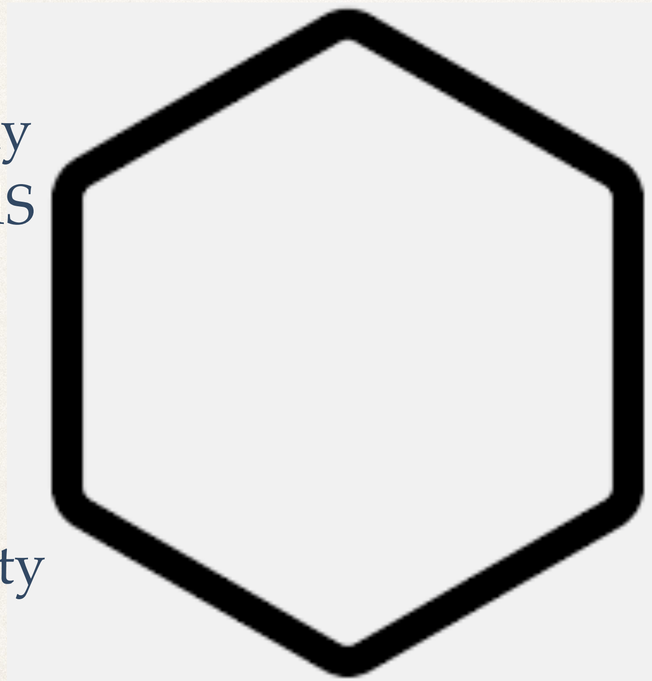
- Soon after 1994, post the discovery of string dualities (D-branes!), Polchinski had his own version of the Elephant (or Amoeba?).
- Different looking perturbation expansions as corners of a (still) mysterious quantum entity.
- Gave confidence in the existence of a non-perturbative completion.
- What is M-Theory? What are its central organising principles?

The Hexagon Program

Spacetime and Qtm. Info.

Holography
Beyond AdS

Deriving
Dualities



EFTs and
Qtm. Gravity

SFT &
Dynamics

String Compactifications
& Our World

- More recently, especially with AdS-CFT, a large number of new insights into questions of Qtm. Gravity and QFT.
- Simultaneously, multiple new tools and powerful techniques. But often disconnect amongst experts.
- KITP'24 Program: Six themes with cross-resonance.
- An attempt to synthesise these strands.
- For experts in subdomains to ask new questions and approach existing puzzles from a novel perspective.

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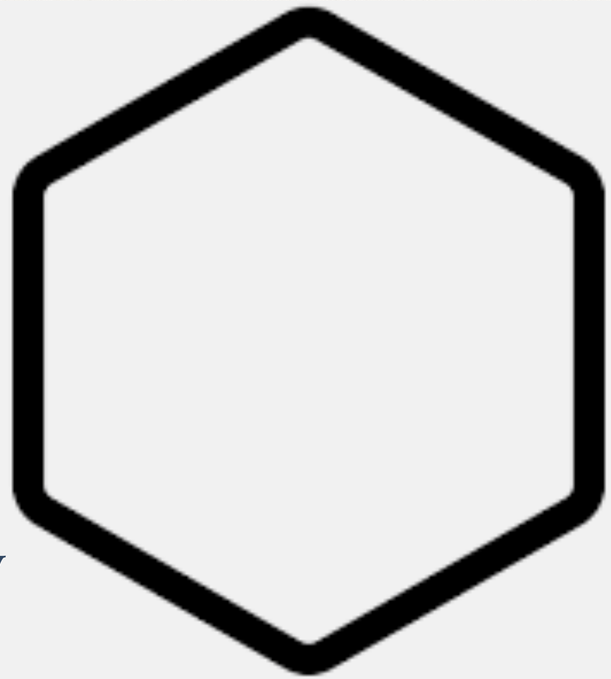

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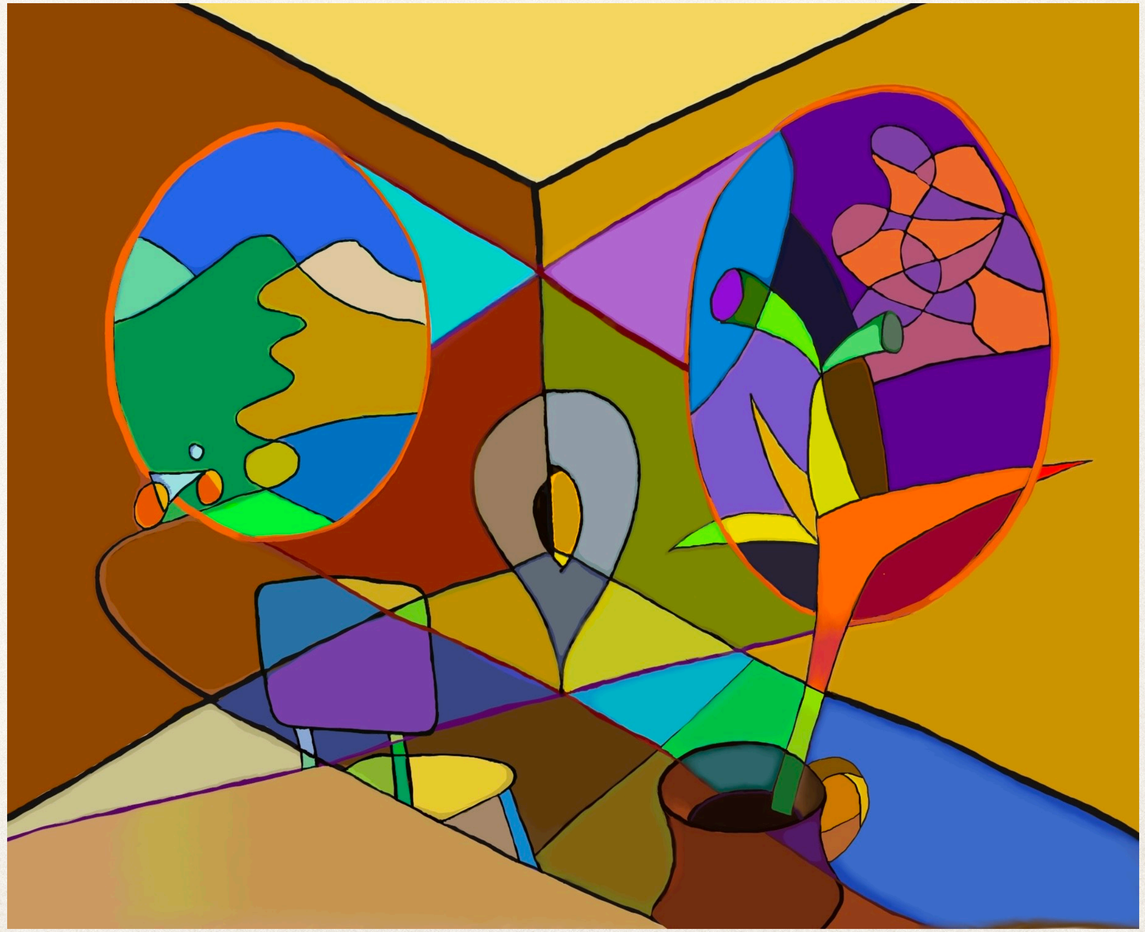

[Artwork by Xi Yin]

Six Interlacing Themes

- Spacetime & Qtm. Info. @ String Scale: How do (semiclassical) developments in BH physics connect to a microscopic classical string theory?
- Deriving Dualities and new approaches to QFT: How exactly do gauge theories encode qtm. grav. phenomena? Holographic duals to non-SUSY gauge theories? New geometric approaches to QFT and scattering amplitudes.
- Holography beyond AdS: In asymptotically flat and expanding universes. Celestial holography and the worldsheet? de Sitter?
- String Field Theory & Dynamics: Off-shell formulation and non-perturbative contributions. Time dependent backgrounds in string theory. Open-closed string duality.
- EFTs and the Swampland: How to characterise EFTs that have a consistent UV completion? Constraints from S-matrix and Conformal bootstrap (dispersion relations etc.).
- String Compactifications: Constrain EFTs from String theory to model our universe (SM-like and dS vacua, inflation).

Worldsheet vs. Spacetime

- Highlight an underlying cognitive dissonance between the worldsheet perspective and a more spacetime one. Might be fruitful to address.
- In Joe's 1994 lectures and ``Big Book of Strings", the worldsheet had the starring role.
- Now: Spacetime dynamics has taken centre stage - D-branes & AdS-CFT.
- Which spacetime? Bulk or Boundary?
- Is the worldsheet perspective irrelevant?
- NO! Only UV complete description of gravity; how we arrived at AdS/CFT.

A Personal Perspective

- Different machineries and intuition in these two approaches.
- How to bring the two viewpoints closer in consonance?
- Offer a few remarks which have guided my own thinking - `clutching at straws' - mostly in a narrow context (but perhaps of wider applicability).
- Gleaned from my collaboration with Matthias Gaberdiel et.al. on tensionless limit.
- Also discussions with Snowmass ``*Bootstrapping String Theory*" co-authors: Eric Perlmutter, Silvia Pufu and Xi Yin.

Six Straws

- Fundamental Discreteness on the worldsheet.
- Gross-Mende like limits.
- Role of Higher Spin/Extended Symmetry.
- A Worldsheet-Spacetime Correspondence.
- Open-Closed-Open Triality.
- Bulk spacetime as a construct, even for closed strings?

QuBit from Bit?

- String Bit picture of worldsheet (Thorn, Klebanov-Susskind).
- Seems to be realised in the tensionless limit of AdS/CFT - worldsheet is semi-rigid - can take only specific shapes (discrete points on $\mathscr{M}_{g,n}$). Also in Matrix Models (w/ E. Mazenc).
- String bits trace out ribbon graph strips - glued together by gauge constraint.
- Also seen in BMN spin chain picture of perturbative gauge theories. (When is it Integrable?)
- Bits correspond to the Qubits of the hologram (transverse d.o.f.)?
- This discreteness is different from quantum discreteness of $\frac{1}{N}$.

High Energy Limits

- Tensionless limit of AdS/CFT also a bit like Gross-Mende limit (flat space). Localised contributions to interior points in $\mathscr{M}_{g,n}$ via scattering equations.
- Interesting to take a further (BMN-like) limit of large operators ($\Delta_i \to \infty$).
- Discrete points on $\mathscr{M}_{g,n}$ effectively become a continuum.
- Realised explicitly in AdS_3/CFT_2. Each Feynman graph is a "saddle point".
- The saddle string configurations very similar to Gross-Mende $\sim \sum_i \Delta_i \ln|z - z_i|$.
- Need a better spacetime interpretation (Cf. Polchinski-Strassler: Soft scattering → Power Law).

Unbroken Symmetry

- High Energy String scattering suggests a large hidden symmetry (Gross).
- Indeed, Vasiliev like higher spin symmetry part of tensionless limit in AdS.
- Organises the spectrum into very large multiplets (Bianchi et.al).
- But how effectively does it constrain correlators? How does it govern the "Higgsed phase" - when string tension $\neq 0$?
- Presence of HS symmetry in spacetime seems to be tied to having a free theory on the worldsheet. Can we make this precise?

Worldsheet-Spacetime Correspondence

- UV limit of worldsheet ↔ IR in AdS_{d+1}↔ UV limit of CFT_d.
- Again, a more direct correspondence between the worldsheet (CFT_2 ?) and the holographic spacetime description (CFT_d).
- Physical states of worldsheet CFT_2 ↔ Physical operators of sp-time CFT_d.

$$Z(\beta) = \mathrm{Tr}_{ST}[e^{-\beta H}]; \qquad \ln Z(\beta) = \int_{\mathcal{F}} \frac{d^2\tau}{\tau_2} Tr_{WS}[q^{L_0}\bar{q}^{\bar{L}_0}]$$

- Strong constraint on the spectrum of both sides.
- Worldsheet gauge constraints (gluing bits) ↔Sp-time gauge constraints (entangling qubits)

WS-ST Correspondence (Contd.)

- Similarly, short distance behaviour (OPE) on WS ↔ short distance OPE on ST.
- Analogous to factorisation of flat space S-matrix on poles (IR) - from WS OPE.
- Seems to imply seemingly unfamiliar bootstrap conditions on spacetime OPE from existence of worldsheet OPE and vice versa. Or is it a tautology?
- Might be good to clarify this in weakly coupled gauge theories.
- Worldsheet reflection of spacetime features closest for holographic dual.

Last Straw(s)

- D-branes around large radius AdS (flat space) give open string description appropriate for large λ. Closed strings are insertions at vertices of graphs - “V-type”.
- Giant graviton D-branes at small radius AdS give another open string description, appropriate to small λ. Closed strings from faces of graph - “F-type”.
- Perhaps useful to explore this Open-Closed-Open Triality.
- Draw the worldsheet descriptions closer to the holographic spacetime.
- And perhaps bulk spacetime seen as a construct even from the closed string point of view e.g. twistor like variables with spacetime from incidence relations (bilinears).

"One can ask whether the situation today in string theory is really as favorable as it was for field theory in the early 60's. It is difficult to know. Then, of course, we had many more experiments to tell us how quantum field theories actually behave. To offset that, we have today more experience and greater mathematical sophistication. As an optimist, I make an encouraging interpretation of the history, that many of the key advances in field theory—Wilson's renormalization group, the discovery of spontaneously broken gauge symmetry as the theory of the electroweak interaction, the discovery of general relativity itself—were carried out largely by study of simple model systems and limiting behaviors, and by considerations of internal consistency. These same tools are available in string theory today. "

–Joe Polchinski

Thank you for your indulgence!