String Theory and Applications

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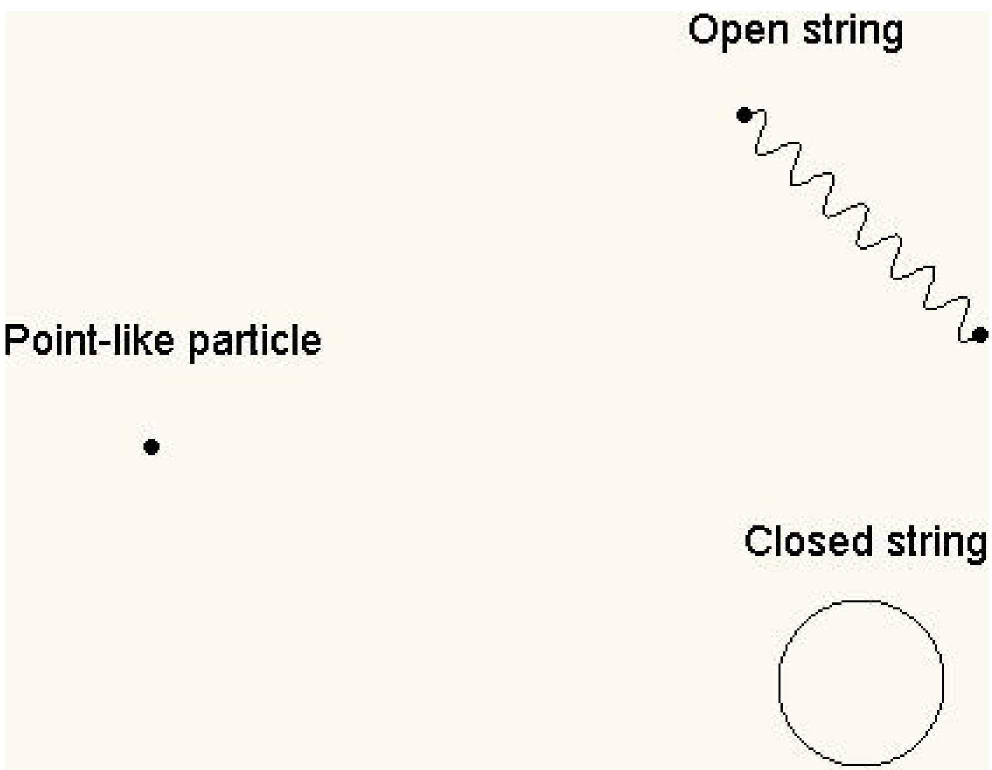
Contents (plan of the talk)

1. Basics

• Basic idea of string theory: replace elementary point-like particles with (elementary) strings.

• Various particles arise as different vibrational (excitation) modes of the string.



• Strings are characterized by their tension T (or equivalently length scale l_s):

$$T = \frac{1}{2\pi l_s^2}$$

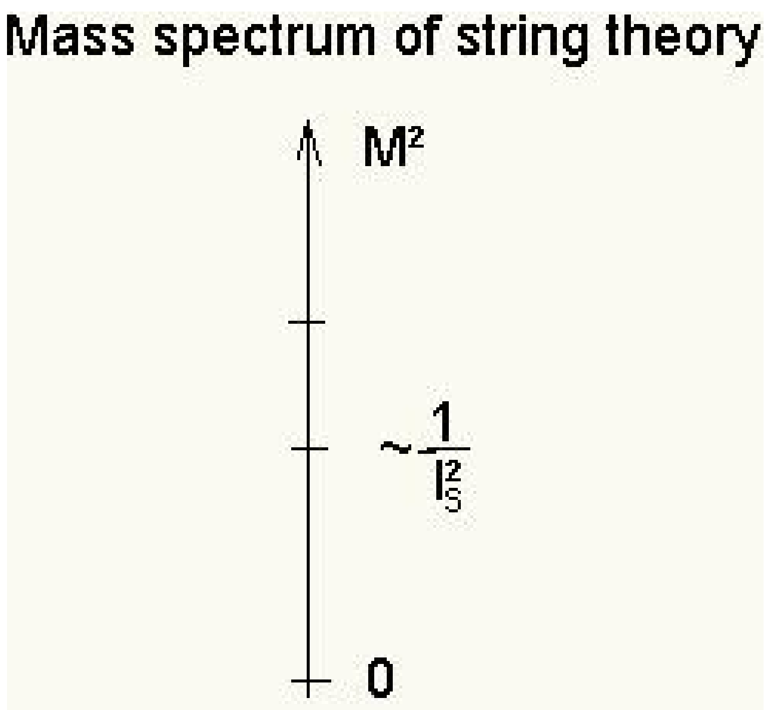
• The string scale is typically taken to be of the order of magnitude of the Planck length ($\sim 10^{-33}$cm), but there are models where this scale can be larger.

• The string coupling constant g_s is determined dynamically by the vev of one of its massless excitations: the so-called dilaton.

$$g_s = e^{<\phi>}$$

• On length scales much larger than l_s the string excitations will have a good description as point-particle states (low energy effective field theory).

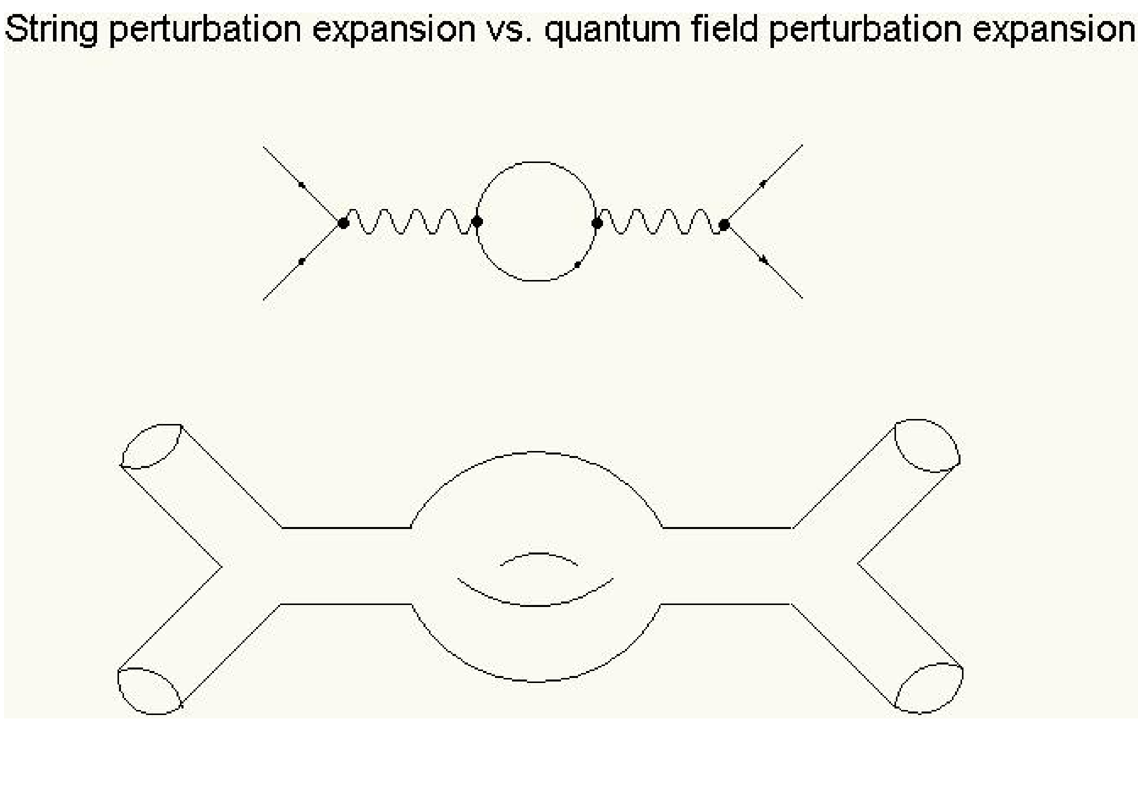
• The mass spectrum contains a massless level followed by an infinite tower of massive modes which are inaccessible at low energy.



• Only the massless spectrum is relevant for low-energy phenomenology.

• Closed strings contain a massless mode (particle) that can be identified with the graviton.

• String perturbation theory has no point-like interaction vertices. It is UV finite, thus a theory containing closed strings includes a consistent theory of Quantum Gravity.



2. Classification

- There are 5 consistent superstring theories:

Heterotic $E_8 \times E_8$,
Heterotic $SO(32)$,
Type IIA,
Type IIB,
Type I.

- They are well defined only in 10 dimensions, thus building a realistic model requires compactification of six extra-dimensions.

$$\mathrm{Space-time} = \mathrm{M}^4 \times \mathrm{K}^6$$

M^4 is four dimensional Minkowski space-time.
K^6 is a six dimensional compact (internal) space.

• Before the discovery of the importance of D-branes ('94-95), only the Heterotic $E_8 \times E_8$ was considered useful for phenomenological applications. A compactification of it on a Calabi-Yau manifold yields a GUT (grand unified theory) based on a subgroup of E_8 (e.g. E_6) with an additional hidden sector in the second E_8.

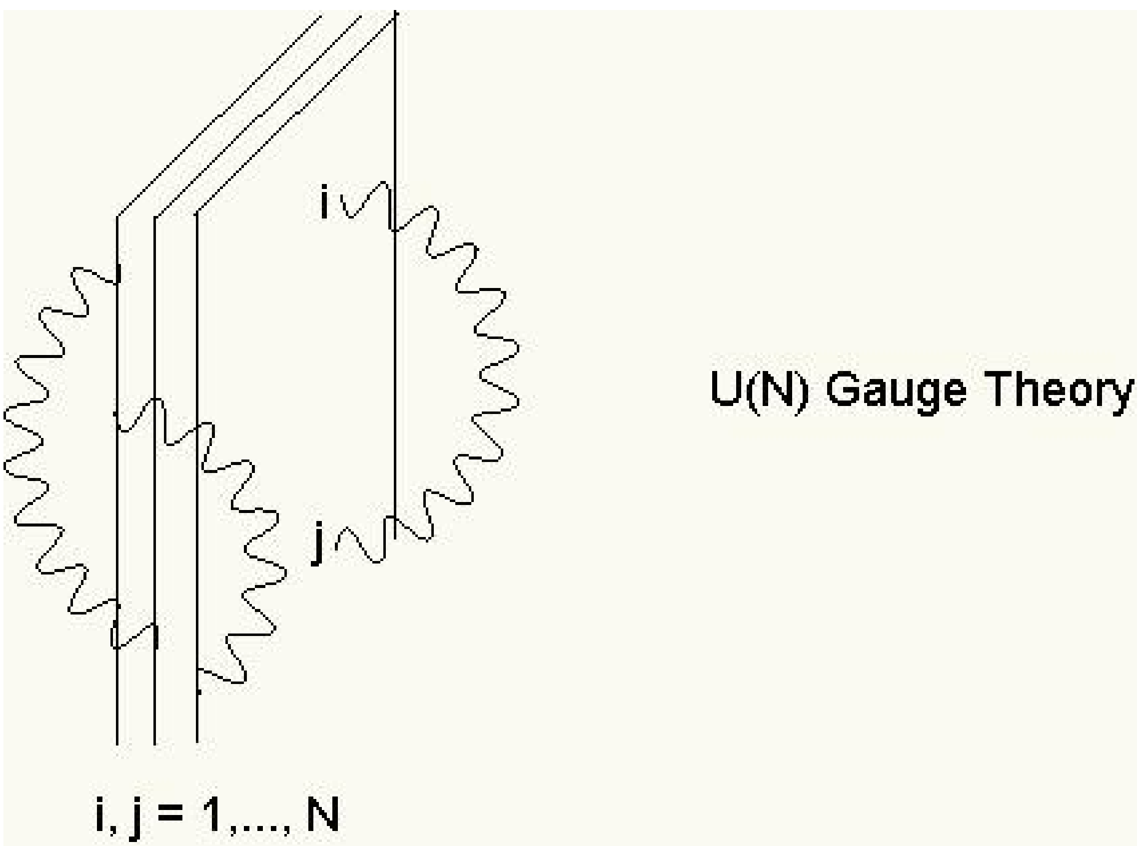
• Various connections were discovered between the known string theories (dualities). This evidence points out to the existence of one unique theory, called: M-Theory (11 dimensional), which has yet to be formulated.

• Low-energy limit of M-theory is 11 dimensional supergravity.

3. D-branes

• D-branes are hyper-surfaces where open strings can end.

• Notation: Dp-brane denotes a D-brane of $p+1$ dimensions: p space and one time.

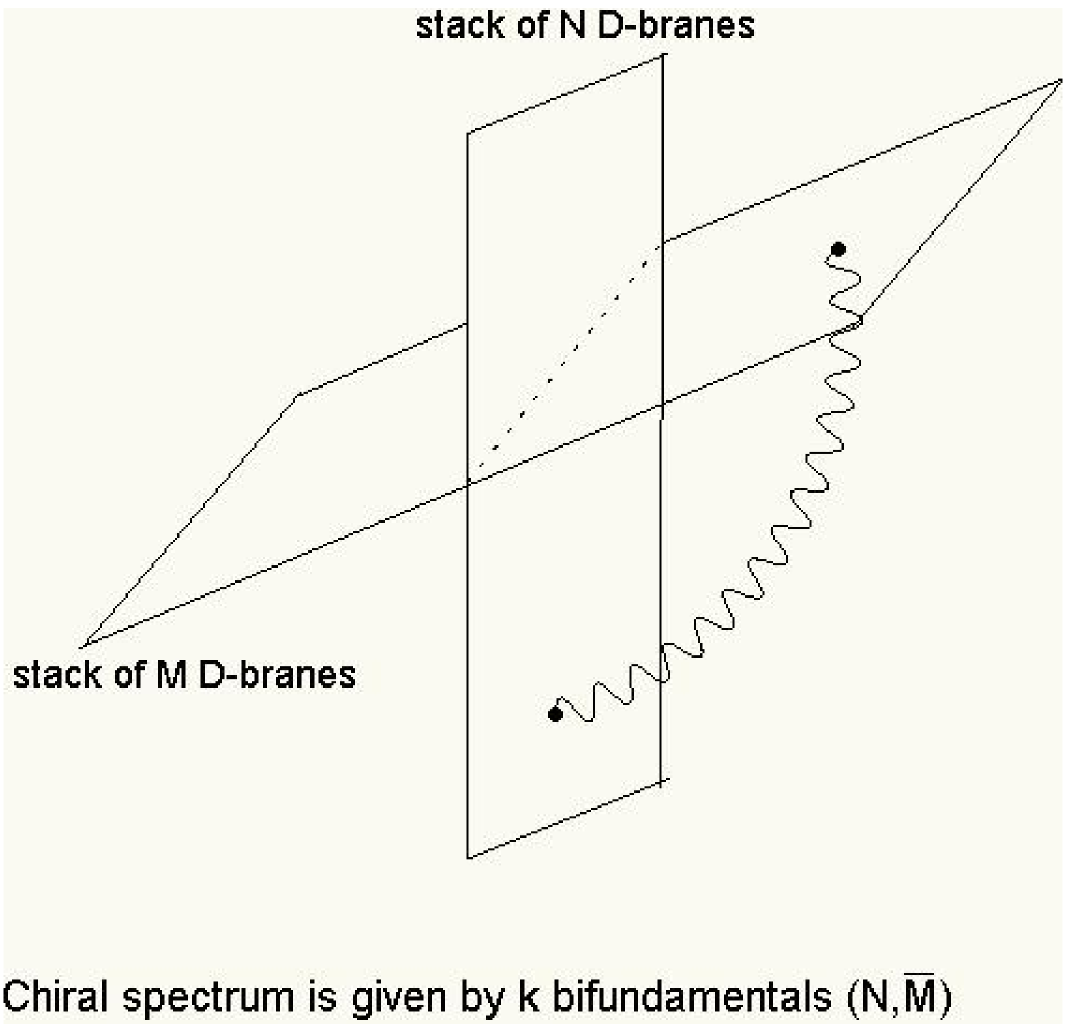


• Suppose that you have N coinciding D-branes then there is a symmetry if a string ends on one or the other of the N D-branes. This symmetry translates in spacetime as a gauge symmetry.

• Gauge interactions arise, thus, from the open strings. In models with both open and closed strings (type I, type IIA/B with D-branes) there is a natural distinction between gravitational and gauge interactions since they arise from different sectors.

4. Intersecting D-brane models

• Suppose that we have a stack of N D-branes and another stack of M D-branes such that they fill four-dimensional space-time and that they have a topological intersection in the internal space equal to k.



Then one gets a gauge group of the form:

$$U(N) \times U(M)$$

and k chiral multiplets in the bifundamental representation

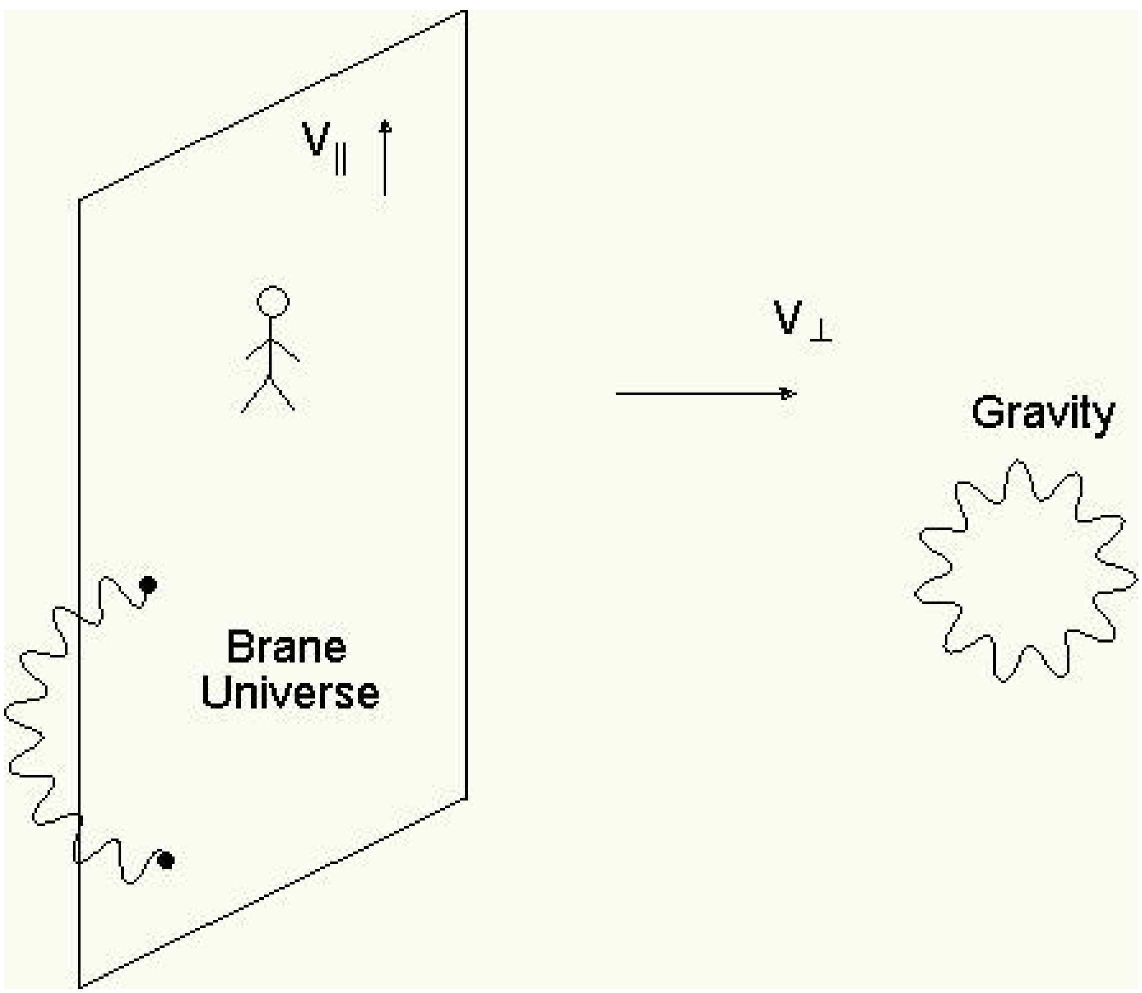
$$(N, \bar{M})$$

This is very interesting from phenomenological point of view and it's pretty much the simplest construction one can write down. More sophisticated models are based on orbifolds, orientifolds and/or fluxes and can yield realistic spectra.

• Bad feature: there is no natural way to get grand unification.

5. Braneworlds

• What if we live on a brane? Gauge fields are confined to the brane while gravity is not. Gravity is weaker because it dilutes in the extra-dimension.



• There can be two types of extra-dimensions: longitudinal and transverse. Experimental bound on the size of transverse dimensions is:

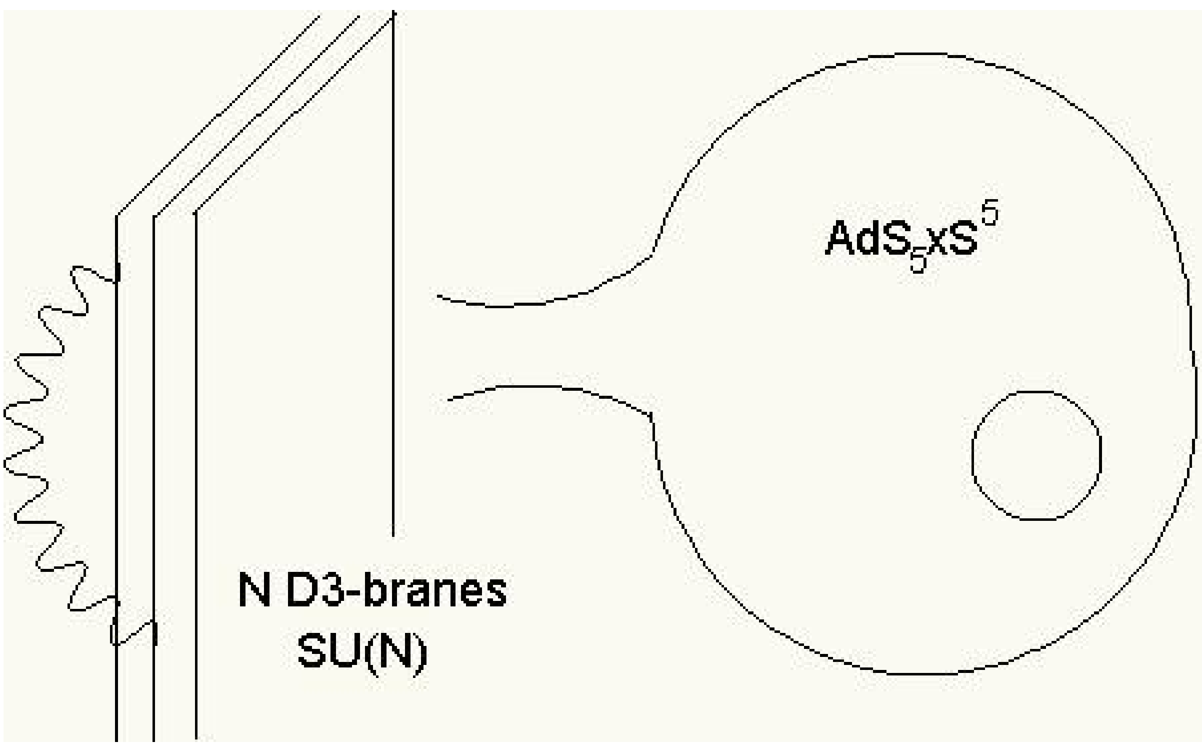
$$R_{\perp} \leq 0.1\text{mm}$$

• Longitudinal extra-dimensions have to be much smaller:

$$R_{\parallel} \leq 10^{-17}\text{cm}$$

6. ADS/CFT correspondence

• There is evidence that supports the following conjecture due to Maldacena ('98):
Type IIB string theory on $AdS_5 \times S_5$ is equivalent (dual) to $\mathcal{N} = 4$ SU(N) super Yang-Mills theory in 4 dimensions.



• This is a strong-weak coupling duality, hence one can use string theory as a mathematical tool to study strongly coupled gauge theories.

$$\lambda = g^2 N \sim \frac{R^4}{l_s^4}$$

if $\lambda \to \infty$ then the dual theory is classical (super)gravity
if $\lambda \to 0$ then the dual theory is string gravity

-THE END-