M- Branes and Gauge Theories

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The Plan

1. What is M theory?
2. Interacting Branes
3. Multiple M2 branes
4. The (2,0) Theory

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What is M theory?

- M theory is to 11d Supergravity what String Theory is to ‘10d Supergravity
- i.e. the strong coupling limit
- 11d Supergravity compactifies to 10d Supergravity, so we should expect to get string theory by compactifying M theory

Why M Theory?

- Because it's there...
- Unites different string theories in one
- May provide non- perturbative, background independent completion of String Theory

The Problem with M Theory

- Like string theory, no background independent formulation
- Unlike string theory, no coupling constant $\Longrightarrow$ no pertubative expansion!
- This means we can't *prove* it's UV convergent
- In string theory, UV completeness come from the string length
- Therefore look for dynamical objects outright- What are they?

M- branes

- look for charged solitions in 11d supergravity- these must have with some associated flux
- By SUSY considerations the only flux is a 3 form C_3 with 4 form field strength G_4
- This corresponds to a 5 dimensional object- we call this an M5 brane
- We also have the 7 form $\star C_3$
- This corresponds to a 2 dimensional object- we call this an M2 brane
- Remember- These only exist in 11d SUGRA!

Matching to String Theory

- M theory has M2 and M5 branes only, string theory has D0, strings, D2, , D4, NS5, D6- doesn't look good
- In fact can reproduce almost all this with M- branes along compact or non compact dimesions- eg M2 brane gives either string or D2 brane
- D0 and D6 branes are geometric objects in M theory ('gravitational waves'and 'Kaluza Klein monopoles') which become dynamic when compactified
- Can use this to define M- brane tensions- we can show that these are consistent in different limits and compactifications

What we want

- We have a description of a single M2 brane- the next step is to describe multiple interacting branes
- Multiple D2 branes are describe by a U(n) Yang- Mills theory, where n is the number of branes
- We therefore look for the strong coupling of this theory- this is the same as going to the IR limit in 3d
- The desired theory should be the IR fixed point of YM

Chern- Simons Theories

- A class of theories based around the Lagrangian density

$$\mathcal{L}_{CS} = \frac{k}{4\pi}\mathrm{Tr}(\mathbf{A}\wedge d\mathbf{A} - \frac{2i}{3}\mathbf{A}\wedge\mathbf{A}\wedge\mathbf{A}) \tag{1}$$

- This is clearly only defined in 3 dimensions
- It lacks a dimensionful coupling, unlike Yang- Mills
- A combination of this and YM will be dominated by this in the IR limit
- Gauge invariance $\implies$ k is quantised
- This Lagrangian density is the same as for Yang Mills Instantons!

Multiple M2 branes

- We want a three dimensional superconformal field theory which has $\mathcal{N}$=8 supersymmetry and is also the IR fixed point of Yang Mills
- There are two candidates for this theory- neither is perfect
- The BLG theory has the full supersymmetry, but can only describe 2 interacting M2 branes
- The ABJM model can describe any number of interacting M2 branes, but only has $\mathcal{N}$=6 supersymmetry
- These theories can be constructed starting from multiple D2 branes, or derived from scratch- see N. Lambert, *M- Theory and Maximally Supersymmetric Gauge Theories*

The (2,0) Theory

- The (2,0) Theory is a hypothetical 6 dimensional superconformal field theory which would describe the interaction of M5 Branes
- There is no real description of it at the moment
- This is mainly because it is non- lagrangian
- It's proven impossible to write down a lagrangian with the right supersymmetries and conformal symmetry in 6 dimensions

Why the (2,0) Theory?

- It's the only 6 dimensional superconformal QFT we know of
- The next step towards M Theory
- Could help explain other things- e.g. S Duality in 4D SYM
- Could provide new techniques to understand QFTs non- peturbatively

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Towards the (2,0) Theory

- Many different techniques, most trying to define it as the limit of some other theory
- I'm working on an attempt to match 5D SYM to the (2,0) theory compactified on a circle
- This involves matching Kaluza- Klein modes of the theory to instantons in SYM
- Still very much a work in progress

Conclusions

- Interacting M- Branes are only useful for learning about M- theory, but also QFT in general
- Next step- M5 branes- the (2,0) theory
- Key point- remembering which QFTs exist in which limits!