Title: Geometry of Particle Physics

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Abstract: TBA

Geometry of Particle Physics

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Based on:
Hep-th/0703047
Hep-th/0508089 with Herman Verlinde
Hep-th/0212021

Main scenarios for (perturbative) string phenomenology:

- Heterotic strings;
- Global D-brane models;
- Local D-brane models.

Main scenarios for (perturbative) string phenomenology:

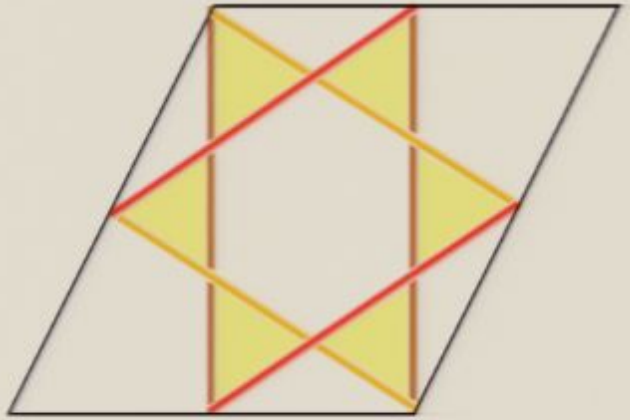
- Heterotic strings;
- Global D-brane models;
- Local D-brane models.

Local models are centered around the idea of a *correspondence principle*:

As $M_{Planck,4} \to \infty$, all the Standard Model interactions should remain finite.

The existence of a large hierarchy provides evidence for this scenario. We don't expect quantum gravity to play a role at the LHC.

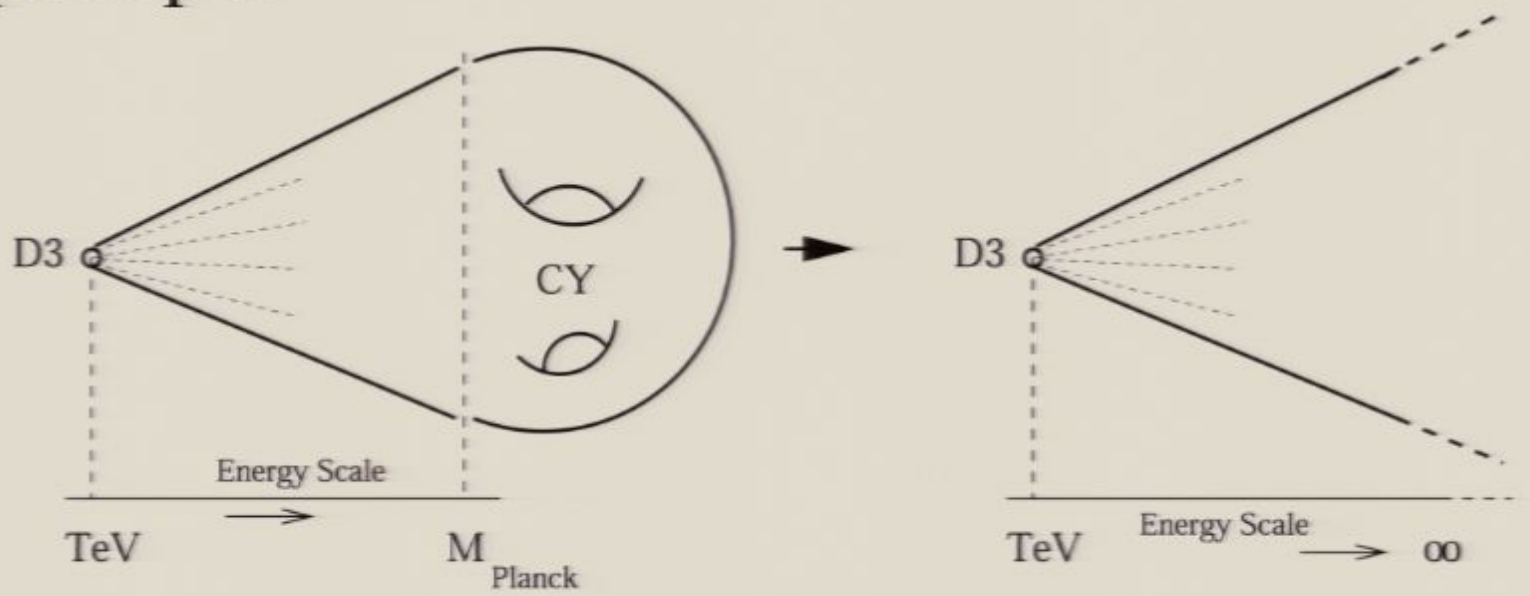
Caricature of a global D-brane model:



As the size of the T^2 goes to infinity, so do the volumes of the cycles that the branes are wrapped on, turning off the gauge couplings.

Chiral fields are located at the intersections. As the volume goes to infinity, they become infinitely separated, turning off Yukawa couplings.

Fractional branes satisfy the correspondence principle.



In addition:

- Holography/Bottom-up — Aldazabal/Ibanez/Quevedo/Uranga
- Adjustability — Berenstein/Jejjala/Leigh
- Uniqueness

Branes at singularities give rise to *quiver gauge theories.*

How do we know the gauge theory corresponding to a singularity?

Can we make a local construction of the MSSM?

Bottom line: it appears that *any* quiver consistent with bifundamental structure of open strings can be constructed locally.

``Theory of everything''

An oriented quiver gauge theory consists of U(N) gauge groups and bifundamental chiral fields.

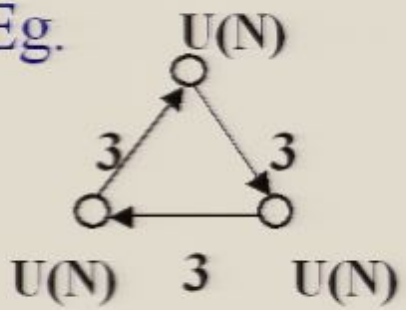
Oriented quiver rules:

(1) For each U(N), draw a node.

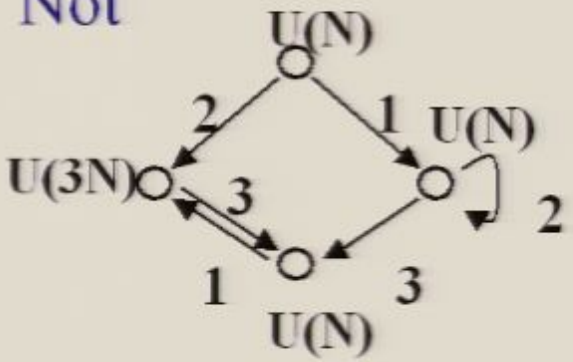
(2) For each bifundamental in $(\bar{N}_i , N_j)$, draw an arrow from node i to node j.

(3) The number of incoming and outgoing arrows is equal (anomaly cancellation).

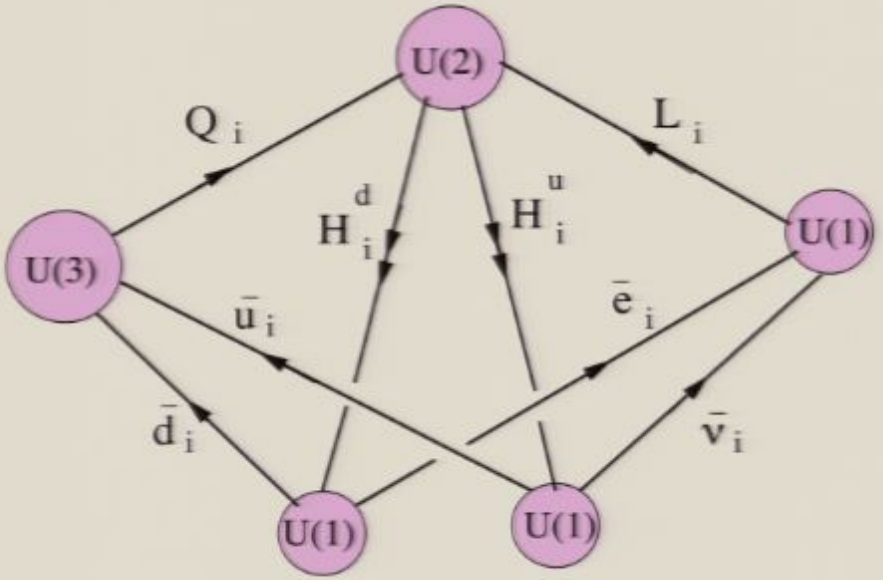
Eg.



Not



Given these rules, the best one can get is



Not so pretty: 12 Higgs fields.

We can do better by working with unoriented models.

Unoriented quiver rules: same as oriented, but

(1) The gauge groups can be U(n), SO(n), or USp(n).

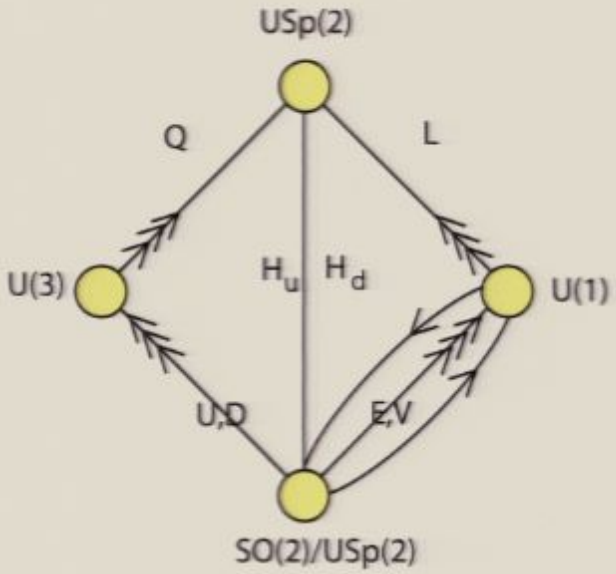
(2) The bifundamentals can be $(\overline{N}_i , N_j)$, (N_i , N_j), or $(\overline{N}_i , \overline{N}_j)$.

[(3) Rules for symmetric and anti-symmetric tensor matter.]

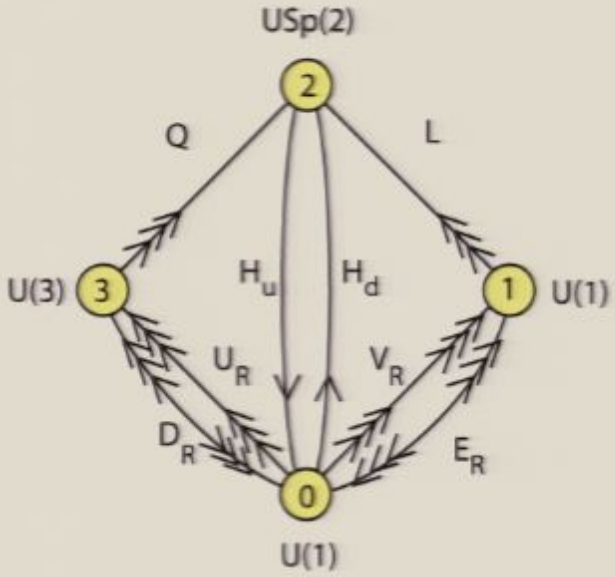
Unoriented models:

Ibanez/Marchesano/Rabadan

Model I:



Model II:

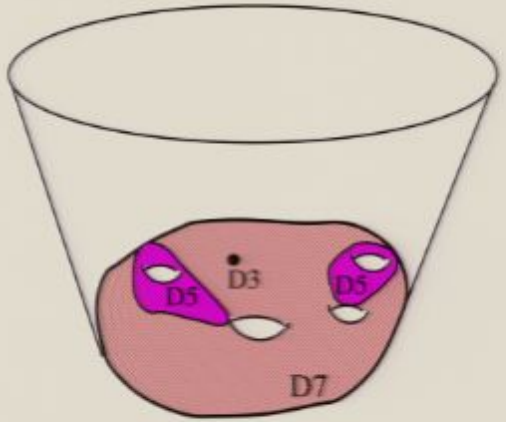


Both quivers give the MSSM spectrum and interactions at low energies.

The models are slightly different in the massive sector.

Quiver technology:

At a Calabi-Yau singularity, a collection of 2-cycles and 4-cycles has collapsed to zero size. We can wrap branes on the collapsed cycles.



A *fractional brane* is a bound state of D-branes wrapped on vanishing 0,2,4-cycles.

For every singularity there is a set of *elementary* fractional branes which are the lightest. Every other fractional brane can be expressed as a *bound state*.

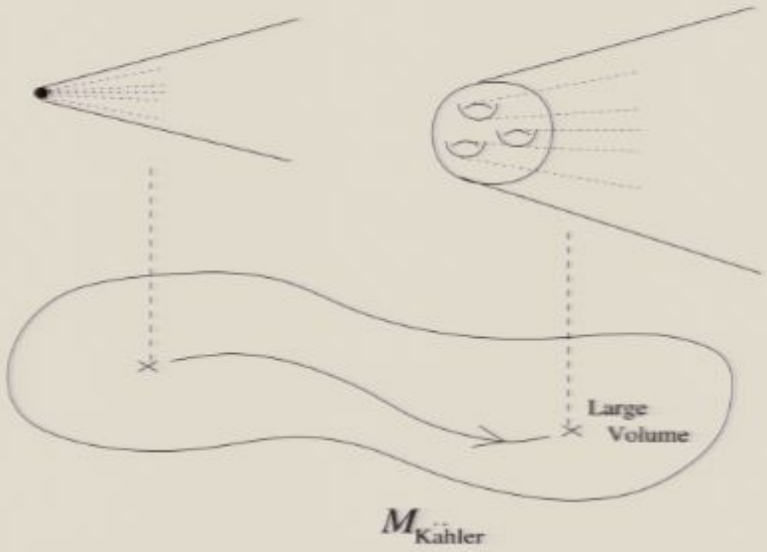
Once we find the elementary branes, we can draw the *basic quiver* for a singularity. The bound states correspond to the possible Higgsings of the basic quiver.

Geometry	Quiver
Fractional brane	Node
Intersection number	Number of chirals (arrows)

Thus the problem is reduced to finding the elementary fractional branes.

The complete boundary state for a fractional branes is only known for special singularities, namely orbifolds.

However, by the magic of topological strings, enough information may be extracted by extrapolating to the large volume limit, where fractional branes can be represented as bundles on the collapsing cycle.



Fractional branes ⇨ ``Exceptional collections''

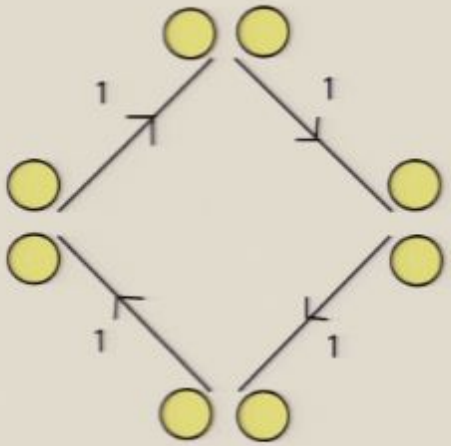
Collapsing 4-cycles are required because the MSSM is chiral.

An isolated collapsing 4-cycle has to have a positive anti-canonical class, i.e. it should be a Del Pezzo surface (P^1 x P^1, or P^2 blown up at up to 8 points).

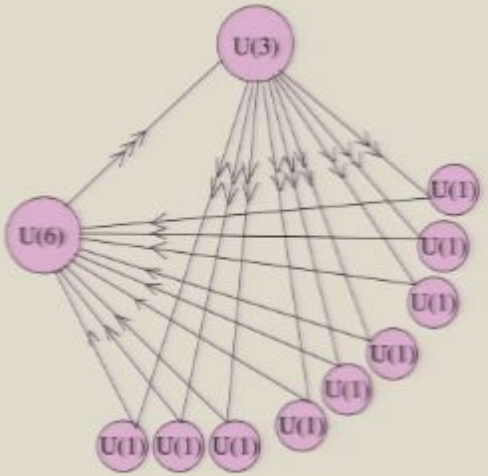
By extrapolating to large volume, one gets for example:

MW, hep-th/0212021

DP5:



DP8:



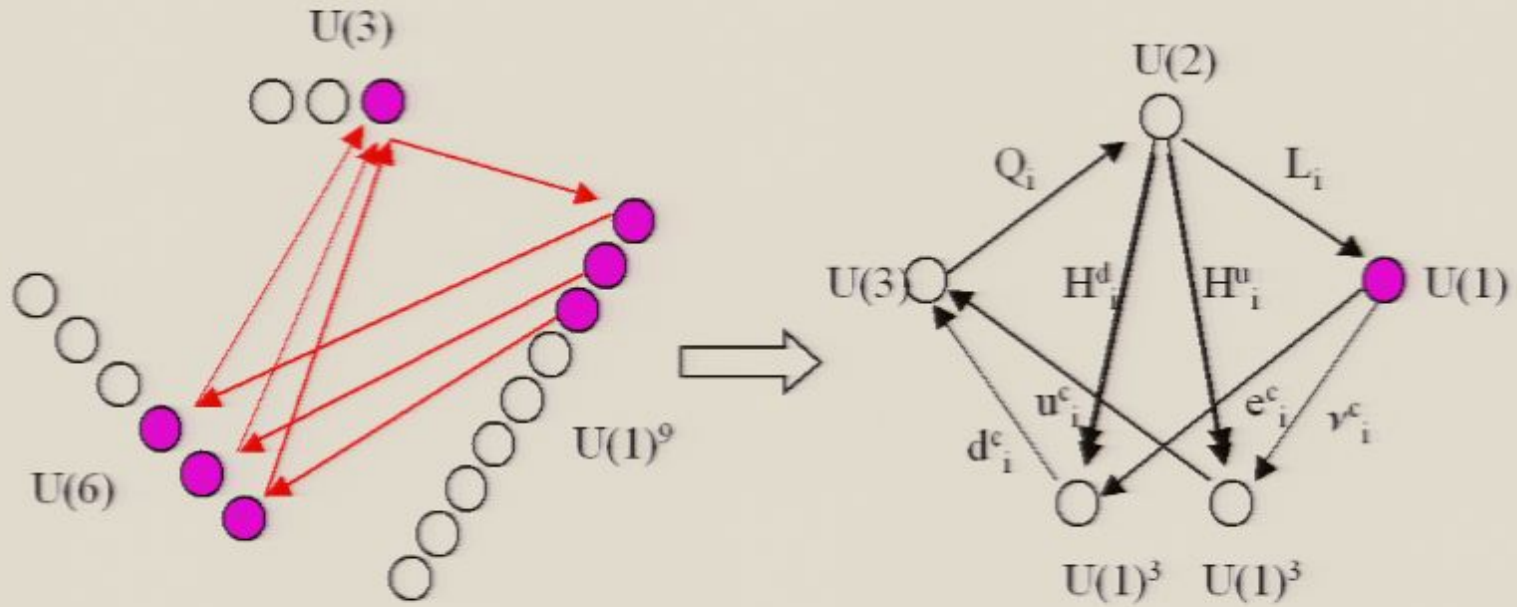
Rough outline of geometry/ gauge theory parameters:

Superpotential couplings	complex structure moduli NC structure moduli
FI terms	Kaehler moduli
Gauge couplings/θ-angles	NS/RR periods
Soft terms	fluxes mirrors of fluxes (torsion)

The final ingredient: we can make new quivers by *Higgsing*.

Oriented model:

DP8: Verlinde/MW



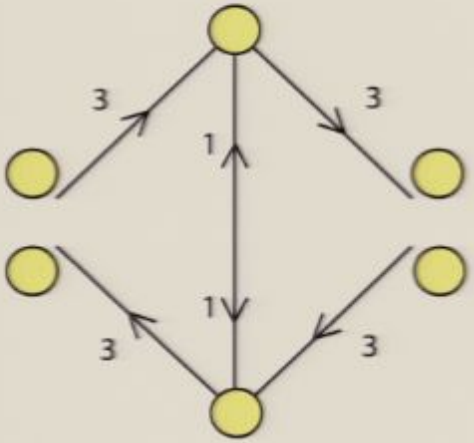
This is (essentially) the the oriented MSSM-like quiver we had before.

All this structure comes from a *single D3-brane!*

Unoriented models:

First draw the covering quivers:

Model I:



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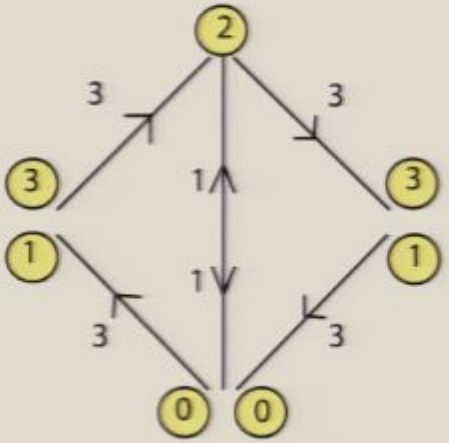

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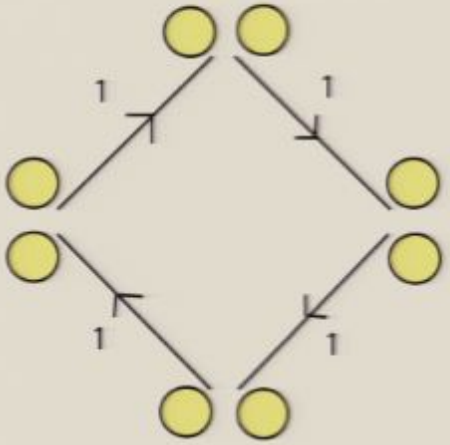

There are obvious similarities with the DP5 quiver, except:

- There is not one but three generations
- There is non-chiral matter (the Higgses).

Unoriented models:

Ibanez/Marchesano/Rabadan

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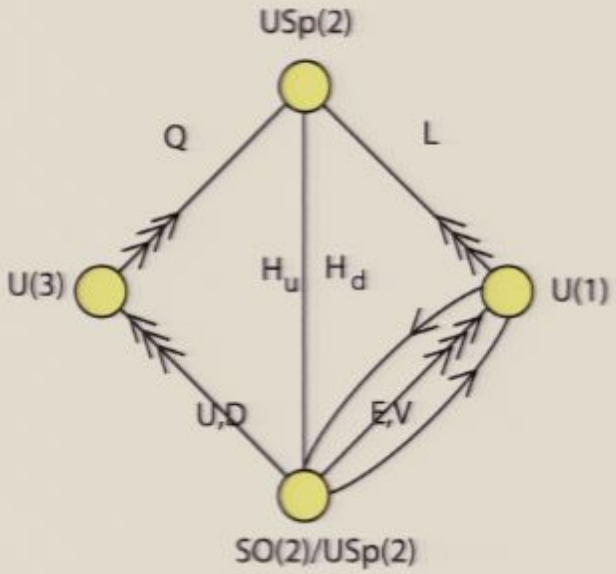

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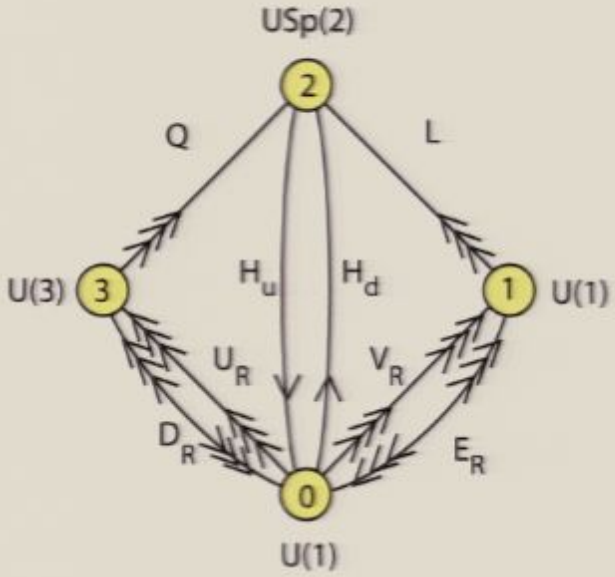

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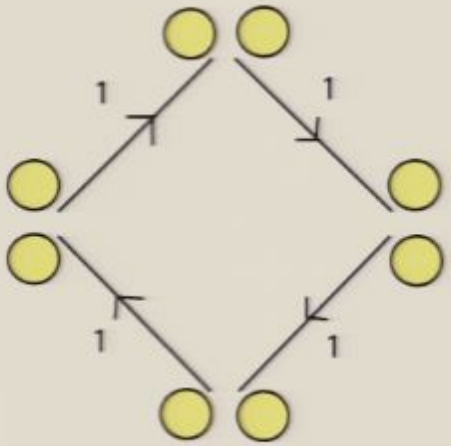

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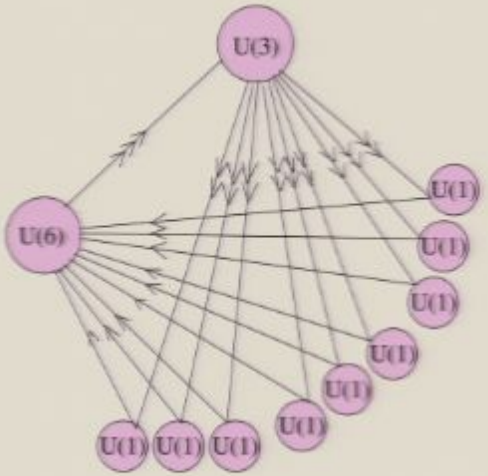

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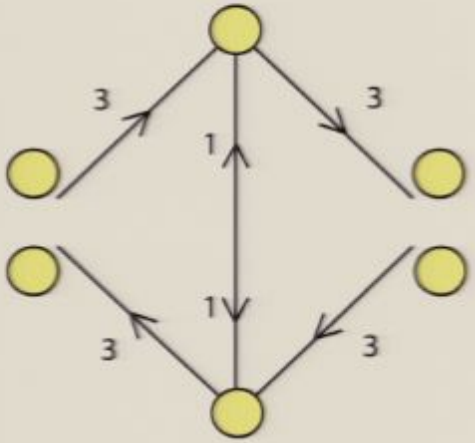

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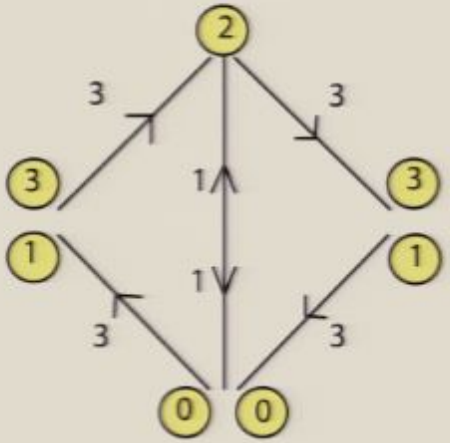

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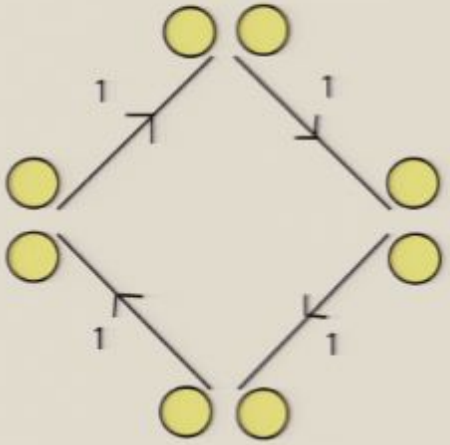

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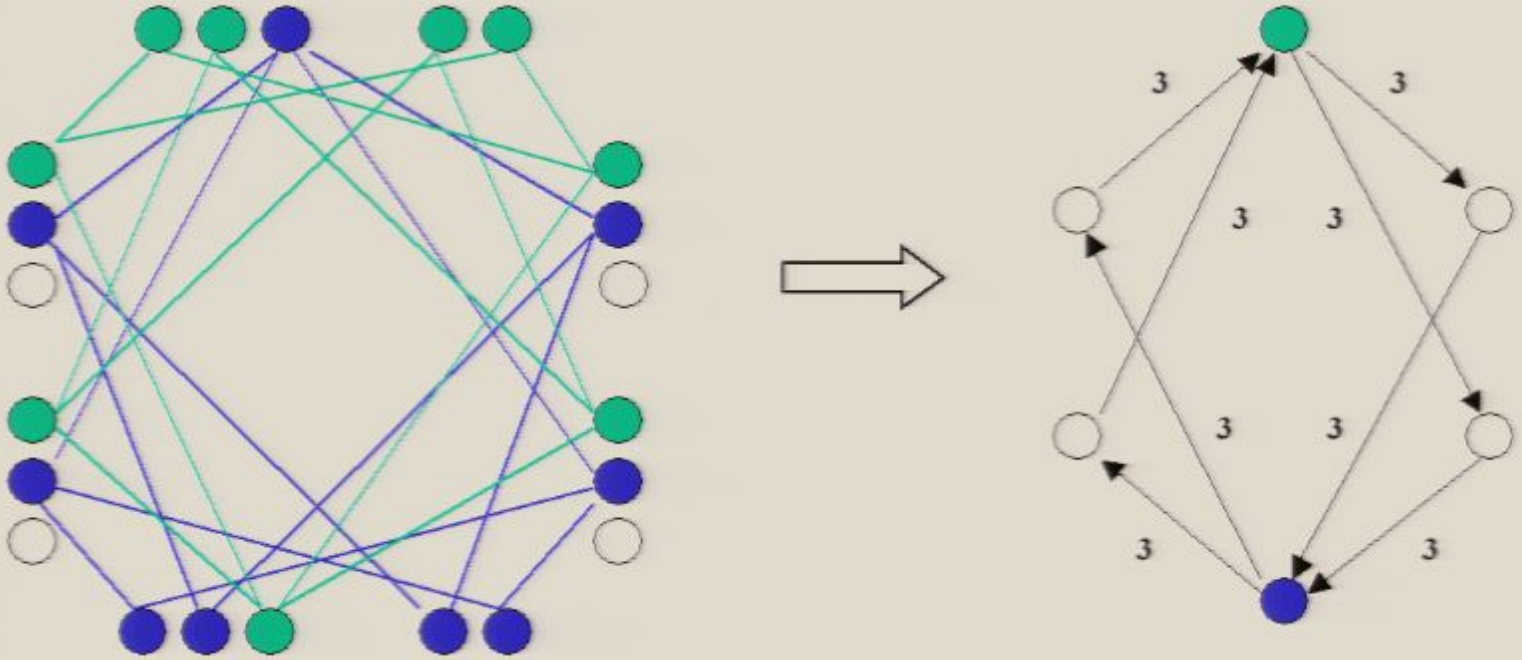
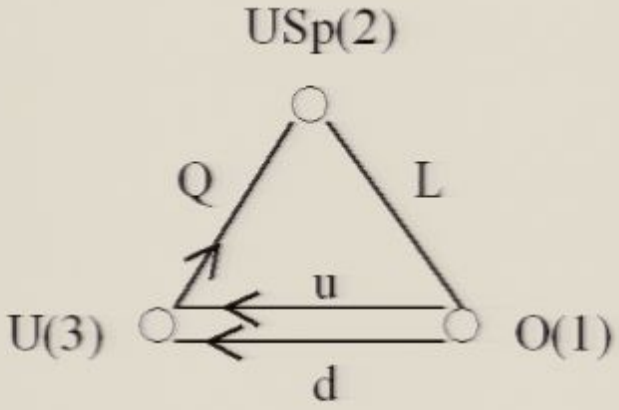
Higgsing:



Superpotential needs to be adjusted to satisfy F-terms and lift non-chiral fields.

Similar trick to get Higgses. After orientifolding, this is model I. Model II is more complicated, but same idea.

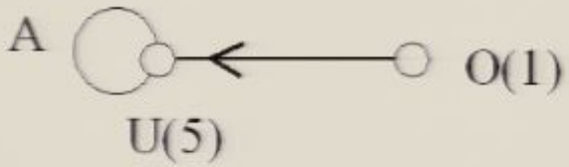
Many other interesting quivers can be constructed by similar techniques. Eg. Models of dynamical SUSY breaking:



The 3-2 model.

Affleck/Dine/Seiberg, Intriligator/Thomas

From Higgsed DP5.

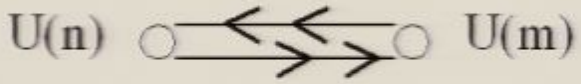


A non-calculable model.

Affleck/Dine/Seiberg

No perturbative or non-perturbative superpotential allowed.

From orbifold. Seems easy to couple to gravity.



ISS metastable model.

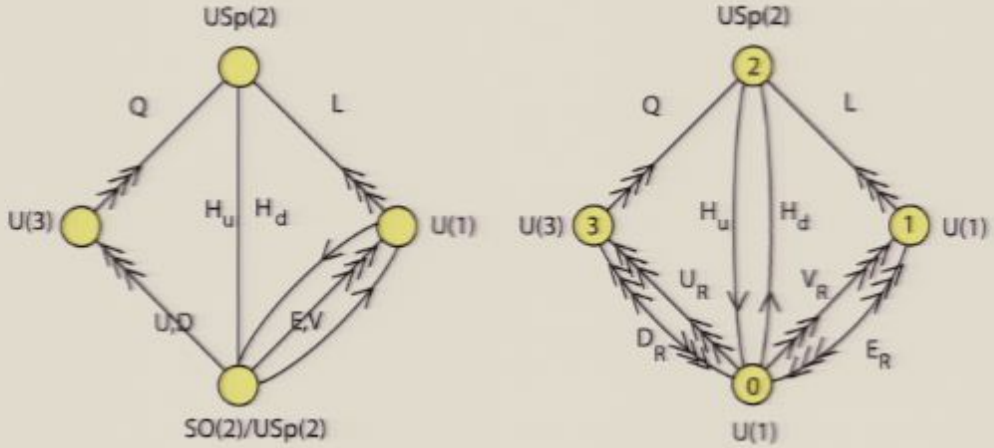
Intriligator/Seiberg/Shih

From conifold with H-flux.

Topological criteria for unification:

Although the nodes correspond to independent homology cycles locally, it is natural to require some of them to be the same cycle globally. This leads to relations between the gauge couplings.

Buican/Malyshev/Morrison/Verlinde/MW



If nodes 1&3 are identified, then we get Pati-Salam unification.

Blumenhagen/Luest/Stieberger, Antoniadis/Kiritsis/Tomaras

Further trivialization:

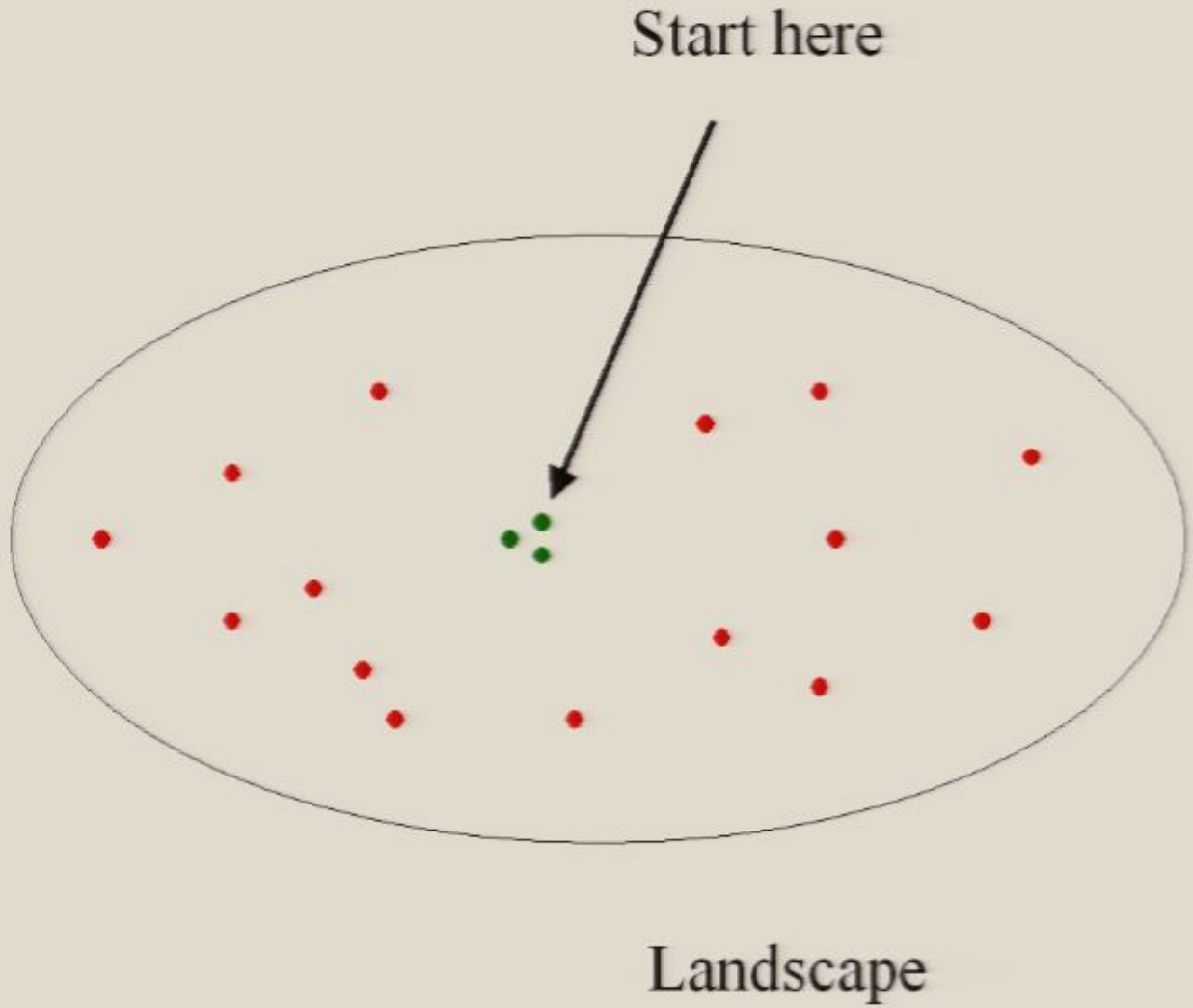
$$\frac{1}{\alpha_{\mathrm{Y}}(M_{str})}+\frac{1}{\alpha_{\mathrm{W}}(M_{str})}=\left[\frac{2n_1}{n_2}+\frac{2}{3}\right]\frac{1}{\alpha_{\mathrm{S}}(M_{str})}$$

QCD string

What happens as the SU(3) node flows to strong coupling?

The net wrapping number of the SU(3) brane is a 2-cycle. It appears that this 2-cycle can undergo a conifold transition where it gets replaced by a 3-sphere, and the brane is replaced by flux.

The QCD string and the graviton are different modes of the same fundamental string.



Many restrictions: gauge coupling unification, flavour symmetry, …

Conclusions:

Local D-brane models provide a bottom-up perspective to model building. Main problem is to put everything together.

Geometric picture of the MSSM, decoupled from gravity.

More generally, it looks like any ``open string'' quiver can be constructed locally. Eg. DSB without runaway.

Parametrize your ignorance. Good ideas still needed to address the landscape.

Sole prediction: gauged U(1)_B with stringy couplings. Observable at the LHC?