Discrete symmetries from the heterotic string

Hans Peter Nilles

Physikalisches Institut

Universität Bonn

5 Golden Rules (2004)

- Spinors of SO(10) (for families)
- Incomplete multiplets (for Higgs)
- Repetition of families (from extra dimensions)
- $N = 1$ supersymmetry
- Importance of discrete symmetries

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These rules have bottom-up and top-down motivation

- grand unification (evolution of couplings)
- quark and lepton (neutrino) masses
- proton stability (R-Parity)

Rule 1 and 5

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- one can incorporate top-Yukawa coupling and neutrino see-saw mechanism
- discrete symmetries with many applications

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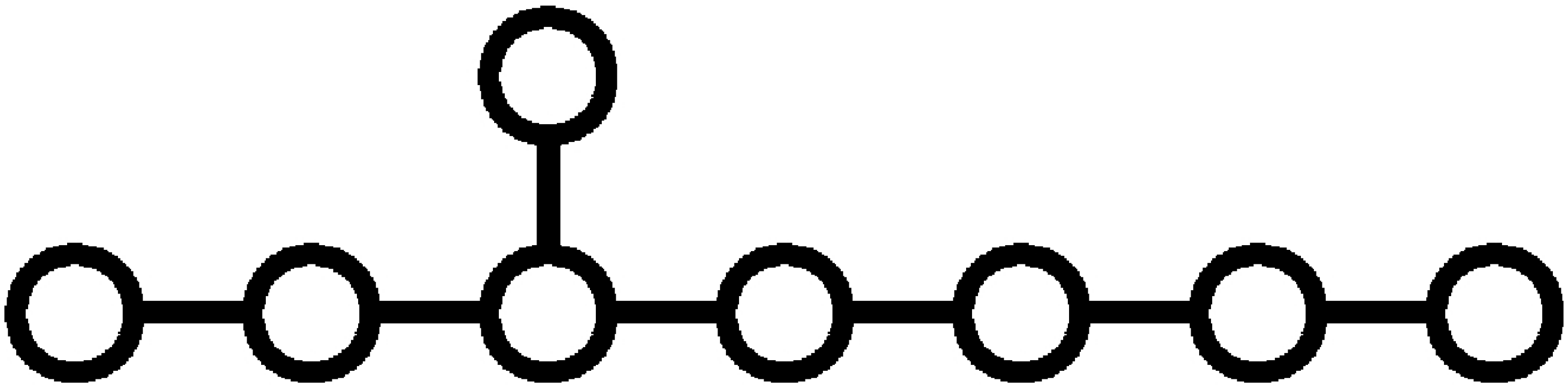
From the mathematical structure we would prefer exceptional groups

- There is a maximal group: E_8,
- but E_8 and E_7 do not allow chiral fermions in $d = 4$.
- How does this fit with our usual picture of unification based on SU(5) or SO(10)?

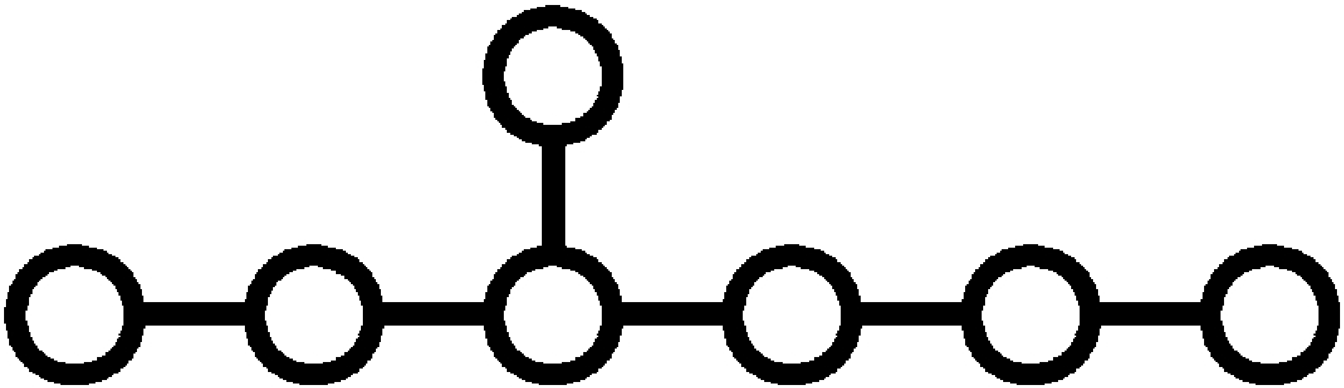
Maximal Group



E_8 is the maximal group.

There are, however, no chiral representations in $d = 4$.

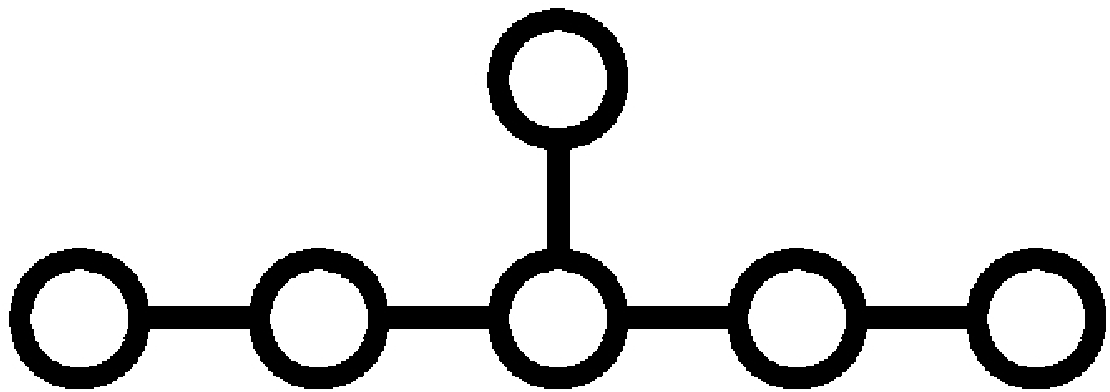
E_7



Next smaller is E_7.

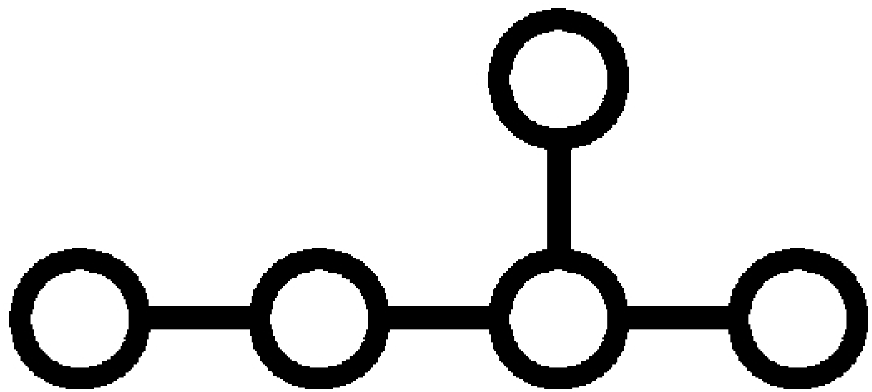
No chiral representations in $d = 4$ either

E_6



E_6 allows for chiral representations even in $d = 4$.

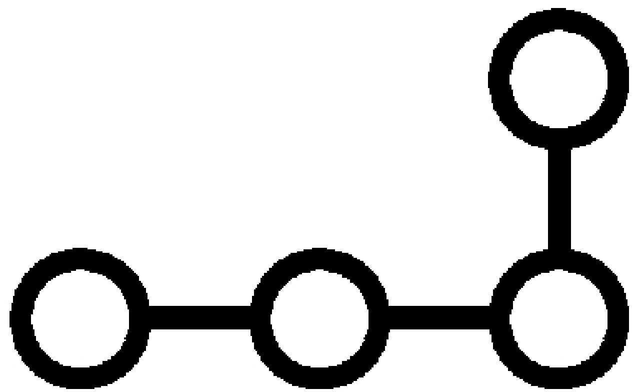
$E_5 = D_5$



E_5 is usually not called exceptional.

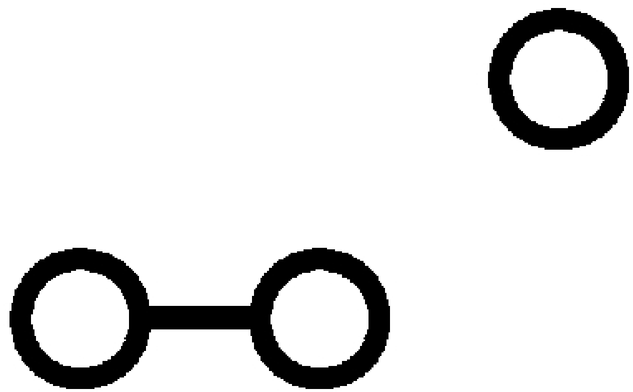
It coincides with $D_5 = SO(10)$.

$E_4 = A_4$



E_4 coincides with $A_4 = SU(5)$

E_3



E_3 coincides with $A_2 \times A_1$ which is $SU(3) \times SU(2)$.

Exceptional groups in string theory

String theory favours E_8

- $E_8 \times E_8$ heterotic string
- E_8 enhancement as a nonperturbative effect (M- or F-theory)

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Strings live in higher dimensions:

- chiral spectrum possible even with E_8
- E_8 broken in process of compactification
- provides source for more discrete symmetries
- from $E_8/SO(10)$ and $SO(6)$ of the higher dimensional Lorentz group

The use of additional symmetries

Symmetries are very useful for

- absence of FCNC (solve flavour problem)
- Yukawa textures à la Frogatt-Nielsen
- solutions to the μ problem
- creation of hierarchies
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Continuous global symmetries might be destroyed by gravitational effects. We have to rely on

- gauge symmetries and
- discrete symmetries

(Banks, Seiberg, 2010)

Heterotic Braneworld

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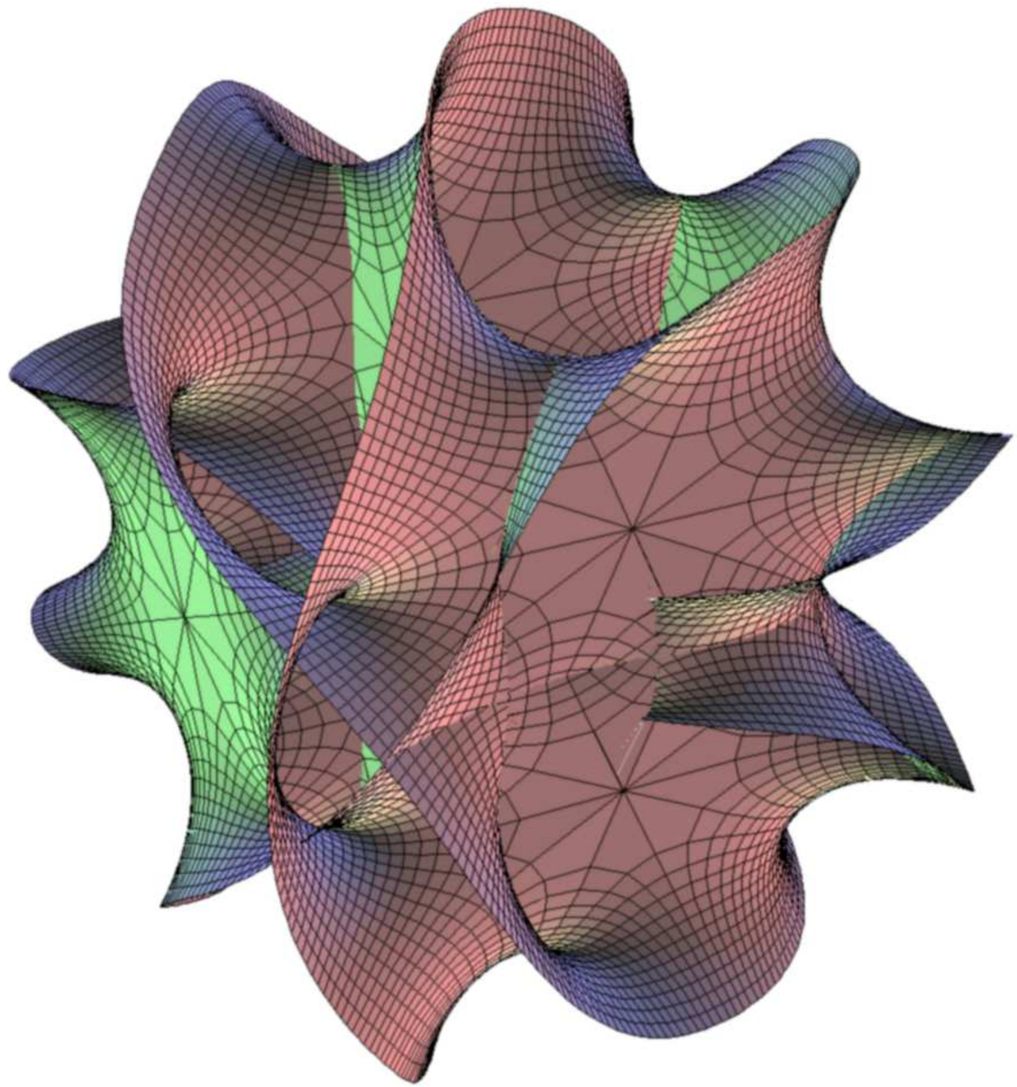
Fields can propagate

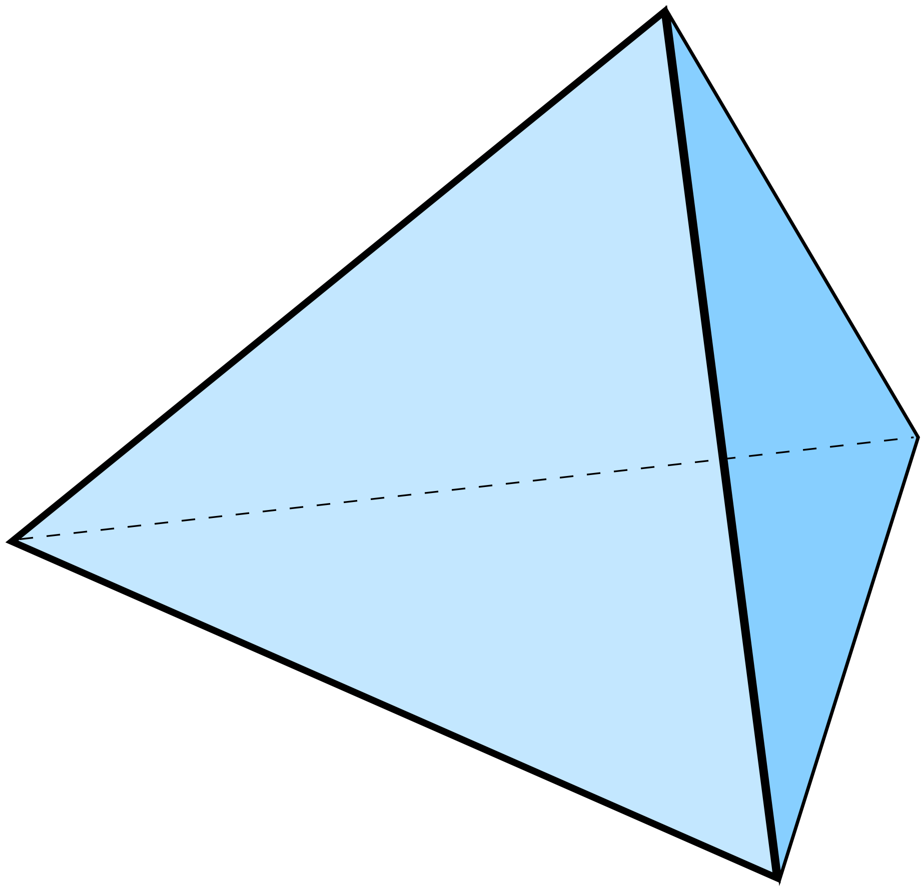
- in the Bulk ($d = 10$ untwisted sector)
- on 3-Branes ($d = 4$ twisted sector fixed points)
- on 5-Branes ($d = 6$ twisted sector fixed tori)

This localization is an important property of the set-up and should be taken seriously (it is not just an approximation to obtain calculability)

Calabi Yau Manifold



Orbifold



Local Grand Unification

String theory gives us a variant of GUTs

- complete (or split) multiplets for fermion families
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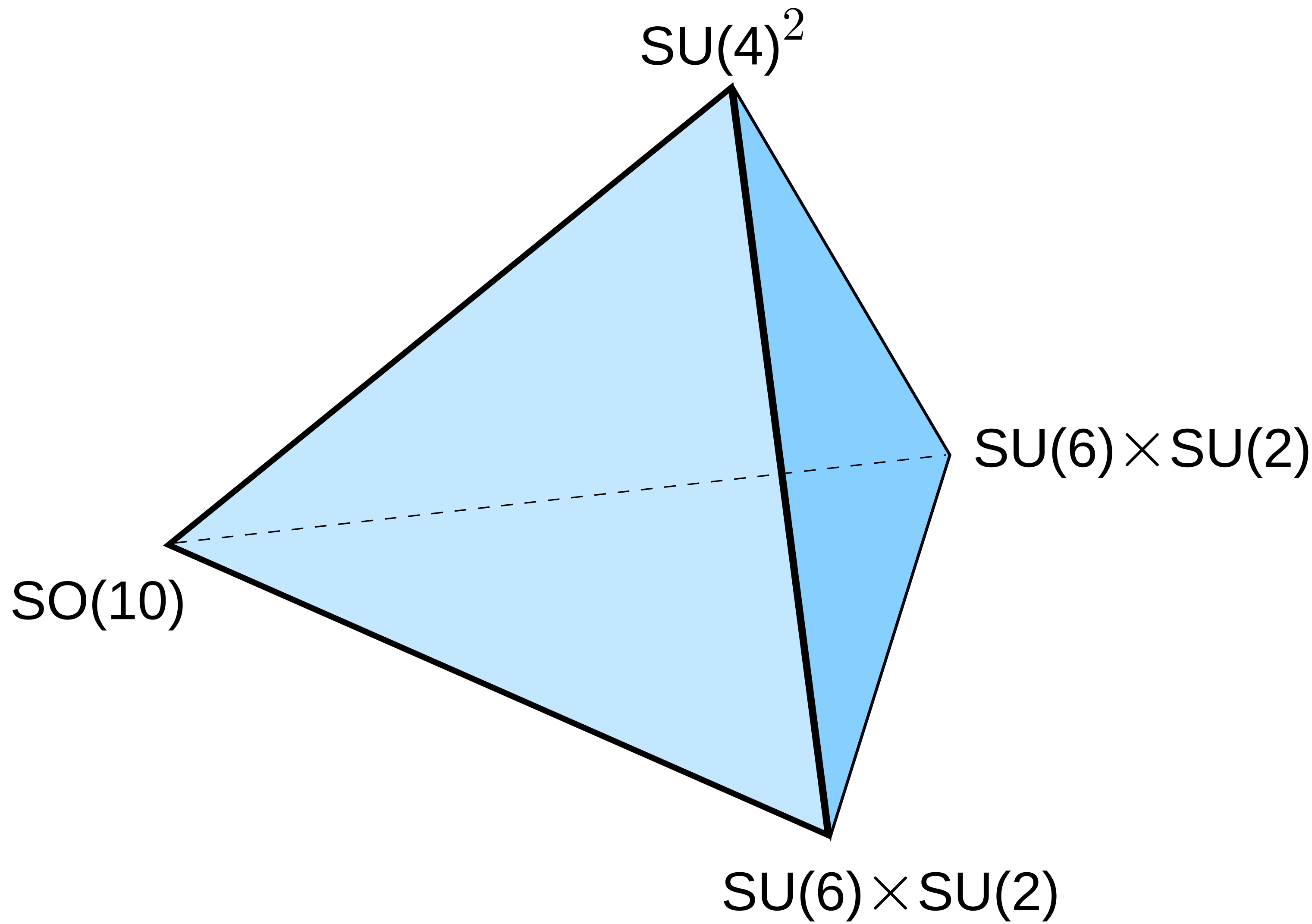
Key properties of the theory depend on the geography of the fields in extra dimensions.

This geometrical set-up is called local grand unification.

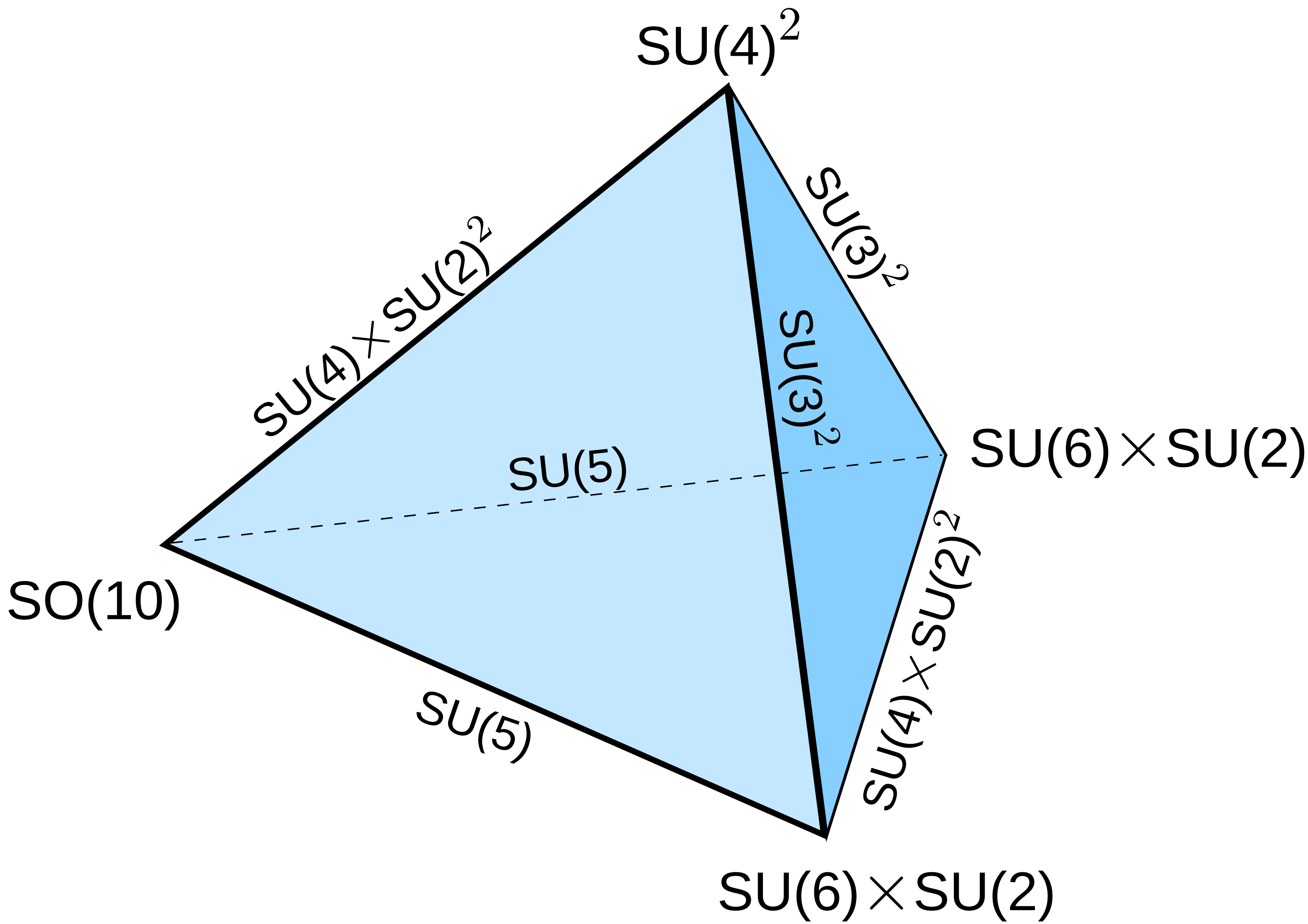
The localization of matter as well as the local structure of the gauge group determines the properties of the theory.

Localized gauge symmetries



(Förste, HPN, Vaudrevange, Wingerter, 2004)

Standard Model Gauge Group



Symmetries

In the heterotic braneworld we find

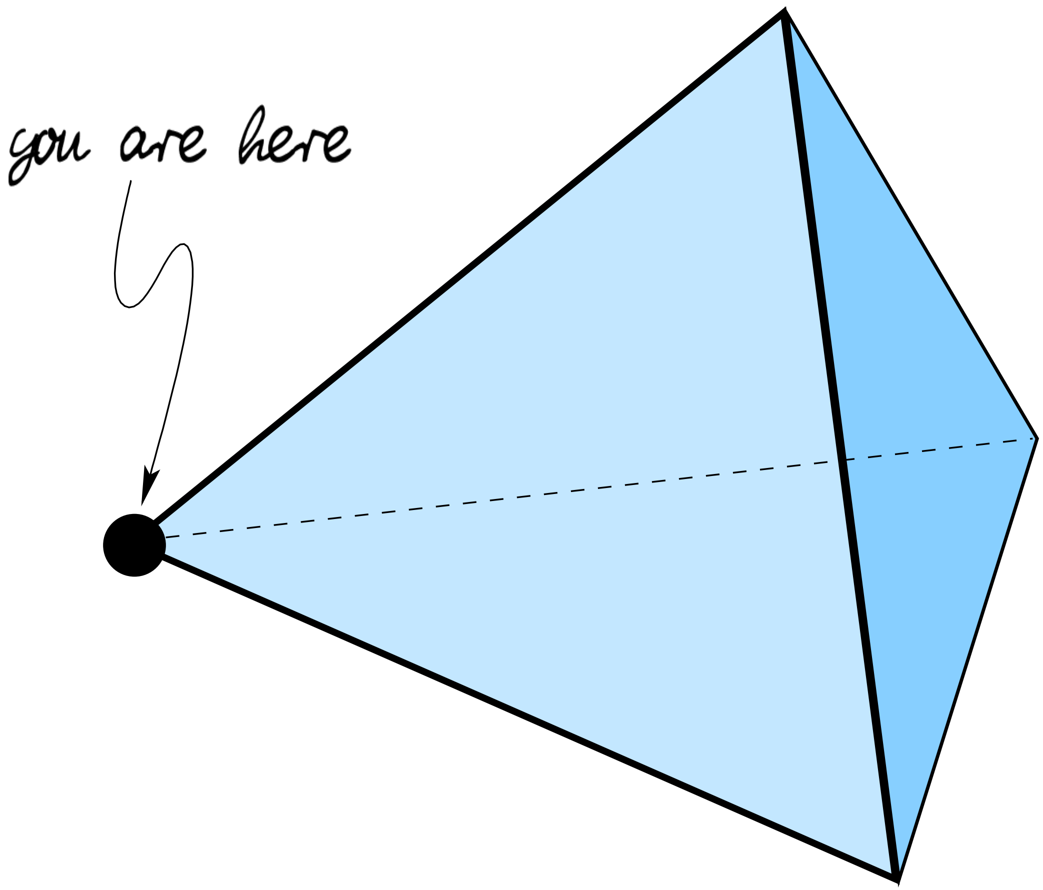
- gauge symmetries (no continuous global symmetries)
- discrete symmetries from geometry and stringy selection rules (Kobayashi, HPN, Plöger, Raby, Ratz, 2006)

The orbifold point is a special point in the moduli space of the compact extra dimensions with enhanced symmetries.

These symmetries might be slightly broken. This will introduce small parameters that lead to a creation of hierarchies.

We might live close to the orbifold point.

Location matters



Symmetries in heterotic braneworld

Applications of discrete symmetries:

- (nonabelian) family symmetries (and FCNC)

  (Ko, Kobayashi, Park, Raby, 2007)
- Yukawa textures (via Frogatt-Nielsen mechanism)
- a solution to the μ-problem

  (Lebedev, HPN, Raby, Ramos-Sanchez, Ratz, Vaudrevange, Wingerter, 2007)
- creation of hierarchies

  (Kappl, HPN, Ramos-Sanchez, Ratz, Schmidt-Hoberg, Vaudrevange, 2008)
- proton stability via “Proton Hexality” or Z_4^R

  (Förste et al. 2010; Lee et al. 2011)
- approximate global $U(1)$ for a QCD accion

  (Choi, Kim, Kim, 2006; Choi, HPN, Ramos-Sanchez, Vaudrevange, 2008)

F-theory

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Phenomenological constructions are based on the concept of local models, e.g. at the local E_8 point. (Heckman, Vafa, 2010)

- a single gauge group like E_8
- containing other symmetries like R-parity as well
- there might not be a global completion!

Local E_8 point does not possess all the ingredients for realistic model building.

(Marsano, Schafer-Namecki, Saulina, 2011; Lüdeling, HPN, Stephan, 2011)

Clarification

Do not confuse

"Local Grand Unification" with "Local Model Building".

- Local Grand Unification appears in consistent (global) string models where the gauge symmetries are enhanced at special points in extra-dimensional space.
- Local Model Building is an attempt to construct models without the incorporation of gravity (these models are potentially inconsistent).

Do not trust the predictions of "Local Models" unless they are confirmed by a global completion!

Rule 6: Global Models

Sometimes it is said that globally consistent models are only relevant for questions like moduli stabilization......

- this needs not be correct (as experience shows)
- the really reliable (discrete) symmetries can only be understood within a global approach (e.g. R-parity)

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Phenomenological analyses of local models typically

- rely on continuous global U(1)s
- that might be broken in the full theory
- what are the remaining symmetries?

We need to answer this question before any predictions can be made!

Rule 7: Berechenbarkeit

Nowadays we need calculability that goes beyond the effective supergravity field theory approach, e.g. exact conformal field theory

- flat orbifolds, free fermionic constructions (Faraggi et al.)
- tensoring CFTs (Gepner models) (Schellekens et al.)

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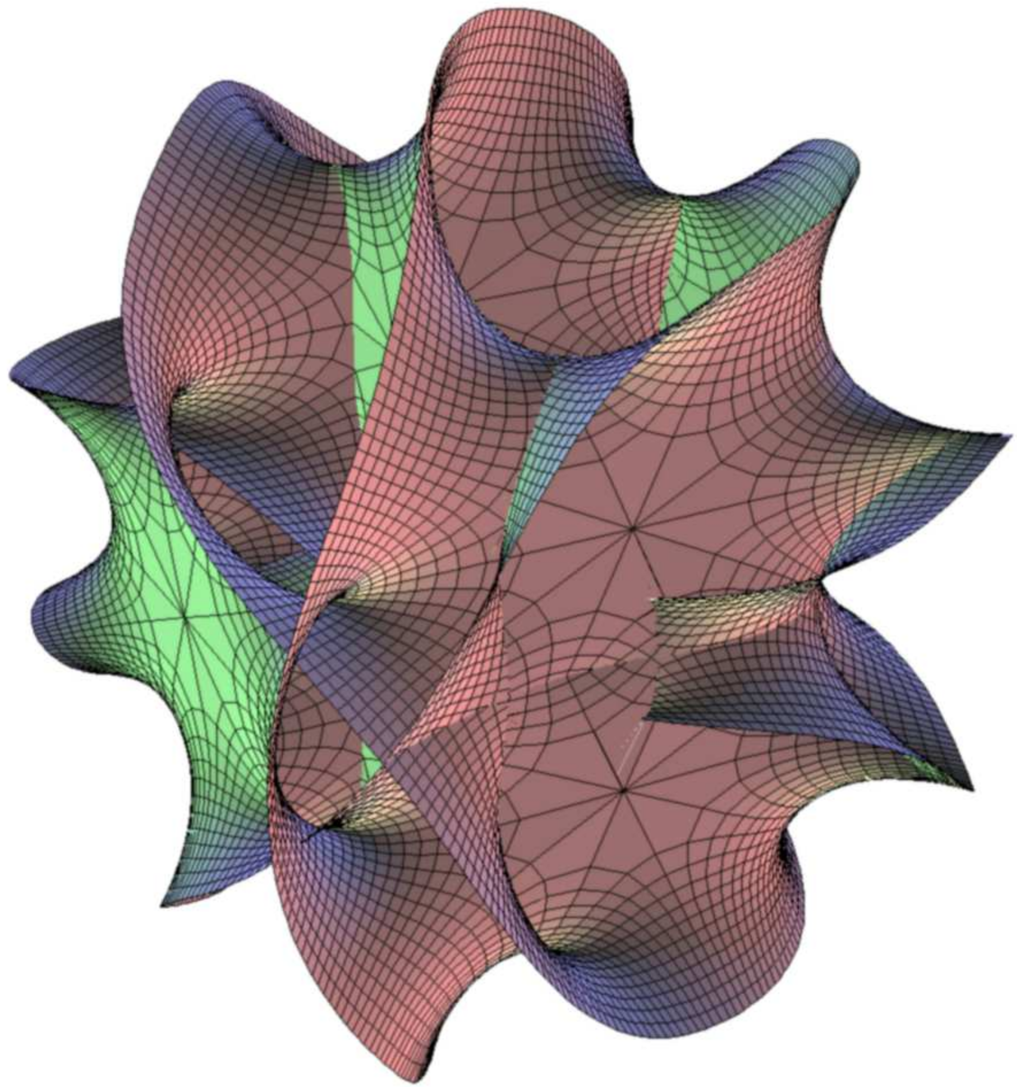
We have to analyze points of enhanced symmetries and enhanced particle spectra

- slightly broken symmetries (Frogatt-Nielsen)
- small parameters to create hierarchies

Hopefully nature is close to points of enhanced calculability.

Calabi Yau Manifold



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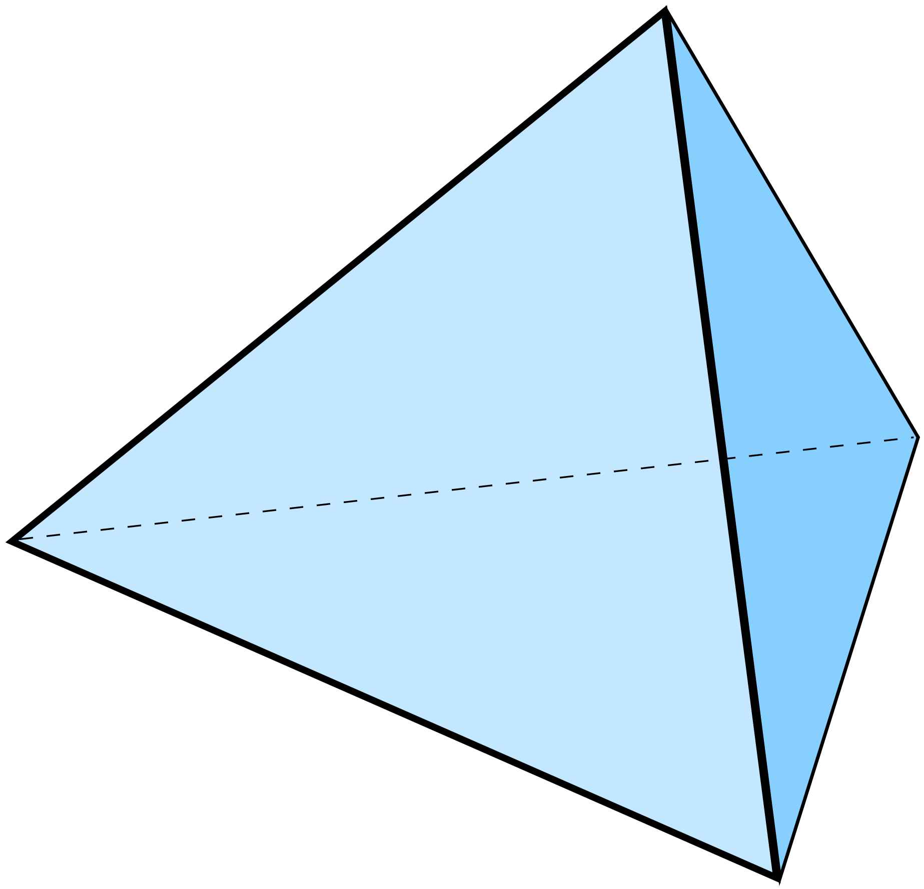

The fate of smooth compactification

Models on smooth manifolds describe generic points in moduli space

- limited calculability in practice (not full CFT)
- do not see locally enhanced symmetries and spectra
- but location of fields is of physical relevance

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As a result, phenomenological analyses of these models often rely on continuous gobal symmetries

- an approximation is needed for “calculability”
- heterotic Calabi-Yau compactification should be related e.g. to a point with exact CFT

For F-theory it seems to be a real challenge to find a flat (CFT) approximation.

Improve calculability

Have to connect smooth compactification to e.g. flat orbifolds (Groot Nibbelink et al.; Blaszczyk et al.; 2009-2011)

- resolution of singularities within toric geometry
- is a good approximation in large volume limit

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But there are still some points that have to be clarified

- relation of number of massless states in orbifold and blow-up
- “missing” Yukawa couplings in large volume limit

Local anomalies might play an important role in the attempt to transfer calculability from orbifolds to smooth manifolds.

(Blaszczyk, Cabo Bizet, HPN, Ruehle, 2011)

The Anomaly Polynomial

The Green-Schwarz anomaly polynomial is a useful tool to study the relation between various schemes. The 12-form

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The Green-Schwarz anomaly polynomial is a useful tool to study the relation between various schemes. The 12-form

$$I_{12}(F_i, R) = I_4 \times I_8$$

contains crucial information on the properties of the model:

- can be computed independently in the different set-ups
- controls the coupling of “axions” to matter fields
- reveals broken and unbroken (discrete) symmetries.

Relate models of reduced calculability to those where explicit calculations can be done.

(Blaszczyk, Cabo Bizet, HPN, Ruehle, 2011)

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- $N = 1$ supersymmetry
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Let us hope that nature sits at a point of enhanced symmetry and calculability.

This is the place