SEED'S TEAR-OUTABLE TOOL FOR LIVING IN THE 21ST CENTURY

CRIBSHEET#9

STRING THEORY

THE KEY QUESTIONS IN STRING THEORY:

What are the fundamental components of the universe? Is there a unifying theory that can explain all basic physical phenomena?

THE BIG AND THE SMALL

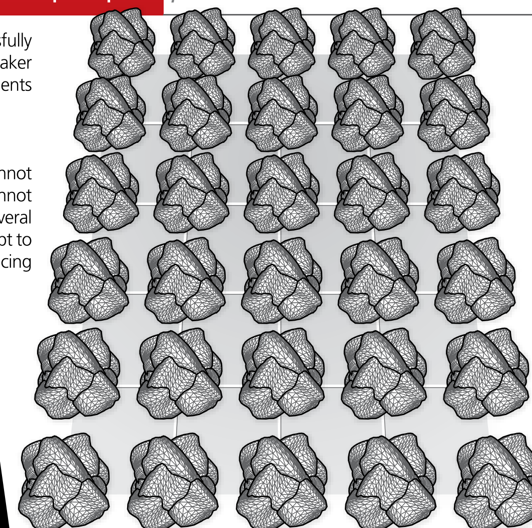
In physics, the description of our universe is divided into two seemingly irreconcilable realms: the quantum world of the very small, and the macroscopic world where gravity reigns. **String theory** is the controversial attempt to unify the two domains into a "theory of everything."

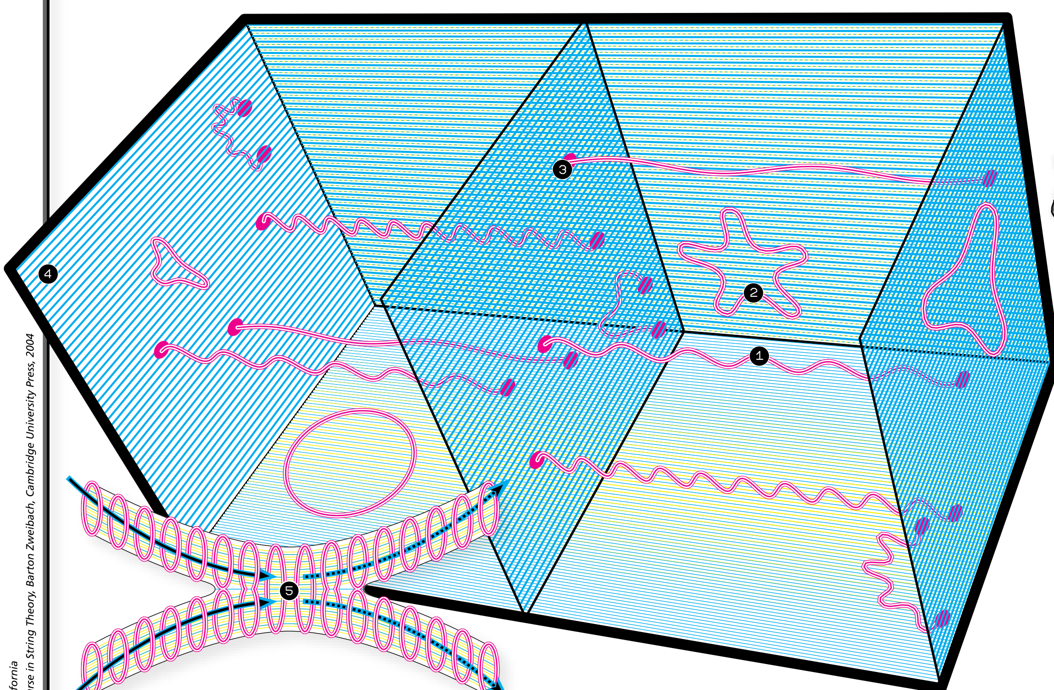
PARTICLES AND FORCES

The universe is made of two groups of tiny fundamental particles: **fermions** and **bosons**. Fermions are all observable matter while bosons transmit the four known forces in nature: **electromagnetism**, **gravity**, the **strong nuclear force**, and the **weak nuclear force**. Physicists have discovered a framework that successfully incorporates all the forces except gravity, which is curiously weaker than the other forces. Called the **standard model**, experiments reveal it as the most accurate scientific theory ever devised.

WHY STRING THEORY?

Because it does not include gravity, the standard model cannot describe the center of a black hole or the Big Bang. It also cannot predict the results of some experiments, nor explain several patterns that exist between particles. String theory is an attempt to fix these problems and unify all matter and forces by replacing particles with miniscule **vibrating strings**.





A string can be any of the fundamental particles, such as **photons** and **electrons**, depending on the **frequency** of its vibration and its **spin**. Strings come in two forms: **open**❶ and **closed**❷. Open strings have **endpoints**❸, located on membrane-like structures called **D-branes**❹, and their dynamics closely resemble the three forces other than gravity. Closed strings are loops; they aren't bound to D-branes and their dynamics resemble gravity. Closed strings combine and split **with each other**❺, as can open strings. Open strings can also become closed strings, showing string theory combines gravity with the other forces.

EXTRA DIMENSIONS

For consistency, string theory requires **six extra dimensions** in addition to the familiar four dimensions we perceive (three in space, one in time). String theorists believe these extra dimensions are folded into imperceptibly small shapes called **Calabi-Yau manifolds** that exist everywhere in space (see example above). But there are an almost infinite number of unique Calabi-Yau manifolds, and there is no known way to discern which, if any, reproduces what we see in the standard model.

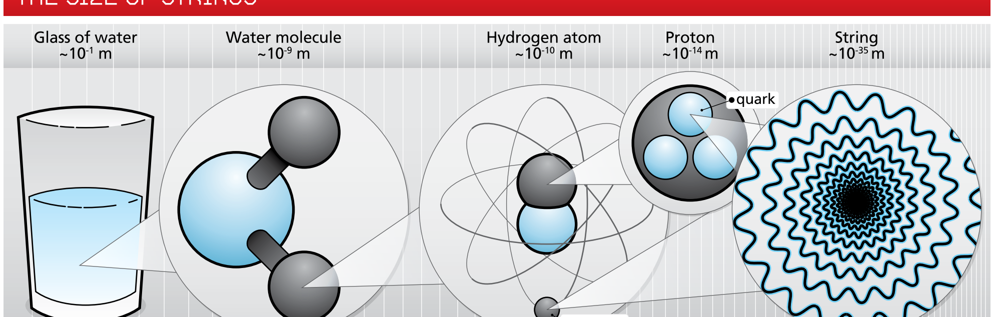
SUPERSYMMETRY

Most versions of string theory require **supersymmetry**, the idea that for every particle of matter there is a corresponding force particle, and vice versa. Next-generation particle accelerators, such as the **Large Hadron Collider** at CERN in Switzerland, could discover some of these supersymmetric particles by smashing together high-energy protons.

A THEORY OF EVERYTHING?

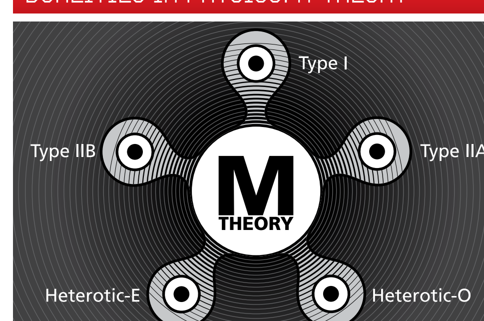
There are five basic versions of the string theory, which hints that string theory itself may not be the final "theory of everything." Profound mathematical relationships called **dualities** exist between the different string theories, and suggest each is part of a deeper explanation that does not rely on strings and branes. This ill-understood framework is called **M-theory**.

THE SIZE OF STRINGS



Strings are the smallest, least accessible objects known to physics. Here, a progressive zoom into a glass of water reveals the relative scales of a water molecule, a hydrogen atom, a proton, an electron, a quark, and a string. The sizes of these objects ranges across thirty-four orders of magnitude. For perspective, if an atom were the size of our solar system, a string would be somewhat larger than an atomic nucleus.

DUALITIES IN PHYSICS: M-THEORY



The five known formulations of string theory appear distinct at first glance, but closer inspection reveals intimate connections between them, indicating they are different parts of a larger underlying theory.

THE ISSUE: IS IT REAL?

Directly observing strings is far beyond our capabilities now and for the foreseeable future. Additionally, string theory's rich diversity makes it difficult to derive any clear predictions that apply to all its versions. Still, particle physics experiments being performed with collisions of very heavy ions at Brookhaven National Laboratory and with proton collisions at CERN could connect string theory with reality. In particular, two discoveries, which are supersymmetry and the existence of extra dimensions, would suggest that string theory is on the right track.

SOUNDBITE

Whether or not strings are validated as a "theory of everything," they provide a unique set of tools to understand and explore the deep structure of reality.

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