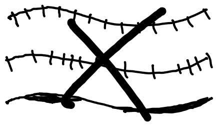
1 Introduction

1.1 Definition

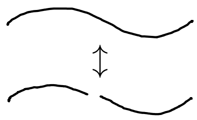
String theory describes the mechanics of one-dimensional extended objects in an ambient space. Some features:

- Strings have tension:

- Strings have no inner structure:

 vs. 

- Several pieces of string can interact:



- Strings can be classical or quantum:

 vs. 

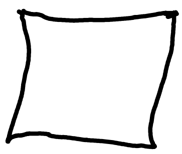
1.2 Motivation

Why study strings?

Extended Objects. We know a lot about the mechanics of point particles. It is natural to study strings next. Or even higher-dimensional extended objects like membranes. . .

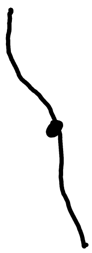
particle

string

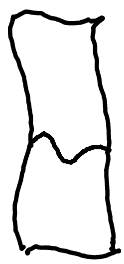


membrane

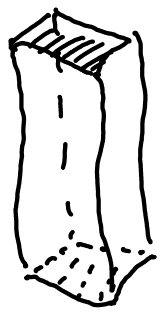
These are objects are snapshots at fixed time t. Introduce the worldvolume as the volume of spacetime occupied by the object:



worldline



worldsheet



worldvolume

The worldsheet of a string is two-dimensional. In fact, there is a great similarity between strings and static soap films.

Quantum Gravity. String theory offers a solution to the problem of quantum gravity (QG). (really?) Sketch without reference to quantum field theory (QFT).

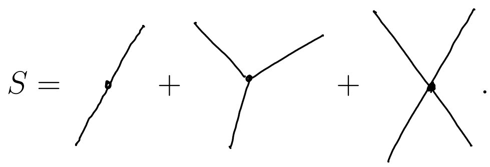
Classical gravity theories:

- Newtonian Gravity (non-relativistic)
- General Relativity (GR, relativistic, geometry of spacetime)

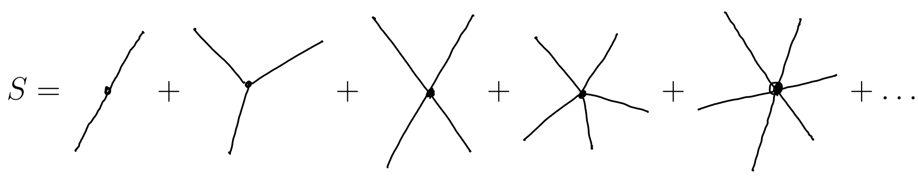
Nature is quantum mechanical, gravity must also be quantum. Need QG for: early universe, black hole radiation. Field quantisation introduces quanta (particles):

- electromagnetism: photon
- strong nuclear forces: gluons
- gravity: graviton

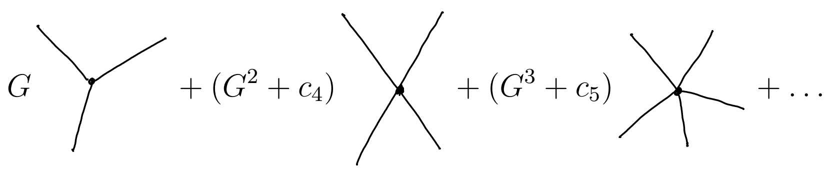
Particles interact through vertices (Feynman rules). Relatively simple rules for standard model



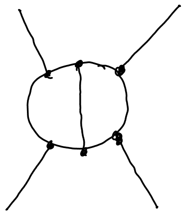
Einstein gravity has infinitely many vertices



In fact, can introduce additional couplings c_k:

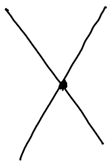
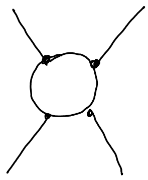
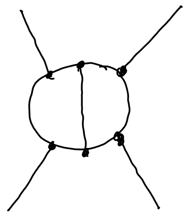


Classically we do not need the c_k, but in QFT we do. Feynman loops generate divergences, e.g.



$$= \infty.$$

Need to sum up all competing processes:

$(G^2 + c_4)$  $+ G^4$  $+ G^6$ 

Divergence can be absorbed into $c_4 = -G^6\infty + c_{4,\text{ren}}$.

All well, but no good way to set renormalised $c_{4,\text{ren}}$ to zero. Unfortunately, divergences require infinitely many c_k. Infinitely many adjustable parameters, not predictive! Only good prediction at low energies, densities: GR.

What does string theory have to do with it?

Quantum string theory turns out to contain gravitons. Moreover, generates no divergences; finite! String theory has just a few coupling constants.

All well!?

Almost, there may be many more couplings elsewhere.

Unification. String theory provides a unified description for all kinds of fundamental forces of nature. (the correct one?)

Electromagnetic and weak forces combine into electroweak forces at sufficiently high energies 10^2GeV. Also with strong forces (Grand Unified Theory, GUT)? Hints:

- Charges of fermions appear to suggest larger gauge group:

$$\mathrm{SU}(3) \times \mathrm{SU}(2) \times \mathrm{U}(1) \longleftarrow \mathrm{SU}(5), \mathrm{SO}(10)?$$

- Estimated GUT scale 10^{15}GeV near Planck scale 10^{18}GeV. Suggests unification of all forces.
- Wouldn't it be nice?

String theory describes gauge theories as well as gravity. In particular, group sequence SU(5), SO(10), ... appears.

Does it describe nature? So far no convincing derivation. Best option: Standard Model (SM) among many(!) "natures".

String/Gauge Duality. Intricate relations between string and gauge theories (used in SM).

In some cases gauge theory *is* string theory.

String theory is part of gauge theory, not just QG.

Treasure Chest. String theory yields many interesting, novel, exceptional structures, results, insights in physics and mathematics. Just to name a few: supersymmetry, higher dimensions, p-branes, dualities, topological insights.

Many Unsolved Problems. (despite 40 years of research)

- How to match with nature?
- How to find direct/indirect evidence? (Susy?)
- What is String Theory?
- How to quantise gravity (otherwise)?