String Theory

In the 1960's, high energy physics ran into a bottleneck. After the spectagular success of quantum electrodynamics (QED) people did not know what to do about other interactions, including strong, weak and gravity. In particular, the strong interaction is strong and clearly the field theory with perturbation theory used so successfully in QED might not be applicable. Many people suggest giving up field theory altogether. But the question is what should replace field theory as the framework for describing various interactions.

In 1960's, W. Frazer and J. Fulco managed to explain the behaviors of electromagnetic form factors of nucleons without using field theory nor perturbation theory. Instead they used analyticity and pole dominance to derive some interesting results for the electromagnetic form factors of the nucleons. This success open up a new direction for the research in strong interaction. A combination of analyticity and dispersion relation seems to give some useful relations among some strong interaction quantities. But the number of relations can be derived this way is rather limited. To go any further clearly more principles are needed.

Next comes the Regge pole theory in which the strong interaction amplitudes are assumed to be controlled by the Regge poles so that the scattering amplitudes satisfy the analyticity and unitarity. This is somewhat a phenomenlogical model and many parameters needed to be introduced to describe the physical reactions. The values for these parameters are not derived from any basic principles but again are obtained from the fitting with experiments. By now many people are ready to give up the field theory which are plauged by all the diveregences and it is very difficult to go beyond the perturbation theory. In many graduate programs, quantum field theory is no longer offered as standard course. It is replaced by dispersion relations which relates many different physical quantities. But there is no simple starting point.

In 1960's G. Chew also proposed the "Nuclear Democracy" scheme in which there is no distinction between composite and elementary particles. But some of the particles are related to some other particles through some commplicated consistent relations. He even use relegions in this endeavor claiming that field theory is like westen relegion there is only one God who controls everthing while eastern relegion e.g. Buddism, there is no one cenetral God to worship. But everything is related to other things. This is a interesting philosophical point of view. But it is not scientific enough to move froward.

In 1968 Venezino discovered that the Euler beta function with Regge trajectories as argument has the properties that give rises to interesting scattering amplitudes and many other useful properties,

$$A(s,t) = \frac{\Gamma(\alpha\,(s))\Gamma(\alpha\,(s))}{\Gamma(\alpha\,(s) + (\alpha\,(t))}$$

where Γ is the stanard Euler $\Gamma-$function and $\alpha\,(s) = \alpha\,(s) + \alpha' s$. The story about the discovery of Veneziano formula is somewhat amusing. Sometime during 1968 or little bit earlier Veneziano got a new job at Weizman Institute in Israel and was taking a boat trip to get to Israel from Italy. During this trip the book named Bateman manucript, which is the bible for people working on Regge theory, fell on the floor and opened up on the page with Euler beta function. This gaves Veneziano the inspiratin of writing the 2 particle scattering amplitudes in term of Euler beta functions which turns out to be the right ansatz. This is known as the Veneziano model. If this story is true this is one of the big accidental discovery. This was quickly generalized to an $N-$particle amplitudes by Koba and Nielsen. The excited-state mass values in these model suggested an infinite set of harmonic oscillators with their frequencies related in a certain way, and that in turn suggested a vibrating string type of mode frequencies.

String theory evolved slowly from the Veneziano model. At begining very few people were working on this because it was not clear what one can get out of this.

In essence string theory is a theoretical framework in which the point-like particles of particle physics are replaced by one-dimensional objects called strings. The string theory describes how these strings propagate through space-time and interact with each other. On distance scales much larger than the string scale, a string looks just like an ordinary particle. In string theory, one of the many vibrational states of the string might looks the graviton, mediator of gravitational force, because it has spin 2 and is invariant under local coordinate transformation. This property makes string theory a very attractive for a theory of gravity and at the same time this means that the fundamental mass scale, i.e. the tension of the string is related to characteristc mass scale of the gravity namely, the Planck mass scale, 10^{19} Gev. This makes the physics of string theory unreachable for any foreseeable future except those low energy phenomenology which migth not have anything to do with string. In other words, there is no experimental support for the string theory at present energies and it remains an interesting mathematical physics which may or may not have anything to do with the reality.

The original version of string theory was bosonic string theory, describing only bosons. Later, supersymmety which relate bosons to fermions was added so that the bosonic theory becomes the superstring theories. In theories with supersymmetry, each boson has a counterpart which is a fermion, and vice versa.

In addition, these theories require extra dimensions of spacetime for their mathematical consistency. In bosonic string theory, spacetime is 26-dimensional, while in superstring theory it is 10-dimensional. In order to describe real physical phenomena using string theory, one must therefore imagine a scenarios in which these extra dimensions would not be observable in the present experiments. This processes is called compactification and can be used to construct models in which spacetime is effectively four-dimensional. However, not every way of compactifying the extra dimensions produces a model with the right properties to describe nature. In a viable model of particle physics, the compact extra dimensions must be shaped like a Calabi–Yau manifold. A Calabi–Yau manifold is a special space which is typically taken to be six-dimensional in applications to string theory. It is named after mathematicians Eugenio Calabi and Shing-Tung Yau.

In 1984 it was discovered by Michael Green and John Schwarze that the open superstring is anomaly free if and only if the gauge group is $SO(32)$ or $E(8) \times E(8)$. Note that theory with anomaly is not self consistent and can not be a fina theory. This discovery has the effect that the choice of gauge group is narrowed down to two. Before this model builder's choice of gauge group is somewhat arbitrary except for some experimental constraints. Many people got very excited about this development that one can from theoretical point of narrow it down to a very few choices. Futhermore, Edward Witten, one of the leading theorists of our time has been going around saying that this is a piece of 21 centry physics falls by accident into 20 centry. Not many people can resist this call for action. Many many people drop what they were doing and jump into the study of the string theory. It spread like a wildfire. But to make the transition to string theory is not so easy because to get into the field one needs to learn many sophistigated mathematics, like differential geometry, homology, Kac-Moody algebra, conformal symmetry$\cdots$ *etc.* This turns the whole high energy physics upside down. The youger generation of physicists embrace this with tremendous enthusiam. For one thing these new mathematics are facinating to learn. Also they do not have to learn the awfully complicate renormalization theory in field theory. On the other hand many older generation of physicists are very unhappy and stayed away from the game by invoking the principle that anything not connected to the experiments is not physics. Besides they are too old to learn the new mathematics any way.

Later in 1994 or so it was found that different superstring theories were different limits of an 11-dimensional theory that became known as M-theory and they are unified by new equivalences, S-dualaity, T-duallity, U-duality,$\cdots$. In 1995 Polchinski discovered that the theory requires the inclusion of higher dimensional objects called $D-$brane. By this time the string theory becomes very complicate and is not so easy to keep track of. Yhe original hope of finding a unique theory quicly evaporated. The only good virture left is the possibilty of accormoding gravitational theory which is not so easy in practice.

In 2003 it the discoverey of the string theory landscape which suggests string has a very large number of inequivalent vacuua. By now the uniqueness of the model is completely lost and the only good virture left is the possibilty of incluision ot the gravity. By now many people have lost interest in the string theory which has more or less turned into mathematical physics and decouples from the experimental observation. The mainstream of high energy physics has come all the way back to framework based on the field theory. Many young theoriest got swept away along the way.