1 First page - What theoretical physicists strive towards

The visible part of our Universe is made of point-like elementary particles interacting according to four fundamental forces. Three of these forces, the electromagnetic, weak and strong interaction, appear to be relatively well understood and unified in a common framework. The fourth one - gravity - remains the most mysterious one, at least when the distance scale becomes very small. The possibility of including the gravitational interaction in this unified picture thus remains the goal that theoretical physicists have been striving towards for almost a century.

What if replacing these point particles by tiny vibrating strings could provide a good framework for a unified description? This was exactly the idea that in the 1970s lead to the formulation of string theory. It gave an enormous boost to research in theoretical physics, and was soon hoped to lead to a "theory of everything".

A huge amount of work that has been done over the past fifty years in order to go deeper and deeper into the structure of string theory. Slowly this led to the idea that its study could be interesting by itself, independent of the final ambitious goal of the theory of everything. Indeed, after the formulation of the so-called AdS/CFT duality it became clear that the study of the motion of a string in spaces with one dimension higher than the one of our real world could provide interesting information about a particle moving in ordinary space-time. The aim of this leaflet is to explain these concepts in an accessible and non-technical language.

2 Second page - How do strings behave?

Who has never played marbles in his or her childhood? Well, if you have ever played marbles on a beach you may remember that after moving on the sand, the marble is leaving a track with the shape of a line. This sign on the ground is keeping track of what the marble has done in its past and therefore it is describing the evolution of the marble in time. Now take your marble and shrink its size, smaller than anything you can think of, all the way to a point. The evolution in time of a point is what a theoretical physicist would call a worldline.

Imagine you want to do the same thing with a string. You take a lace out of your shoe, you dip it into a paint tin, and then you move it on a wall or on a piece of paper. The track that is left by this object is not a line as before, but it is two-dimensional, it is a surface. That is why the evolution in time of a string goes under the name of worldsheet.

3 Third page - The shortest path

The whole world of classical physics is based on the assumption that a free particle chooses the shortest way to go from one point to another. Imagine you are standing in a football pitch and that you want to move from one goal to the other. If you want to pick the shortest way possible, you should obviously just walk along a straight line.

Now, imagine that suddenly a very high hill with the size of the middle-field circle appears in the center. This would mean that the straight line you were following before now implies climbing the hill. If the hill is high enough it is pretty obvious that the straight line is not the shortest way anymore and probably the shortest way would include going around the hill.

What is the difference between the two situations described above? In the first case, the field is completely flat and the shortest way is trivially given by a straight line. In the second case, the hill curves the surface and the shortest way is not trivial anymore and depends on the particular way the space is curved. In other words, the curvature of the space modifies the way you measure length.

4 Fourth page - Minimal surface

A natural question that one may ask is: how do I translate the concept of a shortest way to the case of strings? As we mentioned, the evolution in time of a string is not described by a line, but by a surface. Therefore the concept of length of the line has to be replaced with the idea of an area of a surface. The string follows the path that gives the smallest possible area of the worldsheet. The straight line followed by the point-like particle is replaced by a plane for the string moving in flat space.

What happens then when you curve the space? We have learned that curving the space changes the way we measure distances. Therefore also the concept of a smallest possible area is modified. Have you ever played with soap bubbles? The idea is exactly the same. A soap film at rest always chooses the minimal surface. Indeed if you take a small plastic circle with a soap film, the latter would appear nearly flat. However, if you perturb the system, for instance blowing at it, the surface described by the soap film becomes curved. Something similar happens if you curve the space the soap film is embedded in.

5 Fifth page - Holography

Nowadays we gained experimental evidence that the Universe we live in is at least almost flat. Then why should we be interested in putting strings into a strongly curved background? The reason comes from the discovery of the so-called AdS/CFT duality. Introduced 1997, the duality tells us that learning things about string theory in a curved space in five dimensions tells us something about particles in our familiar space. The idea behind this intuition is the usual idea of holography. Maybe you know the novel "Flatland: a romance of many dimensions" by Edwin A. Abbott. It is a story, written in 1884, about creatures living in a two-dimensional world (say a huge plane). If you live in two spacial dimensions and you meet someone else, you just see a line, you'll never know the exact shape of the creature you are talking to. What if we are confined to live in a four dimensional space-time (the usual three space dimensions plus one additional dimension given by the time) exactly like the inhabitants of Flatland are confined to live in a two-dimensional world?

So you have to imagine a string moving in a five-dimensional curved space-time with its boundary given by our ordinary four-dimensional space-time. Since this is clearly hard to visualise, just think about the inhabitants of Flatland that live in a two dimensional space-time, ignoring the existence of the third dimension. However, what occurs in the third dimension has a direct influence on their life. This is similar to what may happen to us, we might be influenced by a fifth dimension.

6 Sixth page - The future

Do we know everything about holography and string theory after the discovery of AdS/CFT? The answer is obviously no. The deep structure of the duality is still far from being completely understood. Moreover the most famous examples of the duality still refer to theories that do not describe exactly the real world. Rather they describe some simplified version of it which is easier to deal with. There is still a lot of work to be done. The GATIS network is a perfect environment in terms of allowing researchers from many different countries to collaborate to achieve a deeper understanding of all the issues that are described here.

As John Bardeen mentioned in his second Nobel prize speech: "Science is a field which grows continuously with ever expanding frontiers. Furthermore, it is truly international in scope. [...] Science is a collaborative effort. The combined results of several people working together is often much more effective than could be that of an individual scientist working alone." This is the spirit that leads the GATIS community through its daily effort.