VISUAL RELATIVITY

Interdisciplinar Teaching Unit

Xabier Prado

Visual RELATIVITY.

Interdisciplinar Teaching Unit.

Xabier Prado

This work has been presented at the CERN Auditory in Geneve, during the European "Physics On Stage" meeting (November 2000).

We present here a visual and interdisciplinar teaching proposal for the Relativity Theory. It is directed to a pre-university level: "A" level, or the end of the secondary education.

We use an interdisciplinary teaching for three reasons:
- Relativity is interesting for all the disciplines, because it affects deeply to the most basic slight knowledge of the time and the space.
- Each discipline can make an interesting contribution to understand the subject of Relativity better.
- We use a didactic technique based on the geometric and visual facts of relativity. This allows us to present this theory and its consequences almost without mathematical formulas. The graphical vision is very intuitive**.** This kind of education is used from the beginning:

In the subject of **Physics** we present the postulates of the theory of relativity in a visual or geometric form. This allows us to demonstrate the Lorentz Transformatrion in an entirely visual and intuituve way. *The graphics that we use here correspond to a 2-dimensinal simplification of the four-dimensional space/time, or "Universe of Minkowsky".* The principal steps of this "didactic process" are the following:

1- The transformations of the space-time are linear.
This is a consequence of the first law of Newton: **The inertial transformations conserve the states of uniform movement**. Uniform movements are represented by straight lines in the space-time graphs. Linear transformations conserve the straight lines. *Visual representation, Figure 1: Transformation of the s/t square (whose sides are the unitary vectors) into a parallelogram whose sides are the transformed vectors.*

2- The time axis inclines when changing of inertial reference system.
The inclination is proportional to the relative speed between the initial system and the transformed one. *Fig. 2: Velocity is the distance travelled in one time unit.*

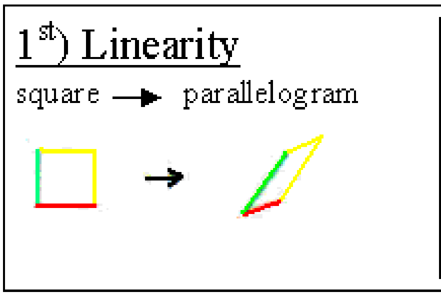

Figure 1

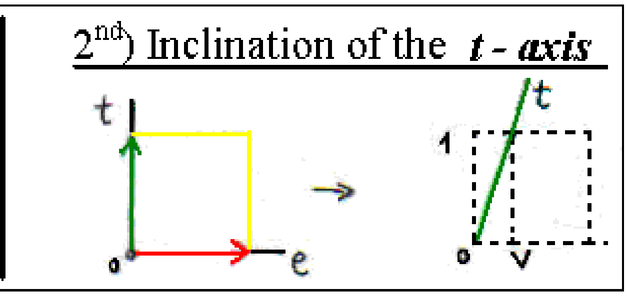

Figure 2

3- The bisectrixes of the axes are conserved.

The speed of light, c, is the same in all reference systems. This is one of the fundamental postulates of Relativity, and it´s a consequence of the Laws of Electromagnetism (Maxwell), where "c" appears as a constant. In a natural scale, c=1. The bisectrixes (straight lines with slope equal to 1) correspond then to rays of light. *Fig.3: There is only one kind of parallelogram that conserves both bisectrixes as diagonals, and it´s a* ***rhombus*** *(an inclined one).* The equivalent classic postulate ("Time is absolute, and the same in all reference systems"), in comparison, would let us to a parallelogram where the horizontal sides remain horizontal (Galileo Transformation).

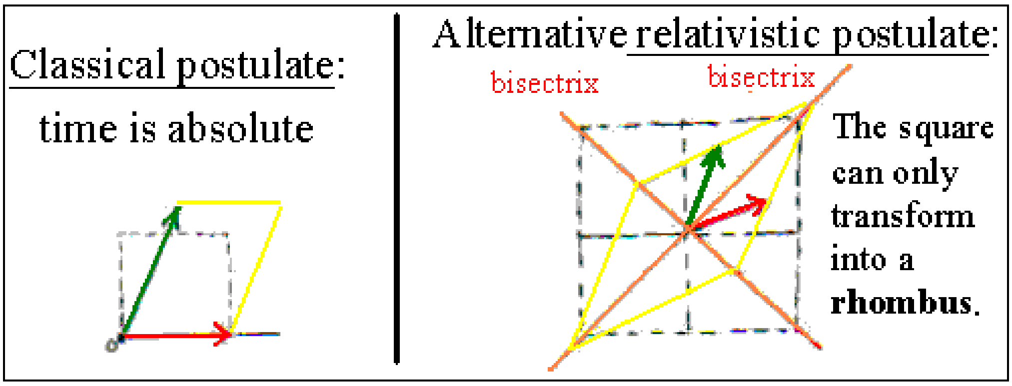

Figure 3

4- **The conservation of the space-time areas.**

This one is a consequence of the principle of **space isotropy**. The scalar characteristics of space-time do not depend on the sense of the relative movement. The space-time area is a scalar characteristic. *Fig. 4: The area of a rhombus is half the product of both diagonals. Therefore, if one of the diagonals gets "stretched", the other must be "shortened" in the same factor.*

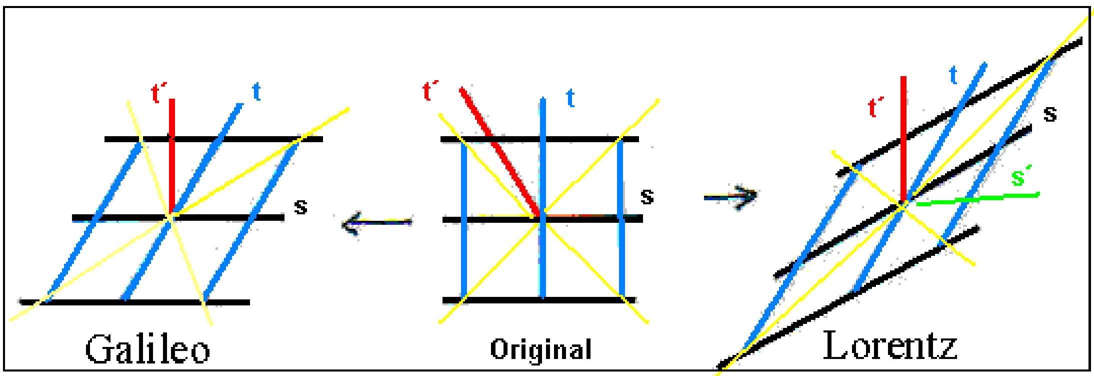

Figure 4

We have now completely determined the Lorentz Transformation among inertial reference systems. We can now use it to explain all the consequences of the (special) Relativity Theory. This shows its essential geometric (and therefore visual) character.

We propose to do at the same time two equivalent demonstrations:
In Mathematics, using matixes in order to characterize the linear transformations being used. In Drawing, to visualize them geometrically.
This allows us also to get exact numerical results, matching the ones that we would obtain using the usual relativistic mathematic formulas.

We will work later in Physics with this geometric vision of the transformation of Lorentz of special relativity. We will present all the effects and consequences of relativity in a visual and intuitive way.
We can explain very easily the well-known effects of the space contraction and the time expansion.

The loss of simultaneity is not so easy to understand. It seems that something disappears and we do not know what appears in its place. In the new geometric vision it is possible to understand quite well what happens. It is also possible to use this to predict very interesting phenomena:

Suppose that we are at the rear wagon of a train at rest. We have a lamp that can sent a light pulse, and direct it to the front part of the train. As it impacts on a photoelectric cell placed at the control cabin, the lights on the whole train illuminate briefly. *We can regard these events at Figure 5 from three different viewpoints:*

b) **a)** **c)**

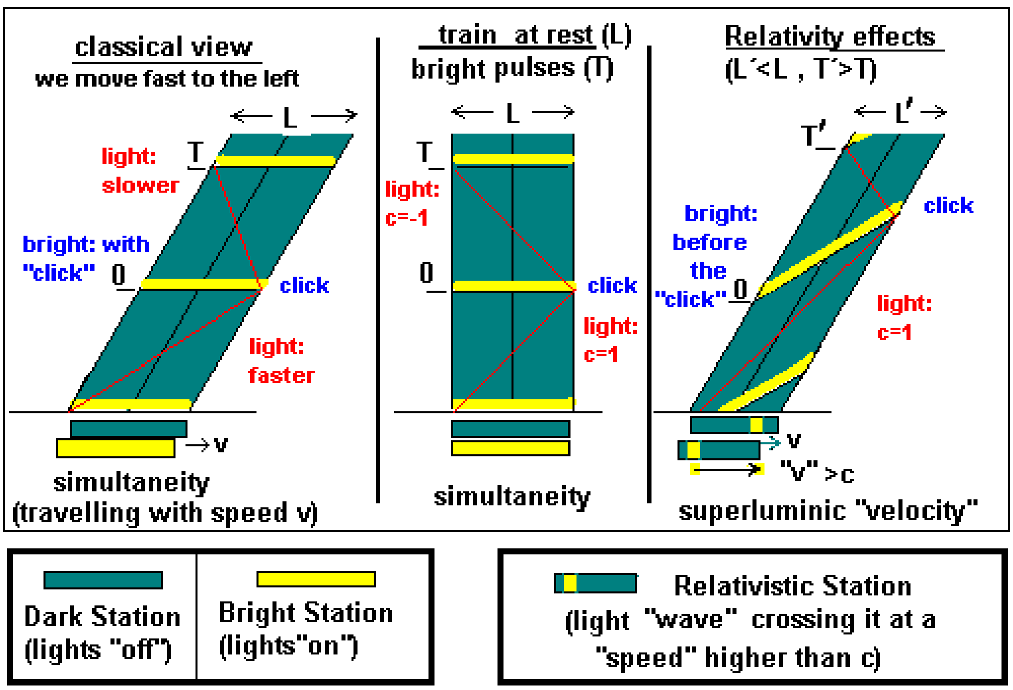

Figure 5

a): *From a system at rest with the train,* ***b):*** *From a similar train that moves to the left with speed "v" (classic, or Galilean, transformation), and* ***c):*** *From the same moving*

train, but under the relativistic (or Lorentz) transformation. We can see that the original train is now shortened (spatial contraction). But we observe more: The illumination travels as a "wave" from the back to the front of the train, pursuing the pulse of light ***before it reaches the interruptor, and at a speed that is ¡greater than "c"!***
It is difficult, on one hand, to accept this apparent violation of the cause-effect relationships: The illumination "starts" before the pulse reaches the photoelectric cell that, **supposedly**, was the cause for it. On the other, it seams to appear a contradiction with the extended notion that relativity doesn´t accept velocities greater than the speed of light.

This is a spectacular visual effect. We can explain that this *super-luminance speed* does not have physical sense. It does not correspond to any true movement. For that reason its existence does not contradict this affirmation of relativity*: No body nor information can travel at speeds that are greater than the speed of the light.*

Press reports that question the theory of Relativity are appearing lately. They are based on experiments that produce **speeds greater than c**. These experiments are very similar to the phenomenon that we have seen. They use quantum wave functions instead of the series of lamps. We have already seen that Relativity explains these speeds that are greater than "c" in a graphical form (they are known as *Phase velocities).*

The Mass-Energy Equivalence is a geometric effect of the **inclination of the space axis**. It can be seen in the graphical transformation of an inelastic collision (or a crash). The famous formula of Einstein (**$E=m*c^2$**) expresses the conservation of the resulting energy. In natural units, where c = 1, the formula states that **E=m.** .

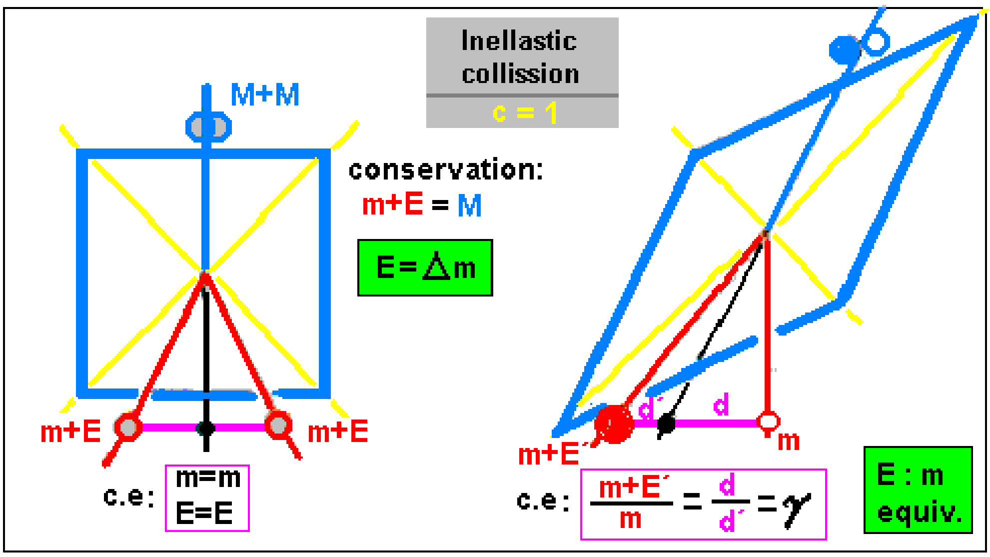

Figure 6

We can see at Figure 6, left, an inellastic collission between two identical particles, with opposite velocities. The center of equilibrium (c.e) remains at rest, due to the simmetry of the situation. We see at the right the same collission in the reference system of one of the particles. We observe that the additional Kinetic Energy of the other particle, Ec, attracts to it the equilibrium center in the same way that an additional equivalent mass would do.

It is also possible to explain a basic slight knowledge of the General Relativity in a visual form.

The students must know the concepts of *force of inertia or fictitious force* in accelerated systems. This is a consequence of the principle of classic equivalence between accelerated systems and gravitational systems.

The relativistic principle of equivalence is very similar and allows us to explain visually the Black Holes and the curvature of the Universe. *(Figure 7)*

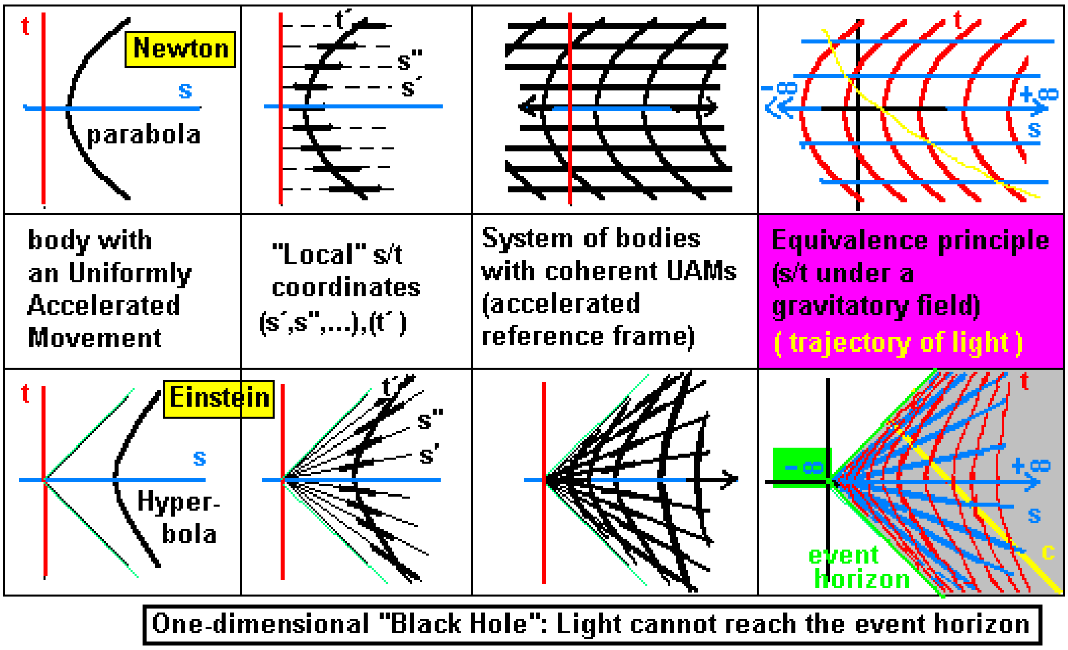

Figure 7

These concepts are very important at the moment. Everybody hears or speaks about them, although they possibly do not understand them.

This importance of Relativity in other fields of knowledge can be pointed out in the classes of Technology, History, Language or even of Philosophy.

In the class of Technology we use these visual concepts of Relativity to explain how the electromechanical devices work.

It is not necessary to use the concept of magnetic field. We avoid therefore the vectorial products and the three-dimensional turns. The explanation is very simple.

The Language teacher can explain the deep change that the theory of relativity must produce in our minds. There has been another change of this class in the history of Humanity. It was the concept of a **spherical earth**.

Figure 8: In a sphere, the horizontal planes and the vertical axes are relative.
This vision hit the previous religious and cultural concepts:
A flat natural world and an absolute supernatural world.

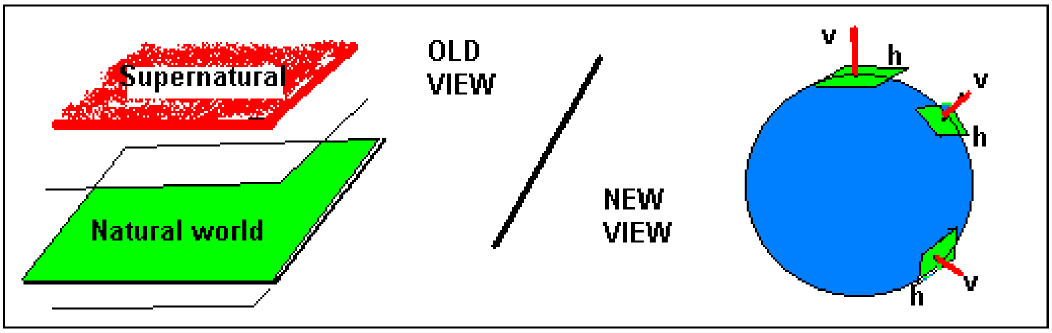

Figure 8

The theory of relativity must change our concepts in a similar way:
The space as a continent where all the things are.
The time as the absolute measurement of the changes that happen in this space.
Figure 9: A representation of the space-time in accordance with the Theory of Relativity is that of ***a continuum.*** *The form of this continuum, for the observers in movement, changes by means of a special transformation.*

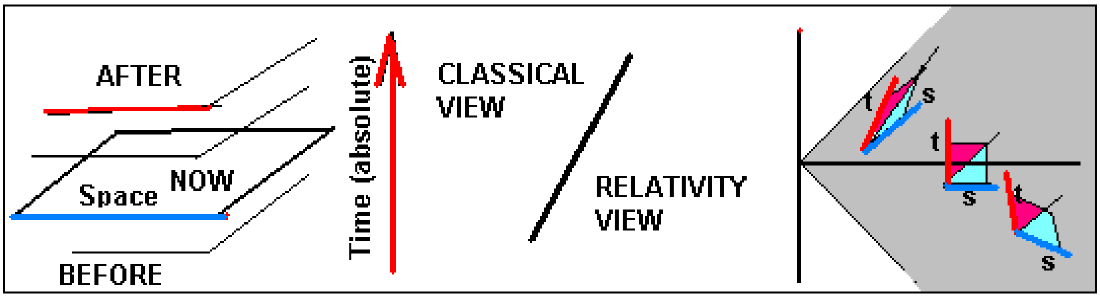

Figura 9

The curvature of Earth is not explained nowadays at the Physics or Mathematics classes, but instead at the Elementary Schools: In Geography, with help of visual models (the Earth sphere is present in most classrooms, even as a symbol of teaching). Possibly in the future the geometric view of Relativity will allow to explain it at elemental levels to all the students, not only to those who will continue scientific studies.
In order that an **interdisciplinary** proposal is possible, it must be able to give a positive answer to the following questions:

From the point of view of the chosen thematic nucleus (in this case, relativity):
Does the interdisciplinary education allow a better teaching of the contents?
In this Didactic Unit we present an intuitive geometric vision of Relativity to fulfil this requirement.

From the point of view of the participating disciplines:
Does the thematic nucleus provide interesting contents for each discipline?
This requirement is more difficult to satisfy. It is really necessary that the teachers of each discipline do not feel like simple assistants of the other subjects.

In each discipline the subject is adapted to the content of the official syllabuses.

Once this first test is overcome, the interdisciplinary syllabus will be a further subject. It will have its own objectives, contents, time, didactic materials for students and teachers, and procedures of evaluation.
Differences with the normal subjects: There is more than one teacher. There is neither own space nor time. We must coordinate the activities of all the subjects. Each school is different. The time for these activities will be also different in each school.
The **interdisciplinary teaching** increases also the interest of students.

The Teaching Unit has the following parts.

- Introductions and general programming. At the end there are three tables with a summary for the different subjects and their connections
- Programs for every subject. Every teacher can so focus on the own contents, without losing mind from the others:
  - Physics.
  - Mathematics.
  - Drawing, Design.
  - Others (Technology, Languages).

Xabier Prado
Pedra da Auga Secondary School
36860 Ponteareas, Galice (Spain)

Tlf+Fax: + 34 986 641017
e.mail: fisica.visual@gmail.com