# The World in Your Computer: Geographic Information Systems

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**Viareggio, 15 November 1997**

## If Leonardo had only had a computer

It has long been known that Leonardo da Vinci and Niccolò Machiavelli were contemporaries in Renaissance Florence, but until now few had suspected that they shared responsibility for a particularly ingenious bit of mischief. Some recent scholarship in America has now revealed that not only did the consummate Renaissance man and the master political schemer *per definizione* almost certainly know each other, but apparently collaborated in one of the first significant uses of technology as an instrument of political policy.

In his book *Machiavelli, Leonardo, and the Science of Power* (University of Notre Dame Press), Roger D. Masters tells us the story: it seems that in 1503 the ruling Council of Ten in Florence were shopping around for ideas on how to subdue those *vituperative Pisans*, as the Florentine Dante Alighieri had described them two centuries earlier in the *Inferno*. Their old antagonists eighty kilometers downstream the Arno River had been making trouble again, and the Signoria wanted to settle the matter once and for all. Combining their skills, Leonardo and Machiavelli obliged by hatching an ingenious and ... well ... *Machiavellian* plot to subdue Pisa by altering the course of the Arno River. Thus deprived of their primary source of fresh water, the Pisans were sure to wither. The green light was given to the proposal, and Leonardo went to work on what was certainly one of the most ambitious works of hydraulic engineering ever attempted up to that time. He drew up several detailed maps of the Arno Basin, as well as another map showing the position of a canal that would redirect the Arno towards what is now the town of Stagno near Livorno. (It was an act of prescience of which only the genius of Leonardo was capable—for, that is exactly where the *scolmatore* canal was eventually built after the disastrous flooding of 1966.) Armed with only his map, however, Leonardo was unable convince his lead architect Colombino of the feasibility of his design, and Colombino chose another of his own making. But Colombino was not endowed with the intellectual powers of Leonardo; after less than a year of construction, the waters backed up over Colombino's dikes and flumes, destroying them and causing the Signoria in Florence to fire Colombino in disgust and finally to drop the whole matter in 1504.

Poor Leonardo might have been able to present a more convincing case to Colombino if he had had at his disposal one of the most important tools for environmental management that modern computer technology has given us: a *geographic information system* or "GIS". (In Italian: *sistema informativo territoriale* or "SIT") Essentially "computerized maps," these systems make a whole range of analyses possible that would have come in very handy for Leonardo while he was arguing his case before his less gifted colleagues. Almost five centuries later, just such a geographic information system has been constructed, albeit for more peaceful purposes: the monitoring of pollution levels in the Arno Basin. Sponsored directly by the European Commission under its LIFE program, the computerized system has become a cornerstone of the Region of Tuscany's ambitious environmental management policy, and the centerpiece of our presentation today.

## Mapmaking from Ancient to Modern Times

Geographic information systems have had a revolutionary influence on mapmaking techniques. Until very recently, mapmakers followed age-old traditions that had changed little in centuries (thanks in great part to the pioneering efforts of Leonardo himself). A good map was a work of painstaking art, and might have a subsequent lifetime of several decades. (Even today it is not unusual to buy a territorial map and discover that it was created in 1947—fifty years ago!)

This all changed in the early 1970s when a presidential decree ordered all of the regions in Italy to manage their territorial resources as effectively as possible. As the peripheries of the cities were built up, bridges and highways constructed, and forests torn down, maps now had to be kept up-to-date with the rapidly changing face of the landscape. Airplanes equipped with special cameras began to fly over pieces of land, and directly capture the characteristics of the land onto magnetic tape, which was then transferred to a computer. The era of digital aerial photography had begun, reducing the time for accurate map construction from years to weeks, *even days*.

In the 1990s, "remote sensing" through digital satellite photography has accelerated the pace of accurate map construction even further. Satellites such as *LANDSAT* and *SPOT* now orbit the globe, photographing wide swaths of the Earth with several different kinds of sensors, each able to capture different kinds of characteristics of the land below them. The results are beamed down to large ground centers that process and distribute the data to many kinds of scientific and commercial organizations.

In Italy, the *Istituto Geographico Militare* (I.G.M.) is responsible for the distribution of many different kinds of maps, from valuable antique lithographs all the way to the most modern multispectral satellite images. In our demonstration today, we will show you a satellite image of the Arno Basin in and around the Pisa area. In our satellite image, we can see the area all the way from south of Livorno up to Lucca and east towards Pontedera.

### *Computerized maps and the global positioning system*

What can we do with maps, once we get them inside of the computer? One of the most exciting developments in recent years, which has suddenly made the variety of applications for computerized maps explode is the *global positioning system*, or GPS, which was created by the United States military as part of the Strategic Defense Initiative under President Reagan (also known as the "Star Wars" initiative). This is a set of twenty-one satellites, all orbiting around the earth in precisely fixed paths. They send signals to the earth that can be picked up by electronic devices, which then essentially use the ancient surveying method of "triangulation" to discover their location on the earth. In combination with a computerized map, this means that a number of application in "navigation" are possible—in fact, one of the biggest GPS markets right now is automated navigation systems for automobiles.

## Working with a geographic information system

As we have seen above, the ability to create maps quickly today by means of aerial photos or satellite photos has made it possible to have computerized maps that are always up-to-date and accurate. The aerial or satellite map gives you the basic "layout of the territory," which can be useful for computerized navigation. But an even more important set of applications has to do with the *content* of the map, not just its shape—and this is where the geographic information system comes in. Today we will take a look at how a real, functioning GIS operates, with the LIFE project as an example.

The most fundamental concept in a geographic information system is the *overlay*. Conceptually, the overlay is a very simple idea, and we have seen it applied to maps many times without thinking much about it. In fact, *any* map always "overlays" some kind of information on the basic territorial map. Here are some examples:

- A *topographical map* overlays information about the altitudes of the terrain, usually with those wavy lines that show areas of identical altitude. This is the kind of map that is used by hikers in the *Alpi Apuane*, who might need to know how high that mountain over there on the other side of the valley is before they decide to climb it.
- A *street map* overlays information about the road network. Every time you take a long trip on the *autostrada* you certainly use one of these maps, to find out the shortest route to take to your destination, the names of the highways, and so on.
- A *political map* overlays information about political boundaries. Naturally, these change a lot—just think of the map of Europe before the Berlin Wall fell. Depending on the level of detail, the map may show you the borders of countries; states; regions; provinces; or cities.
- A *land use map* overlays information about whether the land is used for agriculture, or for building, or for forestry, etc.
- A *geological map* overlays information about the kinds of rocks, minerals, etc. in each area. Among other things, these kinds of maps are used by earthquake specialists in order to think about where the danger of future earthquakes might be highest.
- A *flood map* overlays information about how and where flooding occurs in the various areas covered by the map. This is particularly important for the Arno Basin itself, of course.

Each of these maps is useful on its own, but they would become even more useful if it were possible to use them in *combinations*—for example, a geological map combined with a political map, in order to know who has the rights to some valuable minerals in the soil below a particular area; or, a land use map combined with a flood map, in order to know which residential areas are in danger of being flooded by the Arno (as happened in 1966).

This is exactly what is made possible by a geographic information system. Many different kinds of overlays are made available to the analyst, which he can put together in various combinations in order to assist him in his decision-making. In our demonstration of the LIFE project, we will show how the analyst works with overlays.

## Geomarketing

While the most important applications of geographic information systems today may be those related to the study and conservation of our environment, they are by no means the only applications. In fact, there is a very large group of applications that have great social and commercial implications. By *geomarketing* we mean marketing analysis conducted by means of georeferenced data—that is, data that has been associated with its real place on the map. In the following sections, we present some examples of geomarketing, all of which are based upon the ideas of "overlays" we discussed previously.

### *Analyzing the Highway Network*

In Italy we have a well-developed network of highways, the *autostrade*, run by the association that we all know as ANAS. Suppose that ANAS decided to buy a geographic information system in order to try to improve its services. Consider a scenario in which all of the car drivers who enter a highway take a ticket that they present at the exit. Thus it is possible to calculate the toll paid. But it is also possible to know the route that was taken. Assuming in a first approximation that all of the drivers choose the shortest route and, knowing the hour and day of entrance and exit, it is also possible to calculate at each hour of each day how many people have passed through a particular stretch of the highway.

And, we also know about those people some other things: how much time they have been in the car, and on the average, how much time they will remain before exiting from the highway. This is how the services that are offered by the various vendors on the highway (Autogrill, gas stations, mechanics, etc.) can be adjusted to fit the demand.

### *Helping a Product Distribution Company Improve its Sales*

Suppose that the marketing director of a company dealing in retail products has his staff prepare for him a comprehensive weekly report of all sales of all the company's products, divided up according to region and province, and perhaps even according to individual sales agent. It will be evident from such a report that some sales agents make more sales than others, and that the demand in some provinces is greater than the demand in others. But, aside from being assisted in his accounting related duties, how can a geographic information system help our marketing director *make decisions* in order to optimize his network of sales agents? For starters, the sales can be visualized on a map, in order to highlight the zones where there has been less market penetration.

But, given that the company's products are targeted at households in the middle-to-high income bracket, maybe it would be better to use a different measure; that is, divide up the sales according to a population with a certain income. Sure enough, the map changes color! It quickly becomes evident that the issue isn't *how much* is sold in each region, but how much is sold *with respect to the potential market*.

### *Helping a Bank Improve its Branch Services*

Consider now a bank that intends to open a new branch. Let us suppose that the bank service that enjoys the best position in the market is "arranging credit for small and medium-sized enterprises." Naturally, the branch office should be opened in low-cost areas, in areas where the bank doesn't yet have any other branch offices, and in areas where there are small to medium-size enterprises.

And the competition? Wouldn't it be a good idea to find out where the competing banks have opened their own branch offices in the area? This is something that we can also put on the map, colored according to the density of companies according to their types. The position of the branch offices of the competition can be obtained from the Chamber of Commerce or from the ISTAT census, and the best position for our bank's new branch office can be *calculated* with the help of the geographic information system. Naturally, we can also represent the branch offices that are currently in operation, assigning to them an importance in accordance with the demographic data of the current clients—in turn divided up according to type. All of these different kinds of data (client demographics, ABI bank branch offices, census data) are already available for acquisition by the bank—and *perhaps already present on the bank's own computers*! They need only be organized with a geographic information system in order to be processed in this useful way.

### *Helping the Health Department Improve its Service*

A local health department (USL) would like to rationalize the location of its services in order to improve its services to the residents of the area. On the city map, the services *seem* to be already well distributed: at least, the symbols representing the services on the map seem to be scattered evenly over the map. Yet, some services seem to be subject to greater demand than others. Why is that?

First of all, we can *color* the map according to the population density, perhaps divided according to the density of older people (if, for example, we are dealing with centers for senior citizens); or perhaps according to women of childbearing age (pregnancy consulting centers); or according to number of children (pediatric centers). In other words, always according to the appropriate *measure of interest*.

Then, it is important for us to recall in our analysis that the user population of one of the USL offices is not necessarily simply the group of buildings that encircle the office, but the population located all along the streets that lead to the office. And thus we can color the access streets with different colors for the first hundred meters, then the next hundred meters, and so on, until we have represented the zone *both* according to the intensity of demand *and* according to the distance from the office; so that both of these factors can be taken into account in our decision-making process.

## The most important applications of geographic information systems

To conclude, we offer here a summary panorama over the most significant applications of geographic information systems today.

- Territorial planning
- Managing technological networks (city power grids, water systems, sewer systems, etc.)
- Environmental monitoring
- Protection of cultural patrimony
- Traffic simulation

- Anti-pollution initiatives
- Thematic maps
- Geological maps
- Seismic maps
- Land-use maps
- Urban use maps (piani regolatori urbanistici)
- Management of surveying operations
- Environmental impact studies
- Management of building resources
- Management of agricultural production
- Territorial marketing
- Socio-economic analyses
- Planning of distribution networks
- Analysis of demand for services

## Epilogue

After their devilish plan for the deviation of the Arno was scuttled, the Florentines reverted to their war on Pisa by conventional means, and in 1509 the Pisans finally capitulated. But the Florentines of today should beware. Today their downstream neighbors are armed with a powerful geographic information system, and this time they just might hatch a scheme of their own.