Visualizing multiple dimensional spaces using projection.

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INTRODUCTION

To design energy efficient buildings, architects need new tools that help them consider environmental issues such as sun lighting. To understand the implication of the direct sunlight on a project’s geometry over time, architects make simulations at different times and at different points of view. After that, they estimate the in-between values. These simulations are virtual or physical model based.

Existing CAD programs feature sunlight simulation: the ray tracing is a very efficient method for generating photo-realistic pictures. However, it is very time consuming and has to be recalculate each time the point of view is changed. This process is very time consuming.

The other method consists of simulating the beam light with a projector on a physical model, but it also requires a number of manipulations to be performed.

The masse of a building that is designed at the beginning of the design process has a strong influence on the solar performances of a project. Unfortunately, designers do not have accurate tools that rapidly help them preview how the sun enters a project. Day lighting issues, such as over heating are usually identified once the general volume of the building is determined. It is usually too late to change the project’s masse and the remedies will be limited: they will consist of using shading devices or increasing the energy used by air-conditioners. To optimize the shape of a solar efficient building, architects need new tools to assist them during the early design phases.

Besides that, the existing methods are seldom implemented at the right time in part because of time consumption issues. The main difficulty of visualizing the phenomena using those tools lies in the fact that they do not provide an efficient way to navigate the time dimensions. Both methods produce a rendering at a given moment. Therefore, the ray tracing technology and the use of physical models are not appropriate tools to rapidly visualize how the sunlight enters a project over the time. The purpose of our research is to research an efficient tool to study direct sun lighting over the time.

DIRECT SUNLIGHTING: A 5D PHENOMEN.

Sun lighting is multi-dimensional issue. The phenomenon must be simulated in the three dimensions of the space. In addition, the sun position fluctuates with time, a variable that has two components- the sun angle variation with the diurnal cycle of a day and with the annual cycle of a year. To preview how a project would be lit, the designer must navigate a 5D space that consist of the three dimensions of the space and the two dimensions of time (annual and diurnal).
Spot is a working prototype of a tool that addresses this problem of visualizing multiple dimension space by projecting the time dimension. The user explores the space in a virtual 3D model he can walk trough. The spatial variables that are the distribution of the direct sun light in the space are displayed in the 3D universe. The fluctuation of the phenomena over the time is projected in another graph that is actually a calendar. In the following, I will discuss the different existing models that enable the simulation of multiple dimension spaces and why the use of projection seemed to be the most appropriate method to simulate the sun lighting in an architectural project.

THE DIFFICULTY OF VISUALIZING MULTIPLE DIMENSION SPACES.

In his article "Four-Space Visualization of 4D Objects-1991", Steven Richard Hollasch explains that the difficulty of visualizing multiple dimensional spaces lies the fact that "There are no solid paradigms for three-spaces creatures such as ourselves. This difficulty is best understood imagining the plight of two-space creatures who try to comprehend our three-space world". Nevertheless, the sun path variation is a concrete phenomenon that we can experience. The main difficulty is not to understand an abstract object but to display a multiple 5D space in a 2D display.

Many methods have been developed for this purpose. In “Animating Multidimensional Scaling to Visualize N-Dimensional Data Sets”, Chris L.Bentley and Matew O.Ward identified four general approaches to visualize high dimensional data: 1) use multiple view of the data; 2) rearrange the coordinates system to be non orthogonal; 3) embed data variables and stack them; 4) reduce the number of dimensions using statistical techniques. In this text, I will provide examples for the three first approaches that are of particular interest for architects for the reason that they are graphic-based.

The main approaches to display height dimensional data.

1-“Using multiple view of the data : each communicating a subset of the dimensions”

The scatter plot matrix is an example of this approach that consists of displaying the data in several plots where each view enables the study of a subset of the dimensions. Statistical software programs usually features a scatter plot matrix function.

A pairwise scatter plot is a graph that uses a coordinate plane to compare the relation between two variables; each axis refers to one variable.
In a scatter plot matrix display, all the pairwise scatter plots of the variables are rearranged in an orthogonal graphic. This technique enables the reader to see the relation between all the variables of an \( N \)-dimension space. In the “Scatterplot matrix of Pollution Data” example, the scatter plot placed in the first column of the third row describes the relation between potassium rate and the iron rate in the atmosphere.

This graphic simultaneity displays all the relations between the different variables. This representation would be inappropriate to represent the direct sun lighting in the space for the following reasons: 1) it’s not intuitive to navigate in the dimensions of the space and time; and 2) there is a huge gap between the range of the time variables (annual and diurnal) which would make it difficult to create pairwise scatter plots.

2. **Glyphs/icons:** “the data are displayed along non-orthogonal axes.”

A famous example of this approach is the Chernoff faces, a method developed by statistician Hermann Chernoff.

![Chernoff face](image)

The idea consist of visualizing the data using the properties of a face icon. The faces vary in the eleven characteristics shown in the picture bellow. The icons can be placed in an orthogonal coordinate graph which is interesting to add spatial variables.

Dan Glaser, a researcher from the university of California-Berkley proposed a method that could be considered as a variant of the dimensional stacking. His program (see fig) displays the distribution of the sunlight over a year.

This method is a very intuitive technique to display multiple dimensional data sets. Nevertheless, we would like the representation we will choose to visualize the sun lighting to have more direct analogies with the really phenomena.

3. **Embed or combine data dimensions to form composite spatial dimensions.”**

The example we will use to illustrate this approach is the Dimensional Stacking method. It consists of embedding dimensions within other dimensions; a 2D graph is divided in sections. The variables are ordered by pair. In this representation, each pair variables is called a “speed” that is actually a unique number. Each speed creates a virtual image that will be embedded in the upper speed: the position of the image of a speed \( K \) determines its relation to variables of the speed \( K-1 \).
The distribution of the lighting in the space is conveyed in a floor plan; an image that contains three variables: the X and Y variables of the space projected in a plan, and the light levels. This picture corresponds to a speed number 2. In the classic dimensional stacking, a speed displays two variables only. A number of floor plans are generated to simulate the lighting at different times of the day and day of the year. Those images are embedded in a calendar that conveys the time dimensions. This calendar corresponds to a speed number one in the dimensional stacking model.

This representation is very interesting because it was the first successful attempt to visualize the phenomenon we are interested in. Nevertheless, this method is not completely satisfying for our purpose two reasons. To optimize the shape of a solar efficient building, we would like to have the possibility to navigate the three dimensions of the space, and it would be tedious to visualize a whole building in the cells of this chart.

**PROJECTION**
The projection method consists of transforming a N dimensions space in a N-1 dimensions space.
Architects have traditionally used the orthogonal projection to represent the tri-dimensional volume on two dimensions media (paper or screen). The loss of a dimension requires additional views to be drawn; the plan sections convey the X and Y dimensions, and the Z dimension is displayed in vertical sections. To understand the relation between those views, they have a common dimension.

The variations of the solar path over a year can be represented using the stereographic projection. The sun angles can be represented by the azimuth angle and the altitude angle; The altitude angle describes how high the sun is in the sky, whereas the azimuth informs us about its direction. Architects are familiar with this representation; both dimensions of the time represented, but the space is projected for one point in the space. The cardinality of the spatial information (X,Y and Z) is 1, which means we can not navigate the space.

**SPOT: PROJECTING THE TIME DIMENSION**

Since architects are familiar with the principle that consist of representing the different variables of the data in various views, the main idea was to display the spatial information that is the distribution of light in a virtual 3D space. The spatial information is not projected. Nevertheless, the temporal information are lost since the program actually colors the surface the user is interested in with a gradient that represents informs of the amount of light a point in the space would get over a chosen interval. The time dimensions can be retrieved for any point by having the program generate a calendar that informs of the distribution of light in the time for this particular point.
Distribution of the light over a period of time in the space:
A 4Dim representation (X,Y,Z and the light intensity that is conveyed through a color gradient).

Link: a point in the space

Distribution of the light over the time for one point.
A 2 Dim representation (annual and daily cycles).