"3D-SCALE-CUBE. A SOFTWARE TOOL TO APPROACH SCALE ISSUES IN GEOGRAPHIC VISUALIZATIONS"

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Abstract

Geographic visualization has an important role in geographic research as it provides a meaningful tool for geographical data representation. The increasing power of information technology permits to create more accurate 3D geovisualizations in different scales. The aim of this paper is to present the methodology followed for the development of the 3D scale cube software tool and to discus scale issues in GeoVisualisation.

3D scale cube is a representation model of the geographical, cartographical and spatial scales that coexist and interact into Geovisualisation. 3D scale cube has been developed by the use of mathematical functions that describe their relationships. Mathematic functions assist us to approach and to describe scales' relationships. Plots of these functions are used to depict the behavior of the three scales. Finally combination of these plots into one represents their common behavior into 3D scale cube.

The results of this visual approach with the help of the 3d scale cube will provide a useful tool to scientists to select the most appropriate scale for their digital representations according to the objective of geovisualization but also the sources, demands and limitations that apply in each case.

Keywords: Geovisualisation, scales, Geographical scale, Spatial scale, Cartographic scale, 3D-visualization

1 Introduction

During the last decade scale issue has increasingly attracted the attention of scientists in different disciplines (Marceau and Hay 1999) as those using Geovisualisation in geographic research. The existence of natural or preferred spatial scales and the necessity to find appropriate linkages between different scales recognized as a serious problem in social and natural sciences (Marceau and Hay 1999, Marceau 1999) and in GeoVisualisation.

Scale is not a new issue, nor is concern restricted to geographic information scientists. Scale variations have long been known to constrain the detail with which information can be observed, represented, analyzed, and communicated. Changing the scale of data without first understanding the effects of such action can result in the representation of processes or patterns that are different from those intended (Turner *et al* 1989). For example, research has shown that reducing the resolution of a raster land cover map (going to larger cells) can increase the dominance of the contiguous classes, but decrease the amount of small and scattered classes (like wetlands in some locations) in the representation (Turner *et al* 1989).

The spatial scaling problem presents one of the major impediments, both conceptually and methodologically, to advancing all sciences that use geographic information. In an information era, a massive amount of geographic data is collected from various sources, often at different scales (Goodchild and Proctor 1997). Before these data can be integrated for Geovisualisation, fundamental issues must be addressed.

The creation of a big variety of visualizations uses available geographical data from a very wide number of sources in order to create digital representations (of any size). Exist data in several cases don't have the appropriate spatial characteristics to give the most effective visual result according to the objective of geovisualization. This problem consist "Exist-Data Problem" and it has very critical role to the geovisualization result and to the scientific conclusions than derives from them.

In fact, in most GIS projects for example grid resolution is selected without any scientific justification (Hengl 2006). In the ESRI's package ArcGis, for example, the default output cell size is suggested by the system using some trivial rule: in the case of the point data is being interpolated in Spatial Analyst, the system will take the shortest side of the study area and divided it by 250 to estimate the cell size (ESRI 2002). Obviously such pragmatic rules do not have a scientific background (Hengl 2006).

There are no rules or software tools to help scientists to choose data according to their visualization demands and limitations. It is common that some times data with different resolution blend in order to create visualizations in different spatial geographic or cartographic scale than this there are suitable to. Also some Geovisualisation applications are made with the use of these data in which users see through different scales (scaling). That has as a result some of these visualizations to be not accurate as should be in scale transition.

Such software does not exist in order to assist scientists to resolve problems as the above, problems that consists the “Exist-Data Problem”.

These failures of the common used metric and geographic detail in Digital Geovisualisation and the “exist-data Problem” is our main motivation for this paper.

In this paper the methodology followed for the development of the 3d-scale-cube software is presented and scale issues in GeoVisualisation are discussed. The creation and the use of this software tool aim to approach and to describe scales’ relationships. Also has the intention to resolve “Exist-Data Problem” in the way of choosing, merging and treating geodata for geovisualizations.

2 The meanings of scale

Scale is about size, either relative or absolute and involves a fundamental set of issues in geography (Montelo 2001). Scale primarily concerns space in geography however domains of temporal and thematic scales are also important. The scale issue can be confusing because it has multiple references. The three meanings of scale appear to be the most basic in Geographic visualization are:

I. Geographic scale

Geographic scale historically has been the most widely used (Jenerette and Wu 2000) and refers to the size of the study area (see table). For example, a geographical study can be in local, regional or global scale. The extent of the study area and/or its subsets can affect the analysis results. Different results might be obtained when looking in different geographic scales.

Geographic Scale
Local
Regional
Continental
Global

II. Cartographic scale

Cartographic scale is used for making maps that represents real world locations and distances between locations in useful manner (Jenerette and Wu 2000). Scale is the term most often used to describe level of geographic detail, but its meaning is confused in a digital geographic world. Its primary metric, the cartographers ‘representative fraction’, compares distance to a map or image to the same distance on the ground-but in a digital world, there is no equivalent of map distance, and thus the measure is not defined (Goodchild and Proctor 1997).

Cartographic Scale
Small
Medium
Large

Cartographic scale refers to the depicted size of a map on a relative to its actual size in the world (Montelo 2001). It expresses the amount of reduction of distances used to represent detail on the map. The 25,000 value is called the scale denominator. The distance on the ground equals the distance measured on the map multiplied by the scale denominator.

III. Spatial scale

Spatial scale expresses the fundamental spatial entity used in map making, compared with the true spatial unit. Provides a "shorthand" form for discussing relative lengths, areas, distances and sizes. A microclimate, for instance, is one which might occur in a city, whereas a coarse d is one which involves a continent. It is important to realize that these divisions are more or less arbitrary, and where, on this table, mega- is assigned global scope, it may only apply continentally or even regionally in other contexts. The interpretations of medium- and coarse- must then be adjusted accordingly.

Spatial Scale
Fine
Medium
Coarse

2.1 *Realism to symbolism cube*

The three above mentioned meanings of scale are used in different ways in geographic visualization and affect the visual result. In static visualizations (maps), geographic scale determines to a large extent the cartographic scale placing simultaneous the limits in which it could oscillate also the spatial scale. In dynamic visualizations (web mapping) the question of scale is more complicated because changes in geographic scale are dynamically modified by the user (with the operation: zoom-in - zoom-out). According to this modification cartographic scale should change to correspond to this modification in order visualization be more accurate. Nowadays, a theoretical model that describes this relationship between scale transitions does not exist (Soulakellis *et al* 2007). This lack leads to the adoption of "arbitrary" and many times erroneous choices of geographic, cartographic and spatial scale in visualizations. Which in turn results to visualizations that do not meet the objectives for which was designed. (Soulakellis *et al* 2007)

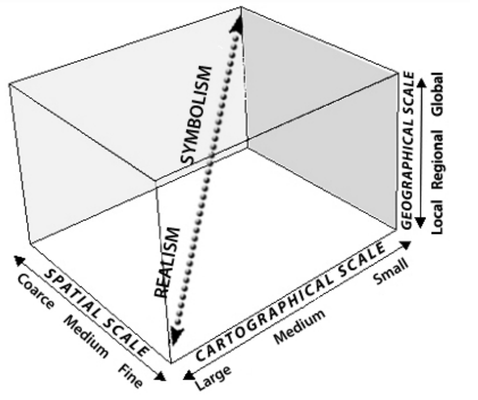


Fig 1 Realism to Symbolism cube (Soulakellis et al 2007)

Based on realism to symbolism cube (Soulakellis et al 2007), the idea of merging scales' behaviors into one model were scale transitions will be represented in a common a plot in correlation with the visualization parameters as visualization size or screen size. The transition between scales from realism to symbolism and their behavior according visual parameters was a critical issue that lead us to the idea of 3D-scale-cube. This cube is a MATLAB based application with Graphical User Interface with the capability of real time calculation of the exact correlation of the three scales when scaling from realism to symbolism and vice versa.

The idea of making 3D-scale-cube, a real time representational model of scale transition, as a software tool was the need of specific rule in the selection of data. Data that will be used for a big variety of visualizations reform realism to symbolism.

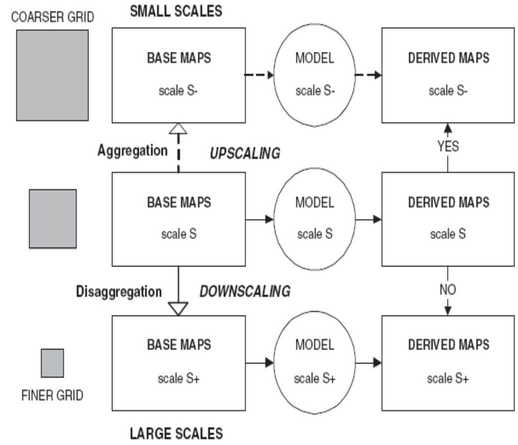
2.2 *Scaling issues in Geovisualizations*

From the begging of map making spatial data representation is a critical issue for geographers and cartographers. In the last years map representations are made with the use of personal computers, thus we have the ability to make digital representations which become most efficient and realistic with the use of 3d visualizations. The increasing power of personal computers helps us to make more accurate 3d Geovisualizations in different scale representations from symbolism to realism. Computer power also has allowed the rapid development of GIS, has also increased the importance of understanding scale beyond the cartographic definition. GIS software reduces the restrictions of the cartographic scale. Once a map entered into GIS software alternation of geographic scale are trivial (Jenerette and Wu 2000). Zooming functions can instantaneously change the relationship between the map distance and real world distance (Jenerette and Wu 2000).

The term resolution, expressed as ground resolution in meters. The enlargement of grid resolution leads to aggregation or up scaling and decrease of grid resolution leads to disaggregation or downscaling. As grid becomes coarser, the overall information content in the map will progressively decrease and vice versa (McBratney 1998, Kuo *et al* 1999, Stein *et al* 2001).

In cartography, coarser grid resolutions are connected with smaller scales and larger study areas, and finer grid resolutions are connected with larger scales and smaller study areas. The former definition often confuses non-cartographers because bigger pixel means smaller scale, which usually means larger study area (Fig. 2) (Hengl 2006).

These transitions in different resolutions and between scales called scaling. Scaling problems in visual representations are too many cause confuses scientists to select the appropriate data for their purpose.



Scaling means transferring data or information from one scale to another. It requires the identification of the factors operational on a given scale of observation, their congruency with those on the lower and higher scales, and the constraints and feedbacks on those factors (Caldwell *et al* 1993). As noted by Jarvis 1995, scaling represents a real challenge because of the non linearity between processes and variables, and heterogeneity in properties that determines the rates of processes (Jarvis 1995). Practically consists of taking information or data at smaller scales to derive processes at larger scales, while downscaling consists of decomposing information or data at one scale in to its constituents at smaller scales (Jarvis 1995).

Fig 2.Upscaling and downscaling in a grid-based GIS. S indicates scale: S- are smaller scales and S+ are larger scales. Based on McBratney 1998, Hengl 2006.

How should aggregate or extrapolate fine scale information to coarse scale? One of the problems frequently encountered is translating information across scales (Jenerette and Wu 2000).

3d-scale-cube is tool to form the selection of the most suitable data in the most appropriate scale for their digital representations according to the objective of geovisualization.

3 3d-scale-cube

3d-scale-cube is a representation model of geographical, cartographical and spatial scales that interacts into geovisualization. 3d-scale-cube software tool has been developed by exploiting the mathematical functions that describe the different scale relationships. These functions help us to approach and to describe scales relationships with the size of visual extend (for example: 100 x 100 pixels visualization box). Plots of these functions are used to depict the behavior of the following three scales a) Geographic b) Spatial and c) Cartographic.

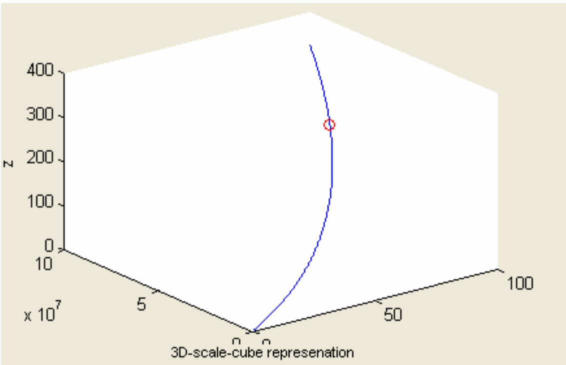


Fig 3. *3D scale cube, Plot of Scales common* behaviour

Finally combination of these plots into one represents their common behavior into 3d-scale-cube.

3.1 *Mathematic scale relations*

Mathematic functions that used in 3D-scale-cube are the following:

I. Spatial scale (x) vs. Geographical scale (y)

$$\boxed{y = ax^2} \quad (1)$$

Where y is the geographical area of interest (in square meters), a is the screen resolution (in pixels) and x is the spatial resolution (in meters). Fig *4* presents the plotted behavior spatial and geographic scales for a visual representation box of 100x100 pixels.

Used variables in the above mathematic expression are:

1. Spatial scale *(x)* express what pixel length size into map visualise from real world in meters. For example one meter (*map_pixel_length)* means that in our map the spatial resolution is one meter and objects till one meters size can be drawn or visualise.
2. Geographical scale *(y)* express which area into map visualise from real world in square meters. For example one square meter (*map_pixel_length)*^{2} means that in our map the area is one square meter.
3. *Screen_resolution_ in_pixels (a)* is the length in pixels for the visualisation window used in each application. For example will be 300x300 pixels. Mark that in our study and to all function and calculations the visualisation window was 100x100 pixels.

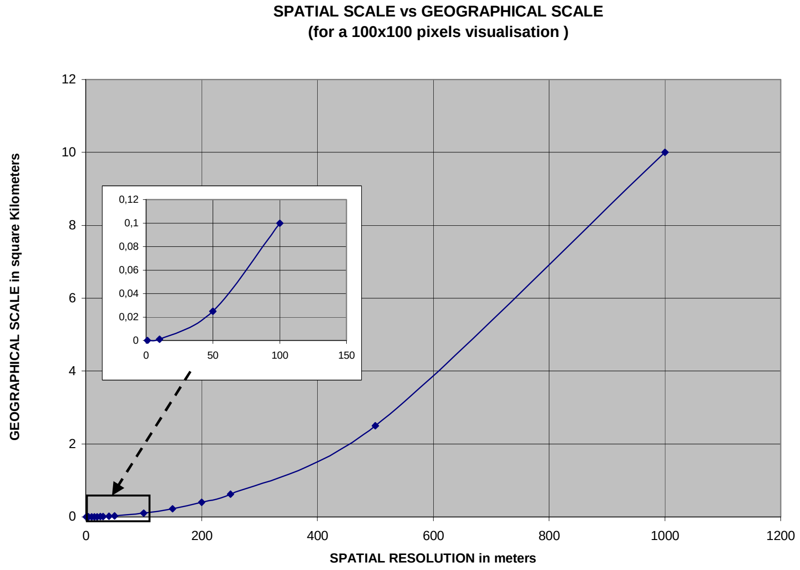


Fig 4 Spatial scale vs Geographical scale. For a visual representation in 100x100 pixel size box

II. Spatial scale (x) vs. Cartographical scale (z)

$$\boxed{z = x/b} \qquad (2)$$

Where x is the spatial resolution (in meters), z is the cartographic scale as a fraction (for example 1/25.000), b is the pixel size (in centimeters). *Figure 5* presents the plotted behavior spatial and geographic scales for a visual representation box of 100x100 pixels.

Used variables in the above mathematic expression are:

1. Spatial scale *(x)* express what pixel length size into map visualise from real world in meters. For example one meter (*map_pixel_length)* means that in our map the spatial resolution is one meter and objects till one meters size can be drawn or visualise.
2. Cartographical scale (z) express the ratio that one unit on the map how many units on the ground represents, for example 1 millimeter represents 25,000 mm.
3. *Pixel_ length_in_meters (b)* refers to the real pixel size which is related to the monitor resolution (relations between pixels size and screen size are in Table 1)

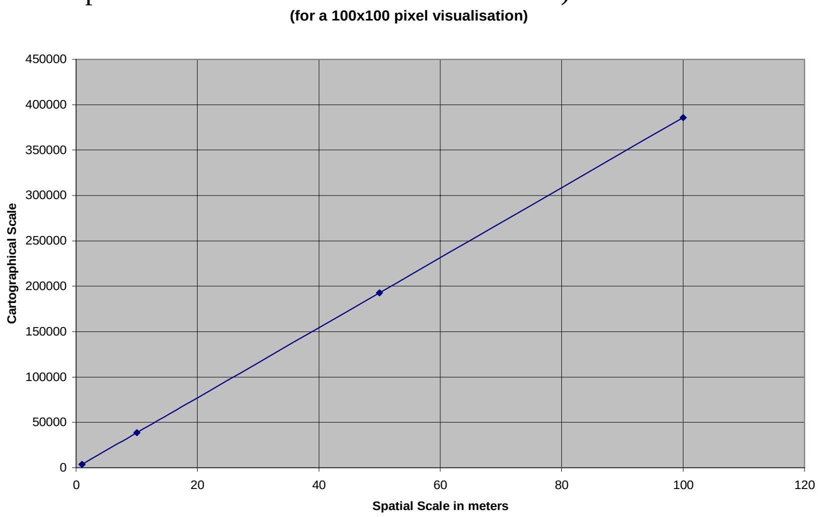


Fig 5.Spatial scale vs Cartographical scale. For a visual representation in 100x100 pixel size box

III. Geographical (y) vs Cartographical (z) scale

$$\boxed{y = a \times b^2 \times z^2} \qquad (3)$$

Where y is the geographical area of interest (in square meters), a is the screen resolution (in pixels), z is the cartographic scale as a fraction (for example 1/25.000) and b is the pixel size (in centimeters). *Figure 6* presents the plotted behavior spatial and geographic scales for a visual representation box of 100x100 pixels.

Used variables in the above mathematic expression are:

1. Geographical scales (y) express which area into map visualise from real world in square meters. For example one square meter $(map\_pixel\_length)^2$ means that in our map the area is one square meter.
2. Cartographical scale (z) express the ratio that one unit on the map how many units on the ground represents , for example 1 millimeter represents 25,000 mm.
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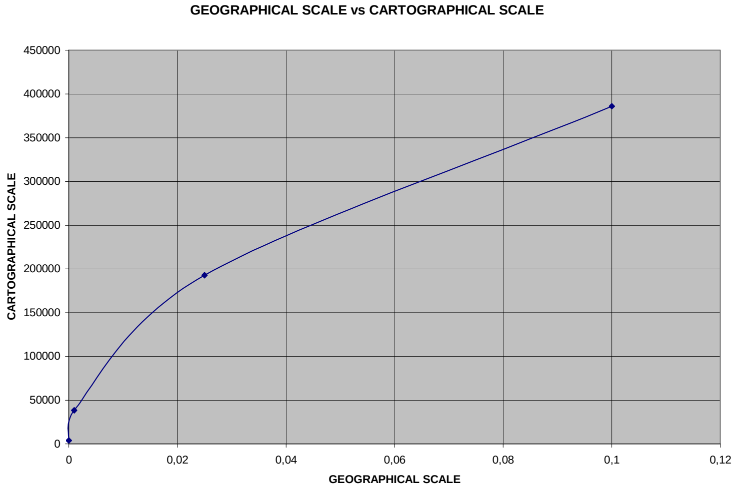

Fig 6.Geographical scale vs Cartographical scale. For a visual representation in 100x100 pixel size box

3.2 *Digital Representations and scaling*

In the last years map representations are made with the use of personal computers, thus we have the ability to make digital representations which become most efficient and realistic with the use of 3d visualizations. The increasing power of personal computers helps us to make more accurate 3d Geovisualizations in different scale representations from symbolism to realism.

Map size according to medium-way of digital representation is an issue that scientists should consider carefully. Size matters in visual representations because the visualization tool is the common pc screen and that means the digital representation has limitations in optical expressions. These lead us to the manufacture characteristics of these screens. Common screens have characteristics with critical rule in Geovisualisation. These are a) Screen size (diagonal size) b) Resolution c) Density d) Ratio and e) Pixel size.

3.2.1 Notebook Monitor Comparison (Pixel Table)

This table shows the screen resolution, pixel density (pixel pitch in pixels per inch, ppi), size of one square pixel, aspect ratio of the screen, number of pixels (megapixels or MP), and pixel area gain compared to a 1024 by 768 pixel XGA resolution for various display sizes (measured by the viewable diagonal).

We noticed that as the diagonal changes, the initial pixel size changes. For the purposes of this paper we took as a default screen a screen with the characteristics shown in *Table 1* with bold letters.

Size	Resolution	Density	Pixel Size	Ratio	Pixels
12.1»	1280 x 768	123.4 ppi	0.2059 mm	5:03	0.94 MP
12.1»	1280 x 800	124.7 ppi	0.2036 mm	16:10	0.98 MP
15.4»	***1280 x 800***	***98 ppi***	***0.2591 mm***	***16:10***	***0.98 MP***
15.4»	1440 x 900	110.3 ppi	0.2303 mm	16:10	1.24 MP
17»	1440 x 900	99.9 ppi	0.2543 mm	16:10	1.24 MP

Table 1 Notebook Monitor Comparison (Pixel Table), for various display sizes. http://www.prismo.ch/surveys/evaluation.php

Also monitor area plays critical role to visualization result as it is the tool in which visualizations projected. Table 1 presents the correlation between the construct-manufacture characteristics of monitors in a common notebook screen. This gives us the complexity of correct visual result according the usable screen (screen size we use) and for a variety of users. The necessity to create some rules to use in each visualization according data and the visual box of representation is critical. These rules will help scientists to create scientific visualizations for a big variety of users and representations.

3.2.2 Notebook Monitor Comparison (Area Table)

The following table (Table 2) shows the active diagonal, screen width, screen height, aspect ratio, viewable screen area and physical area gain compared to a 12.1-inch 4:3 monitor for various display sizes.

Size	Diagonal	Width	Height	Ratio	Area	Gain
12.1"	30.73 cm	26.06 cm	16.29 cm	16:10	425 cm^2	93.6%
14.1"	35.81 cm	30.37 cm	18.98 cm	16:10	576 cm^2	127%
15"	38.1 cm	30.48 cm	22.86 cm	4:03	697 cm^2	154%
15.4"	39.12 cm	33.17 cm	20.73 cm	16:10	688 cm^2	152%

Table 2. Notebook LCD Monitor Comparison (Area Table)

It is clear that viewable screen area is depending on screen size, active diagonal, screen width, screen height and aspect ratio. That means we should take in consideration before making visualizations the visualization area and medium (ex: 1280x1024 pixels size box for a common pc screen) we are going to use in order to make the appropriate data selection.

Our first example made for a representation in a 100x100 pixel box. Mathematic combinations and functions set up for this (100x100 pixel) box but the linearity in the way that functions follows when the box size arises lead us to a conclusion. When the area (in pixels) of the visualization box increases, for example from 100x100 to 200x200, mathematic scale behavior remains unaffected. This conclusion helps us to unify scale behavior into a 3D box and to make a representation model of the geographical, cartographical and spatial scale and the way they interact into geovisualization.

3.3 *3d-scale-cube a Geodata selection tool*

Selection of the appropriate data with scientific rules-background and the creation of patterns in this selection is the main task for 3d-scale-cube creation.

The result of 3d-scale-cube is the description of behavior of the three scales when scaling through realism to symbolism. This cube will assist scientists to approach and to describe scales relationships; also will help to make discernible steps in the way of choosing, merging and treating geodata for geovisualizations in order to resolve “exist-data problem”.

With the use of 3D-scale-cube will be able to discover the relations between scale and between scale transitions in order to find the suitable Geodata resolution for output maps based on inherent properties of existing data. In to this work MATLAB was our tool to study, to resolve and plot all equations and functions related to scales issues as described into this paper.

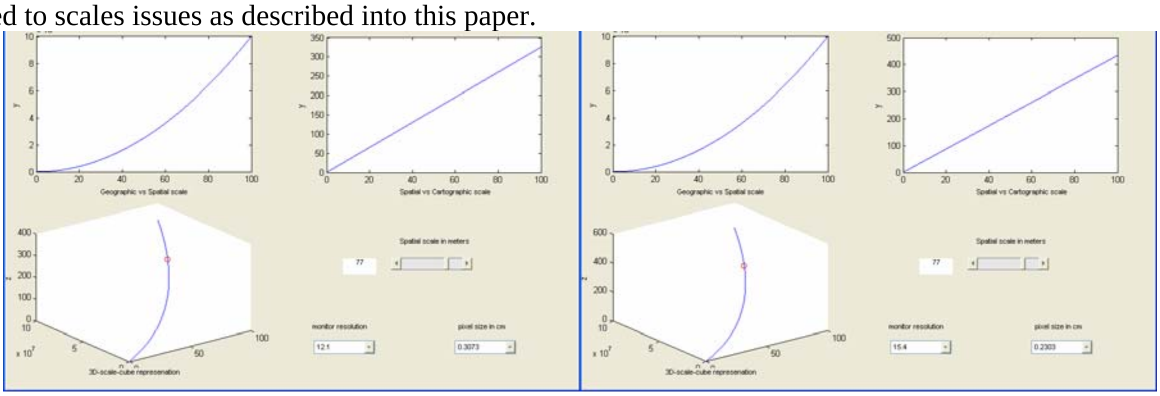

Fig 7 MATLAB GUI represents 3D-scale cube tool for 12.1” screen (left) & 15.4” screen (right) for 70 meters spatial resolution

MATLAB is a powerful tool for which gives us the ability to make complex calculations as the behavior of the three scales into a 3D-scale-cube according screen resolution, pixel density (pixel pitch in pixels per inch, ppi), size of one square pixel, and aspect ratio of the screen. MATLAB’s Graphic User Interface (GUI) has been used to present MATLAB calculations and plots. 3D-scale-cube is the result of these plots. The most important reason that we used MATLAB is that gave us the ability of making dynamic representations (changing parameters and having results in real time) of scale behavior using 3D-scale-cube.

4 Conclusions

Designing a geovisualization is a critical process during which the designer should consider how can be selected the most appropriate datasets or the best scale to visualize existing datasets. These datasets should comply most of the following criteria: i) objective of geovisualization, ii) availability of data, iii) visualization size, iv) screen size and v) scaling.

Available data in several cases don't have the appropriate spatial characteristics to give the most effective visual result according to the objective of geovisualization. This in turn results to geovisualizations that not help scientists to extract correct conclusions for the study phenomenon.

3D-scale-cube is a software tool that includes a big variety of preprocessed geodata combinations that have the appropriate characteristics according specific geovisualization representations. By means of this software users have discernible steps to make data selection according to their geovisualization needs. Also help them to identify their datasets and to categorize them in specific geovisualization. In parallel, it assists scientists to find suitable geodata in order to overcome "Exist-Data Problem" and produce more effective visualization based on the aim of visualization nor the aim of geovisualization made by the limitations of data.

A cube based methodology for the selection of data can be used to help inexperienced users select a suitable data resolution and suitable visualization dimensions without doing extensive data preprocessing and having the best result. Also will assist users to find the most appropriate visualization parameters, such as geographic, cartographic and spatial scales, and viewable area (representation box size in screen) according data availability.

5 Future Directions

Scale issues have always been central to geographic theory and research. Advances in the understanding of scale and the ability to investigate scale related problems will continue with the updating of 3D-scale-cube.

A 3d-scale-cube that includes discernible steps in the way of choosing, merging and treating Geodata will lead to an automated generalization of geographic data as scales change. Thus scientists will have the ability to perform an automated multiscale data selection for their visualizations. Selection that includes all categories of the existing geodata to a hierarchically given way. A 3D-scale-cube as an internet functioning geodata selection tool with MATLAB graphical user interface will be created in order to be more effective to a wide variety of users. A geodata selection tool for spatial, multidimensional and dynamic representations. Representations that include even realistic visualizations in virtual environments.

6 References

Caldwell M.M., Matson P.A., Wessman C., and Gamon J.1993 «Prospects for scaling».In scaling Physiological Processes: Leaf to Globe. Ehleringer, J.R and C.B Field, eds, Academic Press, pp 223-230

ESRI, 2002. Spatial Analyst Help Documentation. ArcGis Users' Guide. ESRI Inc., Redlands, CA, 563pp.

Jarvis, P.G, 1995, «Scaling processes and problems», Plant, Cell & Environment, Vol 18, pp 1079-1089

Jenerette G.D.and Wu J. 2000. «On the definitions of scale», Bulletin of the Ecological Society of America, Vol 81, pp 104-105

Goodchild M. and Proctor J., 1997, «Scale in a digital Geographic World», Geographical & Environmental Modelling, Vol.1, No 1, pp 5-23

Hengl T. 2006. «Finding the right pixel size», Computer & Geosciences, Vol 32, pp 1283-1298

Kuo, W.-L., Steenhuis, T., McCulloch, C., Mohler, C., Weinstein, D., DeGloria, S., Swaney, D., 1999. Effect of grid size on runoff and soil moisture for a variable-source-area hydrology model. Water Resources Research 35 (11), 3419–3428

Marceau D.J 1999. «The scale issue in social and natural sciences», Canadian journal of Remote Sensing, Vol 25, No 4. pp. 347-356.

Marceau D.J and Hay G. J. 1999. «Remote sensing contributions to the scale issue», Canadian journal of remote Sensing, Vol 25, No 4, pp357-366

McBratney, A., 1998. Some considerations on methods for spatially aggregating and disaggregating soil information. Nutrient Cycling in Agroecosystems 50, 51–62.

Montelo D.R., 2001. «Scale in Geography», International Encyclopedia of the Social and Behavioral Sciences, pp 13501-13504

Turner, M. G., O'Neill R. V., Gardner R. H., and Milne B. T., 1989. «Effects of changing spatial scale on the analysis of landscape pattern», Landscape Ecology 3:153-162.

Soulakellis N., Sidiropoulos G., Papakonstantinou A. 2007, «The new developments in the visualization of geographic space with archaeological interest. Requirements, admissions and questions to investigation». In print

Stein, A., Riley, J., Halberg, N., 2001. Issues of scale for environmental indicators. Agriculture, Ecosystems & Environment 87 (2), 215–232.