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Open Source environment to define constraints in route planning for GIS-T

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May 2003

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Abstract

Route planning for transportation systems is strongly related to shortest path algorithms, an optimization problem extensively studied in the literature. To find the shortest path in a network one usually assigns weights to each branch to represent the difficulty of taking such branch. The weights construct a linear preference function ordering the variety of alternatives from the most to the least attractive.

The typical approach to assigning weights to constraints is to value the constraint with a number directly using a slider or input field to select/adjust the criterion within the value range. For application where the number of constraints is large this approach is not appropriate. The use of the traditional approach stimulates simplistic thinking and makes it very easy to neglect the relative importance of each attribute. Since weighting is a potential source of instability in decision-making, we advocate for a method that indicates clearly the contribution of each attribute. Many studies have shown that analysis involving spatial data is greatly improved through a visual approach. Visual environments enhance our learning and reasoning capabilities taking profit of human powerful cognition and pattern seeking capabilities to overcome the complexity which derives from the level of abstraction necessary to analyze textual and numerical data.

In this report we propose a 3D environment that should help to mitigate the negative impact of traditional weighing assignment interfaces. We describe the process of defining constraints using a 3D environment and outline the implementation of the systems. Our main contribution is to discuss the use of open source GIS tools as MDSS in the context of transportation planning, presenting a visual approach that redefine the use of the behavioural impedance taxonomy in order to improve the users' awareness of their decisions.

Keywords: route planning, geographic information systems for transportation, behavioral impedance, 3D visualization.

Introduction

Route planning is the process of defining the best route an agent should take to move from a point to another in a network. Usually, it is desirable to get to the destination using the most efficient path. When we consider that only one unit of flow travels in a path at a given instant of time shortest path algorithms are very useful. The shortest path problem is an important optimization problem which has been extensively studied in the literature [5][19].

Traditionally, studies on transportation systems make heavy use of graph theory because the underlying mathematical model for networks derives from graph

theory and transportation systems are typically modeled as networks where each arc represents a road and the nodes are the intersection of those roads. To find a shortest path in a network, one usually assigns weights to each branch to represent the difficulty or impedance of taking that branch. Route planning in transportation systems involves calculating a weight (or cost) for every possible branch in the graph.

Pereira et al. [20][21][22][18] define a taxonomy for the constraint domain for a pedestrian in urban transportation systems. The authors use such taxonomy to calculate costs for a experimental router application in a multimodal network [22]. We make use of this taxonomy in order to assist decision-makers analyzing route planning problems on defining the impedance of the system.

Defining constraints typically involves criteria of different importance to the decision-makers. Consequently, information about the relative importance of the criteria is required. This is usually achieved by assigning to each criterion a weight that indicates the criterion importance relative to other criteria under consideration. Weights help construct a linear preference function and apply optimization for ordering the variety of alternatives from the most to the least attractive. The larger the weight, the more important is the criterion.

The common approach to assigning weights is to value directly the constraint with a number. For instance, there is usually a slider or input field allowing the user to select/adjust the criterion weight within the value range. If we consider that the taxonomy defines 36 different constraint criteria, it becomes clear that the task is not trivial. Less evident is the harm this technique does by stimulating simplistic thinking: it is very common to neglect the impact of the range, which defines de relative importance of each attribute. This can lead to unsatisfactory or misleading results. Moreover, weighting itself is already a potential source of instability [8] in decision-making: experiments [24][25][26] have proven that identification of criterion weights is complicated even for experts and consequently the results are not reliable [2]. We need a holistic view indicating clearly the contribution of each attribute.

Studies have shown [3] that analysis involving spatial data in general and multicriteria decision-making in particular is greatly improved through a visual approach. Visual environments enhance our learning and reasoning capabilities [30][31][32]. What is more, since human vision has powerful cognition and pattern seeking capabilities, three-dimensional models help the cognitive perception, which contrasts with the level of abstraction necessary to analyze raw textual, numerical data and 2D graphs.

In this paper we propose a 3D environment that should help to mitigate the negative impact of traditional weighing assignment procedures. Such environment should provide insight in decision making processes and improve the understanding of complex information, in the context of route planning for transportation systems.

The remainder of this section is dedicated to explaining the organization of this article. The next topic explains the advantaged of using three-dimensional visualization for analyzing complex data and presents related work on the field.

Follows a brief review on the decision making process and decision making support systems, which is fundamental to the understanding of our proposal. Then we present the software that is being used for developing our systems, along with a description of the environment and the implementation outline. Finally we present our conclusions and future work on the subject.

3D visualization

"The purpose of visualization is insight, not pictures" [3]. Information visualization is useful in aiding discovery, decision making and explanation. Table 1 compiles useful definitions.

Important definitions	
External cognition	Use of the external artifacts to accomplish cognition
Information Design	Design of external representations to amplify cognition
Visualization	Use of computer-based, interactive visual representations of data to amplify cognition
Scientific visualization	Use of interactive visual representation of scientific, often physical, data to amplify cognition
Information Visualization	Use of interactive visual representation of abstract, nonphysically based data to amplify cognition

Table 1 – Important definitions (after [3])

Visualization is the process of creating and viewing graphical images of data with the aim of increasing human understanding. It is a promising direction for exploring and analyzing large and complex data given the capability of scientific visualization in handling a large number of attributes.

Even though there has been available for many years advanced rendering and modeling 3D techniques, conventional GIS has focused largely on the representation and analysis of geographic phenomena in two dimensions. Only recently GIS applications incorporated 3D rendering capabilities [w1]. This way, its use in the analysis of human activities is rather limited to date.

Cognition

Cognition is defined as the conscious process of being aware of thoughts or perceptions, including understanding and reasoning. In simpler terms, it is the way we organize our thoughts and make sense of our environment. To gain a deeper insight on how human process visual information, it is necessary to understand cognition. Humans make use of external artifacts to promote memory or thinking [33]. For example, when we make use of piece of paper to perform a multiplication or use maps to navigate we are actually using a cognitive

enhancement of our memory [3]. The visual representation extends our working memory and analogous to internal ones; they are storage and retrieval devices.

Visual aids can help to understand a phenomenon, but can be terribly misleading if not presented correctly. For instance in [32] Tufte raises the question whether the accident with space shuttle Challenger could have been avoided if the diagrams of the weather conditions for launching had been better designed.

[11] concludes that diagrams improve cognition in three ways: (i) Reducing the number of searches necessary for understanding by grouping information together; (ii) By avoiding the necessity of symbolic labels to search elements; (iii) supporting a large number of perceptual interfaces. [3] describes six major ways in which visualization can amplify cognition.

The use of 3D geovisualization facilitates the task of creating different scenarios allowing the researcher to directly manipulate the attributes of a scene and its features, change the views and alter parameter quickly rendering the results of any of these actions. Also powerful navigational and multimedia capabilities such as fly-through, zooming, panning, dynamic rotation and video output-generation allow for the creation of a close to reality representation of the available data [17].

Related work

Interest in visualization-based user interfaces is not new but has greatly developed in the past few years. Systems were developed for applications from geology [13] to molecular biology [23],[4], medicine [w4] and GIS[1],[14]. Regarding GIS, recent developments in Scientific and Information Visualization [27][28] helped to impulse a new area of research, Geographic Visualization (GVis), which spans both Scientific and Information Visualization. GVis deals with the effective display of data to assist users of geographic information systems.

We now present research initiatives that investigate and implement visualization techniques to support analysis of complex data. Instead of presenting an exhaustive survey, we want to identify how different approaches to analyzing complex data compares to our proposal. For a more comprehensive study, Card et al. [3] describe various successful information visualization applications and techniques.

In [16] the author presents an approach for creating a Knowledge Discovery in Databases (KDD) software environment for use with large spatiotemporal data sets, illustrating their approach studding features in spatiotemporal climatic data sets. This work is similar to the one we propose in the sense that both stress that the user interaction should be flexible and both use of the same visualization tool, IBM Data Explorer.

The content expert searches for clusters and multivariate similarities by interacting with multiple data contexts: geoviews, 3D scatterplots and Parallel coordinate plots. For these representational structures, the system presents many interaction opportunities: assignment, brushing, focusing, colormap manipulation, viewpoint manipulation and sequencing.

Our work differs in the fact that [16] changes the data vector directly in order to get alternative views. We propose a step further and allow the user to manipulate data through the interface.

[12] presents several techniques for visualizing the temporal dimension of a Geographic Information System in the context of urban crime. The researches use VRML and vmlscript to display the data. Their approach is satisfactory for presenting data, which is the purpose of the application. However, comparing with our needs to input data (constraints), it would not be adequate. Here, in the same sense as in [16], the domain expert must manipulate the data set directly or by means of buttons.

In [10], Kwan presents several GIS-based 3D methods for dealing with the spatial and temporal dimensions of human activity-travel are presented. Those methods have the advantage of avoiding the interpretative complexity of multivariate pattern generalization, such as clustering or pattern recognition algorithms.

Kwan presents two major topics, geovisualization of activity density patterns in space-time and geovisualization of individual space-time paths. The first introduces three methods of visualization: Simple activity patterns in space-time; Activity density patterns in geographic space; Space-time activity density surfaces. The later describes two more methods: the space-time aquarium; standardized space-time paths. From the works presented, this would be the one to bear more similarities with our proposal. The similarities go from the area - transportation systems - to the approach - 3D visualization in real geographic space. However, Kwan deals with the spatial and temporal dimensions with a large data set seeking for activity travel patterns, whereas we work with static data hoping to assist domain experts to define constraints for their routes. We also differ in the choice of the tools. Kwan makes use of proprietary software, performing geoprocessing using ARC/INFO and ArcView GIS and the 3D geovisualization using ArcView 3D Analyst. This is by no means a weakness for the software is widely recognized. It does contrast with of our goal, which is to leverage the use of Open Source tools in GIS, however.

Decision Making and MCDM

Decisions are necessary when an opportunity or problem exists, when something is not as it should be or when something can be improved [29]. In a spatial setting, a decision problem is the difference between the desired and existing state of a real-world geographical system, as viewed by the decision maker. Problem recognition involves searching the decision environment for conditions calling for decisions; raw data are obtained, processed, and examined for clues that may identify opportunities or problems. The GIS capabilities for data storage, management, manipulation, and analysis offer major support in the problem definition stage.

Multiple Criteria Decision Making refers to the process of solving problems involving multiple, often conflicting, attributes. There are different ways to look at MCDM problems. A well accepted classification describe them on the grounds of their fundamental components:

- 1) A set of goals defined by the decision makers;

- 2) The decision makers and their preferences
- 3) The evaluation criteria used to define the alternatives
- 4) The alternative courses of action
- 5) The set of uncontrollable variables or decision environment
- 6) The consequences associated to each alternative-attribute pair

It is also possible to classify MCDM with base on multicriteria decision analysis' components: (i) Multiobjective (MODM) versus multiattribute (MADM) decision problems; (ii) Individual versus group decision problems and (iii) decisions under certainty versus decision under uncertainty; MCDM is a catchall definition which includes both multiobjective and multi attribute decision making. Similarly, criterion is a generic term including both the concepts of attribute and objective .

Decision problems can be either compensatory or noncompensatory. Compensatory problems allows for meaningful comparison among decision criteria. For instance, a poor value for one criterion can be compensated by a good value for another criterion. This is summarized into a overall score for an alternative. On the other hand, we cannot compare different attributes and generate an overall preference score in noncompesatory decision problems. In this case it is not possible to obtains quantitative scores and solutions must be eliminated using less-demanding techniques. These techniques attempt to eliminate alternatives until a single or an acceptable small set of alternatives remains. Inferior solutions are removed and the candidate set is systematically reduced adjusting thresholds for the criterion scores.

Figure 1 represents a generalized MCDM process. The first step of the decision making process is to identify a set of criteria for evaluating alternatives. After that, its necessary to define the set of criteria scores that translate the attribute value into a score or common scale. After calculating the scores, we need to compare the alternatives in order to identify relative importance and choose the best alternative or reduce the set of feasible alternatives.

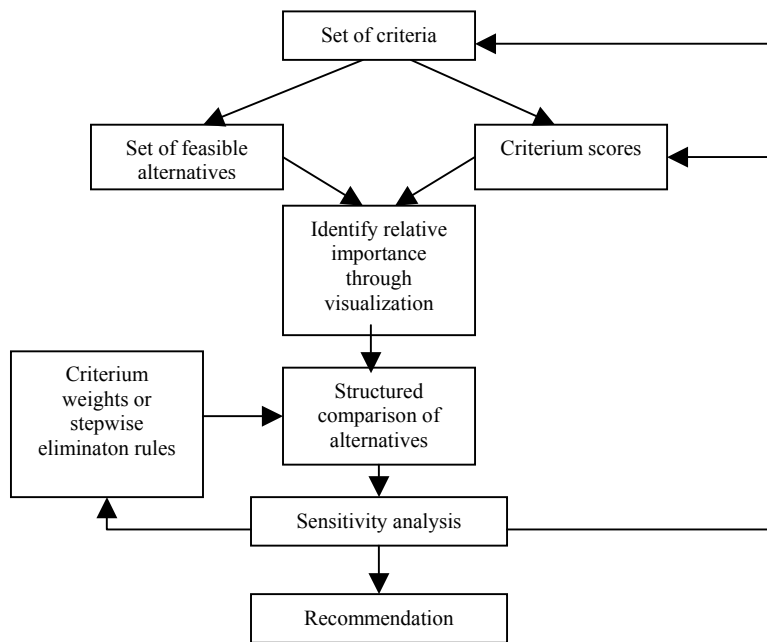


Figure 1

1. Identify a set of criteria for evaluating alternative
2. Identify a set of feasible alternatives
3. Calculate criteria scores, that translate attribute values into a score on a common scale
4. Compare the alternatives through geographic data

Criteria

Criteria is defined as the standard upon which the judgments or rules are based, in order to rank the alternatives decisions according to their desirability. The first step in the decision making process involves specifying a set of objectives broad enough to contemplate all concerns relevant to the decision problem. Evaluation criterion maps are represented as thematic maps into GIS.

Criteria attributes must clearly indicate what degree of the associated objective is achieved. Also, an attribute must be measurable. It must be possible to assign levels to the attribute for each alternative and to evaluate the preferences of the decision maker for various levels of the attribute.

Alternatives

Generating decision alternatives is the second main step in the decision making process. The decision alternatives are represents the set of choices available to a decision maker. In spatial decision making there are two basic components: action (what to do?) and location (where to do?). To each alternative there is assigned a decision variable. A set of decision variables define the decision space for a decision problem. The decision maker reaches a final solution by imposing restrictions on the decision variables. This constraints determine the set of feasible alternatives.

Criterion weights

Taking decisions usually involve criteria of different, often conflicting, importance. Consequently, information about the relative importance of the criteria is required. The common approach is to assign weights to the different criterion according to its relative importance to the other criteria under consideration. The larger the weight, the more important is the criterion.

Each evaluation criteria have a range associated (Figure 2). The weight assigning must vary into this predefined range. It must be made clear to the decision maker the different degrees of importance attached to these ranges of variation. Since the weight value is dependent on the range of the criterion values, a criterion weight can be made arbitrarily large or small by increasing or decreasing the range. The general rule is that we are concerned with the perceived advantage of changing from the maximum level to the minimum level of each criterion outcome, relative to the advantages of changing from the worst to the best level for the other criterion under consideration.

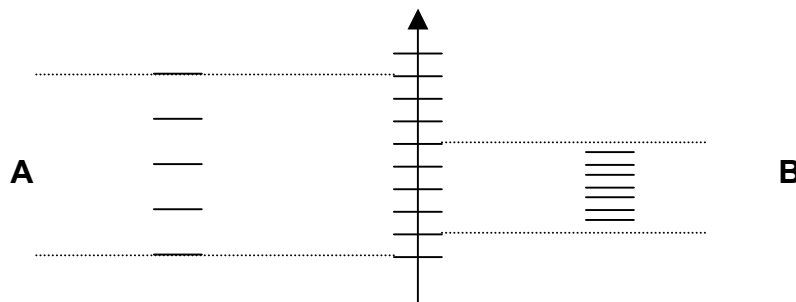


Figure 2
The scales must be commensurable

Weighting is a potential source of instability in decision making data. Experiments have shown that identification of criterion weights is complicated even for experts and consequently the results are not reliable [2].

A number of criterion-weighting procedures based on the judgments of the decision makers have been proposed in the multicriteria decision literature. The procedures include: ranking, rating, pair wise comparison, and trade-off analysis.

Decision Rules

The final step before presenting a final recommendation is the integration of the criterion map layers and the preferences of the decision makers. This is achieved by an appropriate decision rule or aggregation function. The idea is to try to obtain an order on all the alternatives generated according to their performance with respect to the set of evaluation criteria. The preferences are expressed in the decision rule that combines the input data (geographical data and data on decision maker's preferences) into a composite score (criterion or objective outcomes) that order the feasible alternative. The results of the analysis depend not only on the geographical distribution of events (attributes) but also on the value judgments involved in the decision making process.

There are many decision rules available in the literature in spatial multicriteria analysis. See [15] for a detailed review on the subject. We will concentrate on Simple Additive Weighting, which is the most often used technique for MADM.

Defining constraints visually

Behavioral Impedance Background

In [18] the authors point out the necessity for more research on behavioral impedance in transportation systems from the pedestrian perspective. The authors define a taxonomy for Behavioral impedance that takes into account a broader range of criteria such as environmental and socio-politico-economical criteria, in contrast with simply distance and time criteria, applied more commonly in cost functions for SP algorithms.

The BI domain was developed using a meta-model as a starting point for the determination of elements of the taxonomy proposed. Such meta-model was organized as a hierarchy with four levels: Entity, State, Condition and Constraint (Figure 3). The first three levels comprise what was defined as analytical approach whereas the fourth level characterizes the mathematical approach.

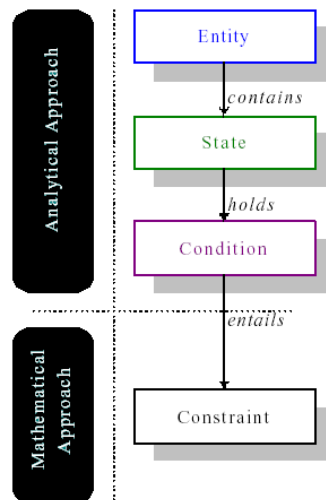


Figure 3 – BI Meta-model

The first level is defined by Entity, which contains a set of States assigned to the second level. The following level is defined by Conditions, which entails the Constraints placed in the fourth level. The taxonomic tree of the BI domain identifies five entities, thirteen states and thirty-six conditions (Figure 4).

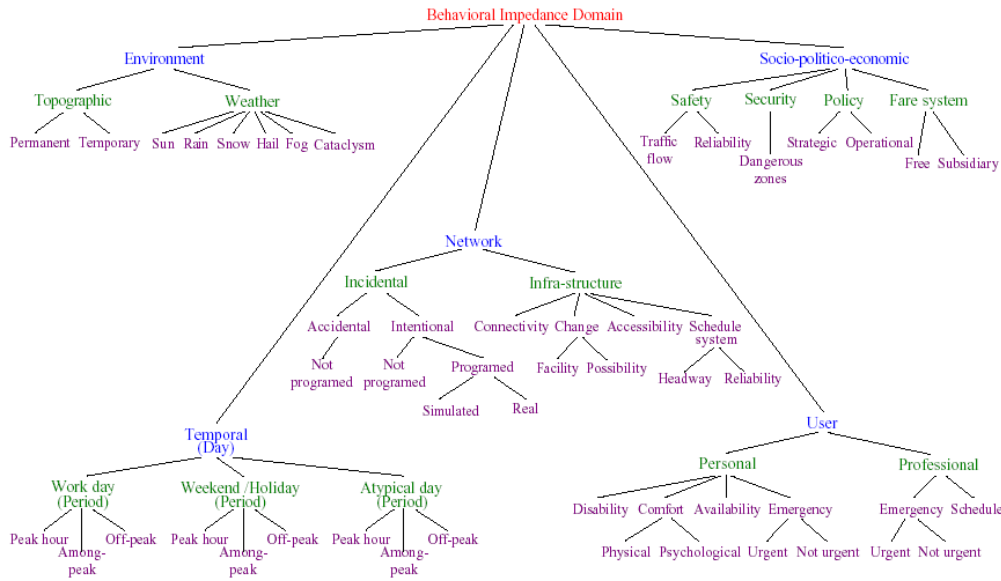


Figure 4 – BI Taxonomy

[22] describes the process used to validate the mathematical model of the BI domain and defines a cost function to be applied to each component arc in the path that represents the route.

To generate the cost function for a path J composed of n direct sub paths $j_0, j_1 \dots j_{(n-1)}$, the researches use the BI table with 36 attributes and the user's profile data representing the user's preferences. The cost function is then calculated using the arithmetic average of these values.

The values for the BI attributes stored in BI table are determined by data collection tools such as questionnaires. This data is stored in the spatial and geographic database management system. The variables that do not depend on a particular user configuration such as meteorological and topographical data and schedules of the transportation lines can be automatically updated by GIS-T.

On the other hand, user's preferences are defined by the user are determined during route selection. These values are provided considering a qualitative and subjective analysis from the user's preferences and converted into quantitative values used in the calculus of the BI cost function.

Finally constraint management module architecture is proposed. The module is composed of main engine and data providers. BIRPA is the algorithm used by the engine to calculate the best route. It makes use of four sources of data: GIS-T database and users of the transportation system as primary data providers and weight table of the BI constraints and data from the theory of planned behavior, regarded as secondary.

The case for 3D interaction

Figures 5 shows a screenshot of the interface windows used to value the constraints in the implementation presented in [22]. This interface makes use of

the regular widgets available in the windows API system to input numeric data. Sliders have been used in other visualization systems to interface user data entry [6]. However, in this case, it makes it very difficult to decision-maker to assess the impact of the each constraint in final result.

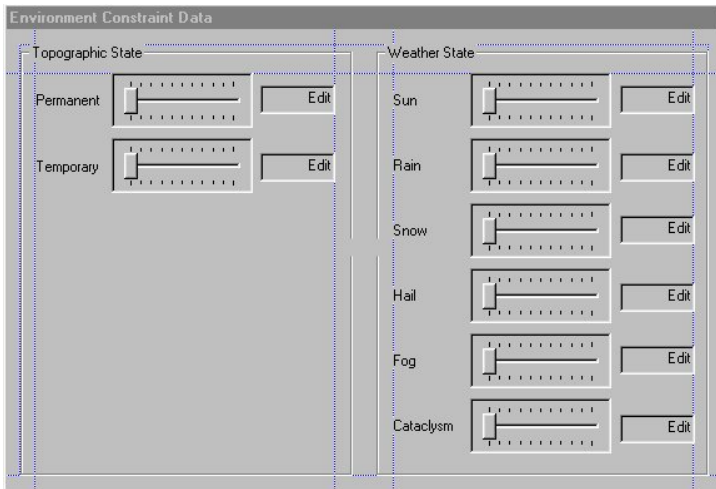


Figure 5

Screenshot of the application Router2.0 where we can see the traditional approach for defining constraints

In order to gather information about the user’s objective preferences we propose an environment capable of visually manipulate the information required to compose the BI table. A major advantage of using a visual environment is that it makes it easier to define restrictions that are related to a geographical region. For example, we can define impedance over an area, instead of defining impedance road by road within that area.

Figure 6 shows the relationship of the main components of our system:

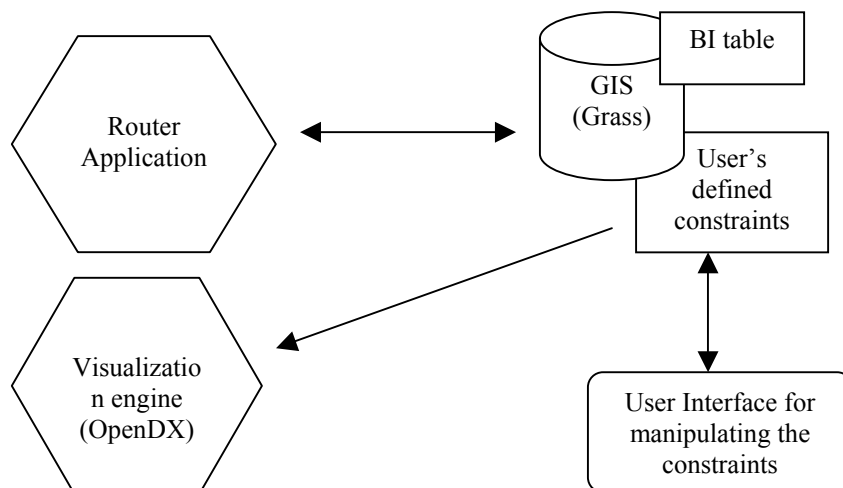


Figure 6 – Components of the environment

The user interacts with the system through the constraint assignment module interface (CAMI) to value the constraints. Later, to get a better insight of the data,

he can make use of the visualization engine to display the constraints in geographic context. There, the constraints are presented as surfaces fitting to pre-defined control points. The values assigned to the constraints are stored in the GIS database for later use in the route calculating algorithm.

System outline

Generally speaking, our main purpose is to improve the user's capacity to make decisions. To achieve that, we propose to allow the manipulation and 3D visualization of constraints for a chosen route or areas.

Geographic information systems incorporate data models and functionality specially tuned to map making and geographic analysis. Although traditional GIS have excellent georeferencing and image processing capabilities, they cannot easily handle data in more than two dimensions [7][9]. GRASS is no exception and despite some new data-visualization capabilities [w2], it is not yet ready to couple with the complexity of 3D data visualization. To address this problem we need to interface the GIS system with a visualization engine. This way, data stored in the GIS database can be better visualized, significantly improving the user awareness of their choices.

However, in order to gain full advantages of such integration, one is obliged to master two separate GIS and scientific visualization systems. A better alternative is strong couple the GIS and the visualization systems sharing data at the physical level to support data storage, management, analysis and display and providing the developers direct access to APIs and data in the GIS and VIZ software.

Despite its complexity, the tight coupling approach seems to be more appropriate to our intentions, since we need as simple interface tailored to facilitate the user's interaction with the system. To implement this environment we propose the use of two powerful, stable, free and open source software: Grass GIS [w1] and Open DX[w2]

Open Source Development

"Open source promotes software reliability and quality by supporting independent peer review and rapid evolution of source code. To be OSI certified, the software must be distributed under a license that guarantees the right to read, redistribute, modify, and use the software freely " [Opensource Org].

The Open Source movement has been around for some years now and is regarded as one of the most striking innovations in software development, emerging with full power in the late 1990's.

Regarding GIS, there are commercially available products capable of performing similarly the tasks we set about to doing [10]. There are many drawbacks though. To quote a few: (i) quite often, these solutions are expensive and virtually inaccessible for the average student. (ii) Also, they do not allow for tight coupling, since we do not have access to the source code. (iii) They either run on expensive hardware or perform poorly. (iv) It's obviously impossible to incorporate functionality, since we do not own the product. Apart from that, using open

source makes it easy for other researchers who may wish to verify our conclusions or make use of our findings without worrying about royalties or software fees.

Moreover, mature Open Source projects are usually highly documented. There are a plethora of manuals, how-tos, FAQs and mail lists available to smooth up the path of the developer.

GRASS

"GRASS GIS (Geographic Resources Analysis Support System) is an open source, Free Software Geographical Information System (GIS) with raster, topological vector, image processing, and graphics production functionality" [w1]

Grass is a powerful GIS and amongst its capabilities are spatial analysis, map generation, data visualization (2D, 2.5D and 3D), data generation through modeling (list of simulation models), links to DBMS and data storage. The first versions of GRASS date back from the early 1980's. It was originally a GIS project of the U. S. Army Corps of Engineers' Construction Engineering Research Laboratory. The CERL released its last version in 1993 (4.1). Since that version, GRASS has suffered many modifications, having its raster and vector engine completely rewritten from scratch. Since 1999 the GRASS 5 development is led by University of Hanover, which basically coordinates programming efforts within the growing GRASS Development Team.

Nowadays, GRASS is a image processing system and graphics production system which comprises over 350 programs and tools. GRASS is capable of manipulating raster, vector, and sites data; process multi spectral image data; and create, manage, and store spatial data.

GRASS can display and manipulate vector data for features like roads, streams, or boundaries and has a important feature to spatial analysis that is the ability to use cell data. More importantly GRASS provides a sophisticated GIS library which can be used for integration with other applications or own developments. The essential characteristic is that GRASS is Open Source. Since we plan to write on top of GRASS libraries, the well-documented GIS libraries and the GRASS Programmers Manual are fundamental.

Tools in GRASS allow the user to animate any spatial data available with options to switch between data layers on the fly. Data used in 3D visualization may also be saved as still pictures, or as mpeg movie files for later replay and analysis. Additionally, GRASS can use field data for model input or simulate parameters based on numerical data.

OpenDX

OpenDX is the open source software version of IBM's Visualization Data Explorer Product. OpenDX is a general-purpose package for the visualization of scientific, engineering and analytical data.. One can use OpenDX very effectively to visualize the output of many different types of experimental or collected data sets or computer-generated simulations. DX tools provide the capability to create

more sophisticated visualizations than may be possible with a Geographic Information System.

DX is similar to a GIS, in that it can map data to geographic locations, but in addition, it offers new capabilities for investigating large quantities of complex data. It can be used to explore geographic data sets but has also been used to visualize data from disciplines as varied as physics, geology, medicine, and meteorology. The aspects of DX which allow it this flexibility are described below. DX is:

Multidimensional - 3D objects can be created and manipulated just as easily as 2D plots. Other parameters or variables can be mapped onto objects as another dimension through the use of color, 'glyphs', or 'isosurfaces', thus allowing visual discovery of juxtapositions, continuities or irregularities.

Interactive - User interactivity allows the scientist to explore the data more completely. For example, created visual objects can be rotated to allow different points of view or the user can interactively modify the imagery by changing input values.

Temporal - DX allows time sequencing or animation so temporal processes can be viewed directly.

Modular - DX allows various levels of sophistication. Generic software building blocks allow a user to create a visual program or 'network' without ever writing a line of code. Although programming skills can be utilized in converting data files to DX format, and in creating new modules for use within the system they are not necessary to create visualizations of complex data.

Acquiring data

As any seasoned GIS user may testify acquiring data is definitely the most time-demanding phase in the process of development of a GIS system. Before delving into the details of the implementation we will describe the process used to convert the cartographic data from the original format to a format that can be stored by the GRASS database and manipulated by OpenDX engine.

Grass5 imports and exports a plethora of formats among bitmaps and vector formats, including GeoTIFF, GIF, JPEG JFIF, ARC/INFO Binary Grid coverage, AUTOCAD/DXF, AUTOCAD/DXF3D, ASCII and others.

OpenDX uses data in a proprietary format. To make visualizations of data, we perform several operations:

- Acquire data into the system
- Prepare data formats for import - Translate the data format you use to a context that DX can interpret
- Import data into visualization program
- Manipulate data realizations
- Produce output

The process is well defined in the user manual. The interested reader should refer to [w3] for in deep details.

Architecture of the user interface module

Defining constraints

As mentioned before, we want to provide decision-makers with a tool that presents as realistically as possible the impact of their choices. We try to achieve this by allowing the user to manipulate the impedance relative to the areas of interest directly over the real geography. This should be done directly, without the artifice of sliders or input fields. Other researchers have shown interest in the effect of user visual experience while interaction with data [6]. The data generated by the CAMI will be used by the OpenDX engine to render the surface and by the router application to calculate the best route. This process is illustrated in Figure 7.

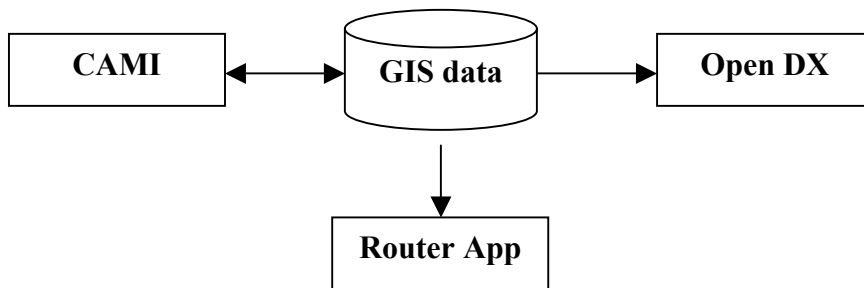


Figure 7 – Data flow

Our approach to represent the constraints in the geographic area define by the user is to draw grid dividing the area in a $(n \times m)$ matrix. Each point of intersection of the lines of the grid with the underlying road layer defines a control point that can be dragged orthogonally in order to assign a value to the impedance of that specific point. The impedance is the height of the surface with respect to the ground level (map level). To implement such a grid polygonal meshes is used. The set of elevated points form a constraint surface, that will be stored for posterior rendering. Control points and surfaces are generated for each of the criteria that are not subjective from the user's perspective in the BI domain. Subjective criteria may be obtained by quantification of qualitative data. It should also be possible to group criteria with respect to their classification on the hierarchy. For example, we could draw a surface for A1, A2 and A3 or draw a single surface A representing all the constraints hierarchically related to A (Figure 8).

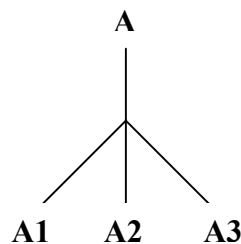


Figure 11

Visualizing constraints

The visualization process can be structure as show below, what is usually referred as visualization pipeline:

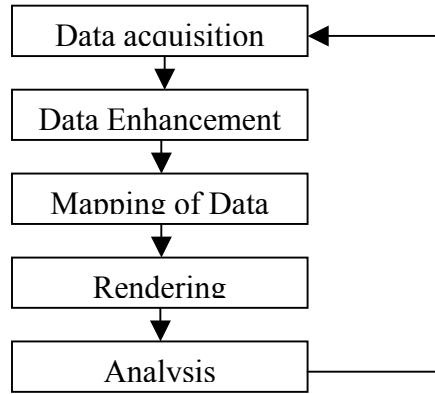


Figure 9

Data acquisition in our case is done by the CAMI. The data generated by the CAMI application should be converted to fit the OpenDX internal format for presentation in the Data Enhancement step. Next, the mapping of the data into the attributes of a visual representation is performed internally by the visualization engine. OpenDX then uses this data to render a surface fitting through the control points in the Rendering step. Finally, the user is able to analyze the image and to perform changes in the parameters of the many stages of the process to change the image aspect.

In our case, the maps and layers representing the constraints are imported by OpenDX, which performs the visualization process.

To present the surface we can render all the surfaces in the same scene in a multi-layered approach, which is advantageous if the decision-maker wants to compare a few criteria simultaneously. We can also show the surfaces side-by-side. To facilitate the identification, it is possible to change the visual attributes of a surface assigned to a constraint, such as color, texture, density, etc.

For visualization purposes, the surfaces could be integrated into a global constraint surface. This surface would represent the overall constraint of the system. The global surface is obtained by multiplying the importance weight (assigned by the user) by the scaled value given to the alternative of that surface. There are two strong assumptions implicit here: linearity and additivity. Linearity means that the desirability of an additional unit is constant for any level (height). The additivity assumption means that there are no interaction effects between attributes. In the real world this two requirements are very difficult to meet.

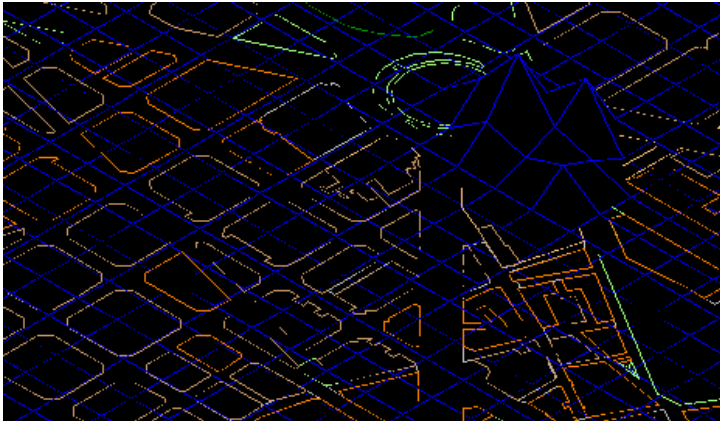


Figure 10

Each constraint is represented by a grid which is rendered into a surface. In order to identify the different constraints, it is possible to modify both the grid's and the surfaces' visual attributes. In the pictures, each colour represents a different constraint.

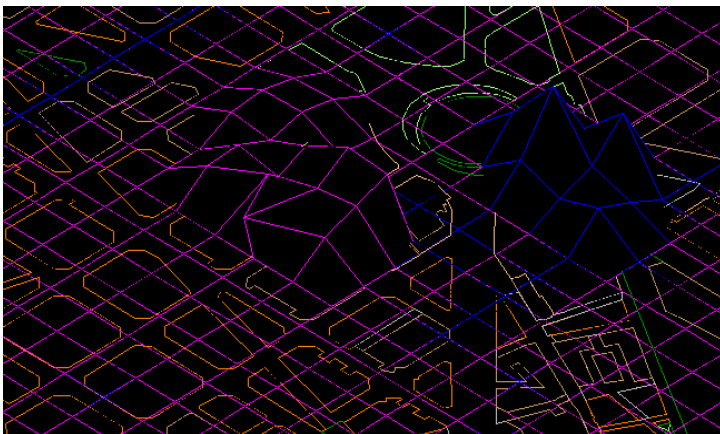
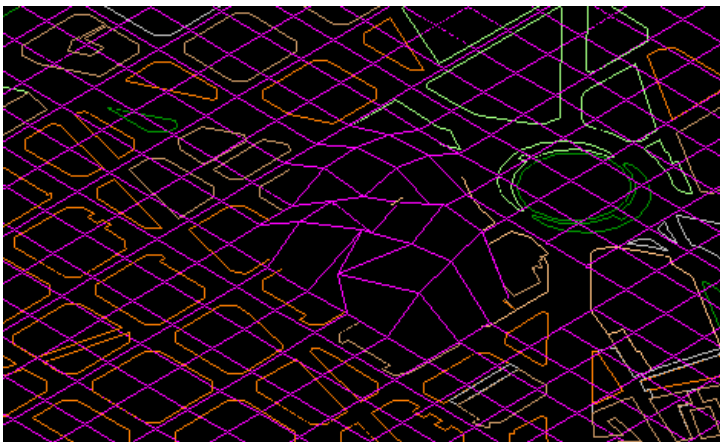


Figure 11

It is possible to render any number of constraints, including the global surface on the same scene. This is useful to compare how each of the constraints contribute to the overall score

Finding the best route

The implementation of the constraint management module proposed in [22] uses tables in a relational database to link the BI attributes and the cartography stored in the microstation files. A foreign key in the X tables connection provides the link to the BI table. Each arc in the network must point to a BI record, otherwise it is considered that this sub-path has null impedance.

Our proposal makes this scenario more complex since now each arch may have more than one BI entry for some or all constraints. The reason is that the control points store the values of the intersection of the grid with the underline road [Figure 12].

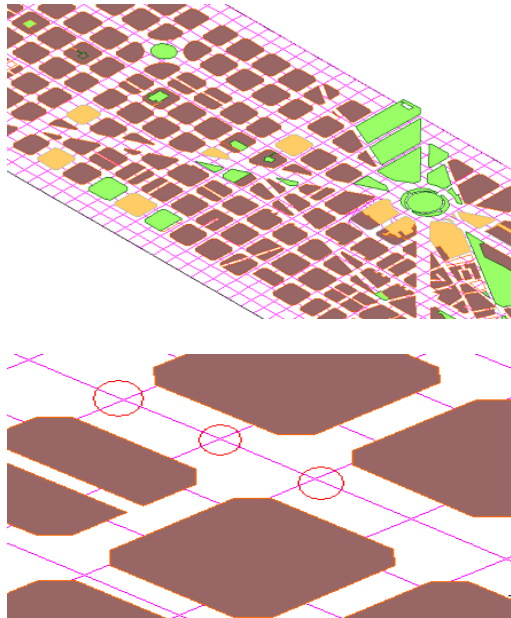


Figure 12
A representation of the grid that defines the control points for the constraints. Below the controls points highlighted in red circles.

A naïve approach to model this situation is shown in the figure 13

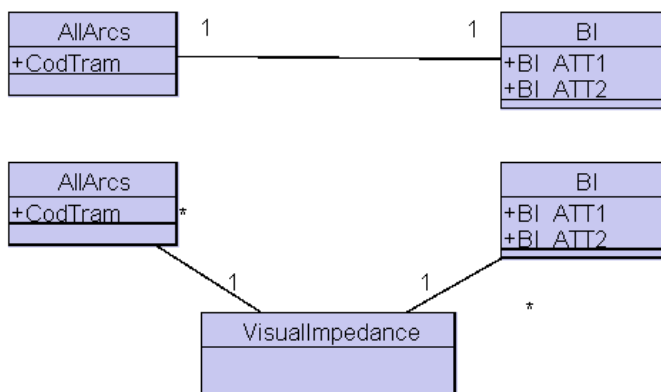


Figure 13
UML classes for the current implementation and our proposal

Every arc now has a list of Visual Impedance Control Points, which in turn holds the values of the BI constraints. The algorithm now must take into account that the arc is subdivided and apply the correspondent impedance according to the location of the sub-arc. In practice, this is equivalent to adding more nodes and arcs to the network, even though there is no related element in the physical world.

Conclusions and future work

This work attempts to enhance consciousness of decision makers on the impact of their choices on the final result of a decision process. Since visualization improves human cognition capabilities, we are trying to make part of the process visually, allowing for spatial thinking. Even though only part of what is proposed is currently implemented, we already have enough information to draw some interesting conclusions.

This far, defining constraints conventionally, using tables, sliders and other similar visual gadgets would provide better precision than using our visual approach. This will be addressed in the next phase, the implementation of a tight coupled application, by showing text labels indication the height-value of the control point element while dragging it around. The sensibility of the dragging can also be used to control precision.

Another difficult implementation task is to relate the points on the grid to the map underneath. In practice, the creation of the control points is equivalent to adding more arcs and nodes to the graph that represents the network. The cartography of Barcelona that we use in this project already has approximately 9000 nodes y 27000 arcs. An explosion in the number of elements lead the performance of the rendering engine and the routing application to unacceptable level. Experiments must be conducted in order to define the best approach to calculating such values, avoiding costly operations.

Finally, the density of the grid defines the granularity of the impedance domain. As it happens, if the grid is too dense, the performance of the rendering engine becomes unacceptable. As would be expected, there is a trade off between quality of image and performance.

Good interaction between the decision maker and the tool is a key factor of success. For this reason an integrated environment is essential. We believe that weighting biases, errors and mistakes can be drastically minimized by using a visual setting. GIS and visualization intersection is a very prosing field that benefits continuously from the development of fast computers and interaction devices. However, there is still a lot of work to be done, particularly with respect to the Open Source GIS. It is still extremely complicated to embed GIS functionality into an integration framework.

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