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From Tabular Data to Metaphoric Landscape Visualisation – A Template-based Approach

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Abstract

This paper presents a template-based approach to the generation of metaphoric visualisation from tabular data. This technique allows a coherent transformation between a relatively abstract visual representation (e.g., a treemap) to a more expressive metaphor (e.g., a virtual atlas). It enables easy customisation of existing metaphors by ordinary users and uncomplicated introduction of new metaphors by expert users. It provides automation in much of the pipeline for creating a metaphoric visualisation, except aspects where crucial semantic input is necessary. The technique was realised in a software system, vis4me2*. As a case study, the outcome of the latest UK Research Assessment Exercise (RAE2008) was used to demonstrate the usability and effectiveness of this technique.*

1. Introduction

Metaphors are tools for communication as well as for thought [Sti93]. Lakoff *et. al.* [LJ80] explain that metaphors can be found not only in our words but also in our thoughts and actions. Ortony proposed three theses, namely *compactness*, *vividness* and *inexpressibility* [Ort75], which characterise how metaphors may aid communication and thought processes. Visual metaphors are a form of non-linguistic metaphors and can be seen frequently in visual arts, performing arts, advertisements, icons and signs, culture symbols, colour symbolism, and so forth. Visual metaphors are elemental components of information visualisation. They can "transfer chunks of experience from well-known to less well-known contexts" (*compactness*), can "impress a more memorable learning" and understanding (*vividness*), and can carry "the extra meanings" that cannot be encoded adequately in a language [Sti93].

Most visualisation involves the use of colour symbolism, icons and signs. Many conceptual metaphors, which have frequently been used over a period, have become part of the standard vocabulary of visualisation. Examples include fisheye view, tree, pie and bubble in non-spatial data visualisation; and spline, skeleton, seeding, and dye in spatial data visualisation. On the other hand, "vivid" metaphors can be found in visualisation for the masses, from historical maps to television graphics. Figure 1 shows four examples of such metaphoric visualisation.

Ziemkiewicz and Kosara recently showed that the choice of visual metaphors in visualisation affects users' interpretation [ZK08]. This inspired us to consider the need for providing users with the capability of switching between different visual metaphors in information visualisation. Such a capability is widely available for many types of visualisation, such as between a bar chart and a bubble chart, and between a tree map and a node-link diagram. However, for more expressive or "vivid" metaphoric visualisation, such capability has not been reported previously in the literature.

This work presents a template-based approach to the generation of metaphoric visualisation from tabular data. In particular, we have employed this approach in a system, called *vis4me2*, which addresses the following technical requirements:

- It should allow a coherent transformation between a relatively abstract metaphor (e.g., a treemap) to a more expressive metaphor (e.g., an illustrated map).
- It should enable easy customisation of existing metaphors

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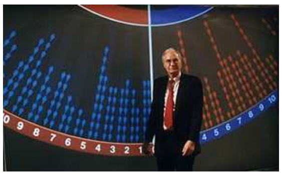
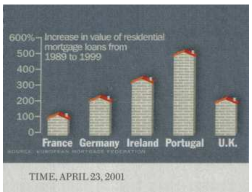
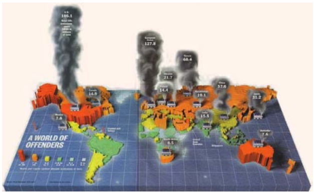


(a) BBC election visualisation

(b) BBC weather visualisation



(c) Increase of mortgage loans Time Magazine, April 23, 2001



(d) "A world of offenders" Time Magazine, April 23, 2001

Figure 1: *Examples of metaphoric visualisation. (a) The* swingometer *visualises the impact of the vote swing on British election results. (b) In May 2005, the BBC controversially replaced 2D symbol-based weather visualisation with 3D visualisation, where rain and snow are shown as animated 3D metaphors, cloud cover is indicated by shadows, and seas and oceans are visualised using a rippling effect. It won an industrial design award in 2006. (c) A simple metaphoric bar chart. (d) A 3D illustrated map where land evaluation represents yearly CO_2 emission per capita, while smoke height represents total CO_2 emission.*

by ordinary users and uncomplicated introduction of new metaphors by expert users.

- It should provide automation in much of the pipeline for creating a metaphoric visualisation, except when crucial semantic specification is necessary for handling the input.
- It should demonstrate its usability through a fairly large case study, for which we chose the outcome of the latest UK Research Assessment Exercise (RAE2008) [HHSD09], often referred to metaphorically as the UK research landscape.

2. Related Work

The word *metaphor* derives from *metapherein* in Greek, which translates as "to carry over" or "to transfer". Metaphor is an important aspect of studies in language, philosophy, cognition and education [Ort93]. Kövecses defines metaphor as "understanding one conceptual domain in terms of another conceptual domain" [KÖ2]. He further states that "if metaphors are primarily conceptual", they "must be realised not only in language but also in many other areas of human experience". Feinstein studied the nature of visual metaphor and examined the differences between visual and linguistic metaphors [Fei82]. In [Ort93], Gentner and others presented four essays on the important role of metaphors in science. The extensive studies on metaphor in the literature assured us that using metaphors in visualisation is not just a gimmick.

There is a rich collection of previous work on colour symbolism (e.g., [Hea96]), and iconic communication (e.g., [HE74]). There have been some uses of "vivid" metaphors in visualisation, such as "city" metaphors in network and software visualisation [RGA*00, PBG03], and "pile" and "room" metaphors in document visualisation [MSW92, HC86].

The use of a 3D layout does not necessarily bring desired advantages in information visualisation (e.g., [Mun08, SJOC01]).There are also studies on interactions in virtual environments [vRv97, FBZ*99], which have indicated the merits of engagement and enjoyment in 3D visualisations. While the focus of this work is placed on the technical aspects of a system to support the creation of metaphoric visualisation, we take into account both viewpoints, and aim to offer a means to allow coherent transformation between 2D and 3D metaphors and between abstract metaphors and more expressive metaphors. We believe that in this way the system developed can provide users with options for different tasks and opportunities to create and learn new design concepts.

Ziemkiewicz and Kosara [ZK08] conducted an important study on the effects of using visual metaphors. In particular, they researched into the hypothesis that "the process of understanding a visualisation involves an interaction between these external visual metaphors and the user's internal knowledge representations". Their study confirmed such connections, and hence the importance in "shaping information" with effective visual metaphors. In this work, we aim to provide users with a means to create and experiment with different "shapes" of information.

Nowadays, systems such as Many Eyes [VWv*07] are truly visualisation services for the masses. These systems reduce the users' burden in creating visualisations. One approach is to reduce the complexity of input data by restricting it to a number of data templates (e.g., Many Eyes). Another approach is to employ advanced algorithms to generate automatically visualisations from data [Fei85]. Recently, Mackinlay *et. al.* [MHS07] presented a set of user interface commands, "Show Me" as part of the user interface of Tableau. Gilson *et. a.l* [GSGC08] used several ontologies to create automated mappings from data to visualisation. In this work, we took a halfway approach by dividing the mapping process into an interactive part and an automatic part. We use the interactive part to determine semantics in the data (e.g., hierarchical relationship), while maintaining the generality of the automated part.

3. Application and Design Consideration

3.1. The UK Research Assessment Exercise

In the UK, higher education funding councils conduct a *Research Assessment Exercise* (RAE) every five to seven years [HHSD09]. The previous RAEs took place in 1986, 1989, 1992, 1996, 2001 and 2008. The main purpose is to produce quality profiles for research activities in different disciplines in each university. Each discipline in a university is referred to as a *Unit of Assessment* (UoA) and is assessed by a sub-panel. There were 67 UoAs in RAE2008 (e.g., UoA 23 - Computer Science and Informatics). The results are used as a basis for allocating research funding to each UoA in every university. For a research-intensive university, quality-related (QR) funding, constitutes a large portion of university income. For example, the 20 top universities in England will each receive between £22$M \sim$ £119M such funding in the 2009-10 academic year, representing 30 *percent* $\sim$ 64 *percent* of their income [HEF09].

The results of RAE2008 were published in December 2008. The main dataset is a table of 2366 rows (including 4 rows of headings) and 12 columns. Each row of data contains the assessment of a UoA in a university. The main columns are Institution name, UoA number, UoA name, Number of staff submitted, followed by the percentage of research activities at each quality level of 4$*$ (world leading), 3$*$ (internationally excellent), 2$*$ (recognised internationally), 1$*$ (recognised nationally), and unclassified. In addition, there are separate tables for individual UoAs and a summary table for all universities.

The readership of the raw data includes academics, administrative staff in universities, and various funding agencies. The data, if suitably presented, will also be interesting and useful to potential students (both postgraduate and undergraduate), central and local governments, public and industrial organisations which collaborate with universities, and to a certain extent, the general public.

3.2. Design Considerations

In the media, RAE results are referred to metaphorically as the UK research landscape. It is this metaphor which inspired us to visualise RAE2008 results metaphorically. The data has two essential hierarchically levels, A: the universities in the UK and B: the UoAs. Many users are interested in exploring the data with an order of $A \rightarrow B$ by locating a university first and then examining each UoA within the university. Meanwhile, many are also interested in the order of $B \rightarrow A$ by selecting a UoA first and the examining the activities of each university in this particular discipline.

Each university or UoA is associated with a real-value attribute indicating the number of staff submitted to RAE2008. This number is often referred to as a "volume" or "capacity" weighting and is sometimes used to moderate the rating.

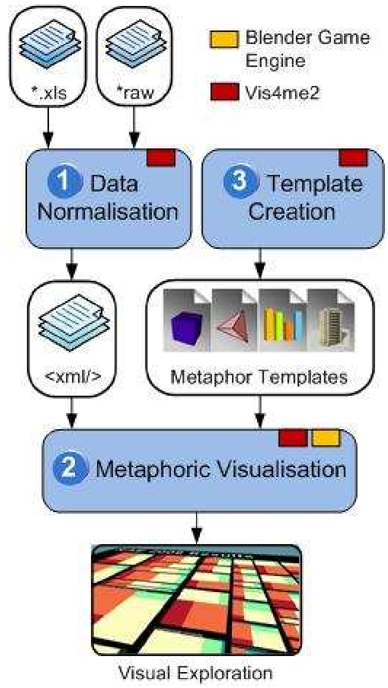


Figure 2: *The* vis4me2 *suite includes three functional components, which are used as tools for transforming tabular data to a relational database, creating and exploring metaphoric visualisation, and creating metaphor templates.*

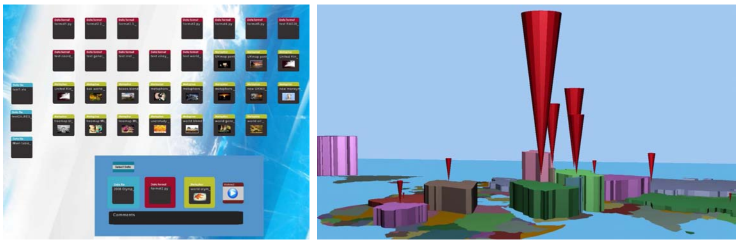
The percentage values of research activities at different levels are associated with each UoA, at 5 percent intervals (i.e. $0\%, 5\%, 10\%, \ldots, 100\%$). For each university, a weighted average at each quality level is calculated as a percentage value in real numbers. Because there are five quality levels, one can naturally consider these as sub-categories under A as well as B. Let us denote the percentage values associated with A as C_A and those with B as C_B. There are many options that one may organise the hierarchy of A, B, C_A, C_B. In this work, we adopt the hierarchy commonly used in the media and the academic community by attaching C_A to A and C_B to B. In other words, we can represent this hierarchy as $(A \rightarrow C_A) \rightarrow (B \rightarrow C_B)$.

The RAE2008 data is inherently suitable for treemap based visualisation, while that at level (A) can also benefit from geospatial visualisation. These two types of visualisation are thus the main focus of this work.

In this work, we decided to adopt a 3D layout as the principle layout for *vis4me2* because of the following reasons:

- Many metaphoric visualisations for the masses are of a 3D nature (e.g., Figure 1(b,d)), or contain 3D features in 2D presentations (e.g., Figure 1(b,c)). Considering the past and present popularity of metaphoric visualisation, there must be some cognitive advantages in using such visual

	A	B	C	D	E
1	Region	Country	Reserves (bbl)	Production (mbl/d)	Reserve life (Years)
2	North America	Canada	179	3.3	149
3	North America	United States	21	7.5	8
4	North America	Mexico	12	3.5	9
5	Middle East	Saudi Arabia	267	10.2	72
6	Middle East	Iran	138	4	95
7	Middle East	Iraq	115	2.1	150
8	Middle East	Kuwait	104	2.6	110
9	Middle East	United Arab Emirates	98	2.9	93
10	Middle East	Qatar	15	0.9	46
11	Latin America	Venezuela	87	2.7	88
12	Latin America	Brazil	12	2.3	14
13	Eurasia	Russia	60	9.9	17
14	Eurasia	Kazakhstan	30	1.4	59
15	Asia and Oceania	China	16	3.9	11
16	Africa	Libya	41	1.7	66
17	Africa	Nigeria	36	2.4	41
18	Africa	Algeria	12	2.2	15



(a) Tabular data (b) *Vis4me2* user interface (c) A 3D landscape generated

Figure 3: *From tabular data to visualisation. The example dataset contains estimated oil reserves ($10^9 bl$) and daily oil production ($10^6 bl/day$) in 17 countries [EIA09]. The data in (a) is first normalised using the* data normalisation *tool, resulting in an XML-based relational database. A template is applied to the XML database in (b),resulting in a metaphoric landscape in (c).*

representations. In general, Ortony's three theses, *compactness*, *vividness* and *inexpressibility* [Ort75] are also very much applicable to visualisation. This suggests that there is inherent synergy between 3D metaphors and 3D visualisation.

- There is implicit geographical information in our main case study, i.e., RAE2008 data. When a 2D spatial position is used to encode the geographical location of a university, the third dimension can be effectively used to encode other attributes, as for instance in Figure 1(d). We are also motivated by the need to visually depict the *UK research landscape*.
- We wish to provide users with smooth transition in exploring the hierarchical relationship between the "research landscape" of the UK and that within each university, and switching between different metaphors, between a treemap and an illustrated map. A 3D landscape layout can offer intuitive cognitive connections between different visualisations.
- Technically, a system that can generate 3D metaphoric visualisation is more generic than one for 2D visualisation only. We carefully designed our metaphoric representations to facilitate 2D visualisation from a bird-eye view (see Section 5).

4. *vis4me2*: System Overview

vis4me2 is designed to take a tabular dataset as the input and generates a metaphoric visualisation as output. The name *vis4me2* is an anagram of "me-ta(2)-phor(4) vis.", underlying our long-term aim to develop visualisation techniques for the masses. Figure 2 gives an overview of the pipeline from data to visualisation, and the three main functional components. An input tabular dataset is first transformed to a relational database by the *data normalisation* tool ①. The relational database is then loaded into the *metaphoric visualisation* tool ②, where the user can select different metaphors from a list of templates, and explore the created metaphoric visualisation. For experienced users, a *template creation* component ③ is provided to create new metaphor templates. Each component tool has its own interface, and can be run individually or from the *vis4me2* top-level user interface. The component-based approach was chosen for the flexibility to update components independently.

The system was built around *Blender*, a free open source 3D content creation suite [Ble09]. In particular, the *metaphoric visualisation* tool ② accesses the *Blender Game Engine* for exploring the created metaphoric visualisation. The *template creation* tool ③ is essentially the *Blender User Interface*, with additional libraries of template components built for *vis4me2*. Most additional code in *vis4me2* was written in *Python* as *Python* scripts can run within *Blender* and call on *Blender* routines.

The input data can be stored in either a raw ascii data file, or a *Microsoft excel* spreadsheet. The system accepts and maps multi-dimension quantitative data, which is dependent on the layout template configurations. In the current implementation, *vis4me2* supports hierarchical tabular data in the form of $L_1, L_2, \ldots, L_n, V_1, V_2, \ldots, V_m$, where L_i is a category name at level i, and V_j is an attribute value. Figure 3(a) shows a small example dataset in *excel*, with five columns of data, i.e., $L_{region}, L_{country}, V_{reserves}, V_{production}, V_{reserve \cdot life}$. The RAE2008 data also conforms to this format. A category name at a particular level can be a reference to a location or region in a geographical database.

The *data normalisation* tool ① transforms the tabular data to a relational database stored in an XML file. The term "normalisation" here defines the process of eliminating the duplication of data [CB04].

The *metaphoric visualisation* tool ② loads an XML database, associates it with a metaphor template, and dynamically creates a 3D metaphoric landscape for the database. The system provides the user with a list of templates, and the user can select and apply different templates to the data in a way similar to applying a template to a set of presentation slides. The default view of the 3D metaphoric landscape is a bird-eye view, facilitating an overview close to a 2D flat visualisation. As this tool is directly powered by the *Blender Game Engine*, the user can explore the landscape and navigate through different hierarchical levels. Figure 3(c) shows a view of a metaphoric landscape created from Figure 3(a). The application of a selected template to an XML database will be detailed in Section 5.3.

For *template creation* 3, *vis4me2* utilises and adopts the *Blender*'s file format (`.blend`) for storing the templates. To create a new metaphor template, a user is required to provide an appearance design and a layout design of the metaphor. The appearance design involves object modeling and simple algorithm specification for mapping data values to appearance attributes (e.g., colour map). The layout design involves primarily the specification of an automated layout algorithm. These two design aspects are usually interrelated. For example, the geometry of a geographical map is an essential part of the appearance design, and it also provides the basis for the layout algorithm. To facilitate reuse of appearance and layout designs, a model library and an algorithm library (in *Python*) were provided to support template development. The design mechanisms are detailed in Section 5.

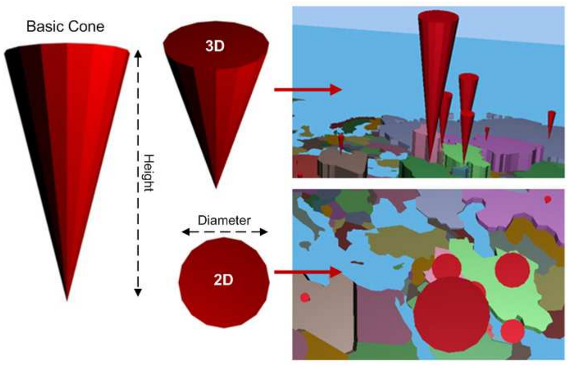
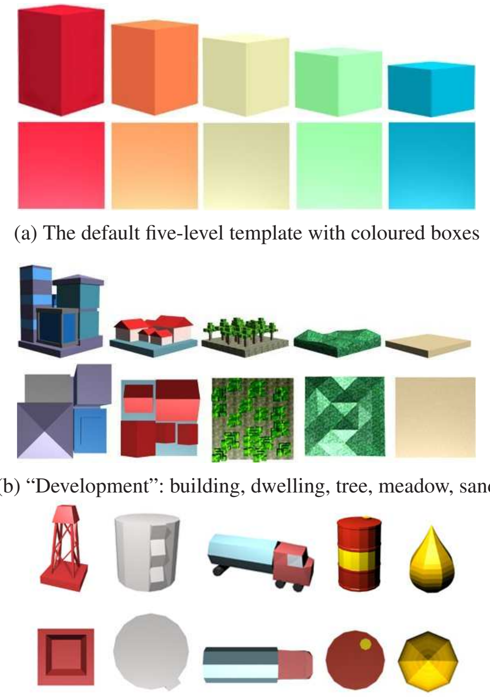


Figure 4: *2D assisted 3D cone metaphor visualisation*

In the implementation, we allow a smooth transition between 3D and 2D visualization. All metaphors in *vis4me2* are designed to be meaningful in both 3D and 2D (bird-eye view). Figure 4 shows how a 3D cone metaphor could be visualized in 3D and 2D, while retaining the quantitative meanings associated with the representation. In this case, the quantitative meanings are carried by the height in 3D and diameter of the cone base (top flat surface) in 2D view. The smooth transition is aided by a proportional data mapping of the height of the cone to the diameter of the cone surface based on the assigned value, while the tangent of the cone is maintained to be constant through out the template. This approach is also used in other metaphors as shown in Figure 5, where each metaphor carries a distinctive geometric and texture appearance which are visible in 3D and 2D.

5. Template Design and Application

Each template consists of two aspects of the design, namely *appearance* and *layout*. In the following sub-sections, we detail these two aspects, and summarise the process of applying a template to an XML database within the *metaphoric visualisation* tool.



(a) The default five-level template with coloured boxes

(b) "Development": building, dwelling, tree, meadow, sand

(c) "Oil & Gas": Rig, Silo, Tanker, Barrel, A Drop

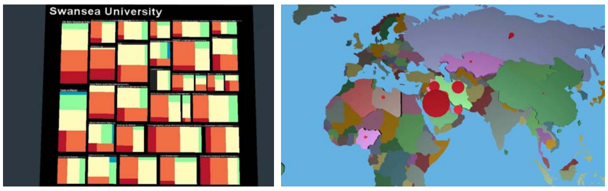
Figure 5: *Examples appearance metaphoric templates, each of which is shown with a 3D view and a bird-eye view.*

5.1. Appearance Template

vis4me2 has a built-in default appearance template. It has a very basic design with combined colour and height symbolisms. The default template contains a cuboid with variable colour and height as shown in Figure 5(a). Both height and colour will provide visual cues during exploration. Colour becomes the dominant visual cue when viewing from above, and we adapt one of the diverging palettes by Wijffelaars *et al.* [WVvv08] as the default colour map. Both height and colour variation can be either mapped to the data bands (i.e., sub-ranges) or scaled according to the data values.

Figure 5(b) shows a generic appearance template for five-levels of development which are selected based on 20% intervals of 100. The metaphor uses "sand" to symbolise the poorest status of development and "tall building" for the most developed status. In Section 6, we will show its use in visualizing the RAE2008 results. *vis4me2* currently provides 15 built-in templates.

The appearance templates are constructed and modified using the *Blender User Interface*, part of which is very similar to most 3D model builders. As *Blender* is designed to support computer game design, its user interface also enables an experienced user to write *Python* scripts to control interaction and animation.



(a) (b)

Figure 6: *A treemap template and a geographic template.*

5.2. Layout Template

At particular hierarchical level, L_i, the goal of the layout algorithm is to determine the placement of all L_{i+1} sub-categories that belong to L_i. The layout algorithm takes into account that L_i is bounded by a spatial domain, which is usually determined by the layout at L_{i-1}. It may also be moderated by an attribute field V_j associated to L_{i-1}. For example, in the case of a treemap layout for the Oil Reserve dataset in Figure 3(a), at a particular region, $L_{NorthAmerica}$, the layout algorithm has to place its sub-categories, Canada, U.S. and Mexico, and the size and placement of each sub-category can be moderated by one of the three attribute field (e.g., the total reserves of 179, 21, 12 billion barrels respectively).

vis4me2 has a built-in default layout template. It places each of the sub-categories along a line. The width of each sub-category along the line can be moderated by an attribute field. Another template is a 2D matrix layout with a uniform base size for all sub-categories. All such templates can be enhanced with an appearance template, where the object representing each sub-category can, for instance, be scaled (e.g., in height) and coloured according to attribute fields.

We provided users with a treemap layout algorithm, which was implemented based on the squarified treemap algorithm by Bruls *et al.* [BHv00]. Figure 6(a) shows the application of a flat treemap layout to the RAE2008 results of a university. In this layout, each group of 4-5 patches is a UoA, and the size of each UoA represents the number of staff submitted, and the size of each patch represents the percentage of the corresponding quality level (e.g., 1*, 2*, etc.).

When sub-categories in a particular hierarchical level are references to geographical placenames, it is possible to provide a layout algorithm based on geometric data of the geographical region concerned. *vis4me2* is currently supported by two geographical databases, a World and a UK map. In the World map, each country is represented by a triangulated polygon. In the UK map, each postcode is represented by a geographical position on the map. This is particularly useful for the RAE2008 data, because city name alone is not sufficient to separate different universities in the same city. Figure 6(b) shows the application of the world map template to the Oil Reserve dataset in Figure 3(a).

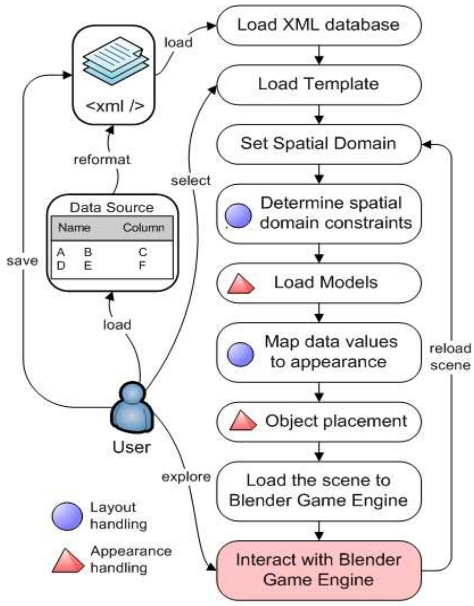


Figure 7: *Applying templates to an XML database.*

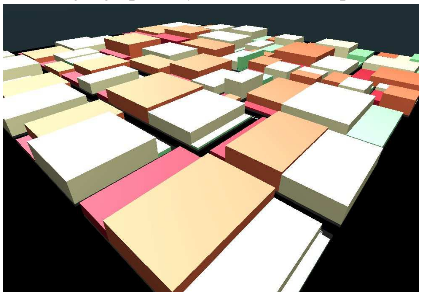
5.3. Template Application

The *Metaphoric visualisation* tool plays the principal role in transforming a normalised tabular dataset to a metaphoric visualisation. The mapping itself at this stage is automatic, once an XML database is loaded into the system. Figure 7 outlines this process.

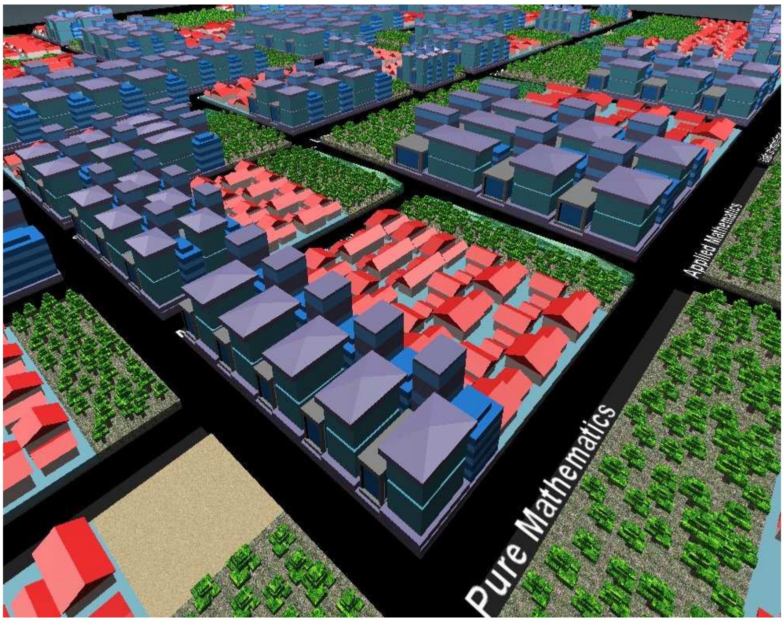
An input XML database may or may not specify a template. If it is the latter case, the built-in default template will be used. The camera view is initialised to a bird-eye view of the top level landscape. This setting determines the spatial domain which will be used by the layout script to determine the constraints in relation to a particular layout template. Different appearance scripts are then executed to load the relevant models in the appearance template, and map data values in the XML database to appearance attributes, such as colour and height symbolisms. Another layout script is then called on to place the metaphoric objects in the scene. The scene is then loaded into the *Blender Game Engine*, where the user can explore the scene interactively. These algorithmic steps are performed dynamically.

Whenever the user moves up and down the hierarchy, this triggers the change of the spatial domain, and activates the "reload" loop in Figure 7 to set a new spatial domain accordingly. During the interaction, the user can select a different template, triggering the rerun of the template application process.

(a) geographic layout, 3D bar metaphor



(b) treemap layout, box metaphor



(c) treemap layout, development metaphor

Figure 8: *Different metaphoric visualisation of the RAE2008 results.*

(a) 3D cone metaphor (b) bird-eye view as 2D visualisation (c) oil and gas metaphor

Figure 9: *Geospatial metaphoric visualisation of the oil reserves data. The height of land elevation represents the amount of total oil reserves, in years, of each country in the dataset. A different metaphor is used to depict the production per day.*

6. Results and Remarks

Figure 8 shows several metaphoric visualisations of RAE2008 results. In 8(a), a landscape metaphor was used for part of the RAE2008 data, showing the results of UK universities. In this case, the cuboids for each university are stacked together, and the absolute height represents the staff number. The relative height represents the percentage of the research outputs in the five different quality levels. A geographical template was used. In 8(b), a treemap layout is combined with the cuboid metaphor (Figure 5(a)), where both the area and the height of each cuboid represent the percentage, the colour represents the five quality levels, and the area of each region (a group of 3-5 cuboids) represents the number of staff submitted. In 8(c), a more expressive treemap is applied to several universities, using the development metaphor in Figure 5(b). In comparison with 8(b), the metaphor attracts attention as well as provides a more memorable mapping from the quality levels to their visual representations. Some quick insights from the landscapes are the large cluster of submissions from london districts and high number of submissions of certain institutions.

Figure 9 shows several metaphoric visualisations of the oil reserves data. In 9(a), the height of land elevation represents the total amount of old reserves of each country in the dataset. The height of each cone and the radius of its base represent the production per day. Note that when visualising the landscape from a bird-eye view as in 9(b), it resembles a typical map-based visualisation. Hence the cone-based metaphor can help the transformation between 2D map-based visualisation and 3D metaphoric visualisation. In 9(c), the oil and gas metaphor in Figure 5(d) is used to visualise the production per day.

7. Conclusions

We are aware that understanding and appreciation of metaphors depends on personal experience, education and culture background. In many ways, this is similar to colour symbolism in visualisation. We are aware that the meaning of metaphors can be explained, and translated across languages. Their popularity is often influenced by circumstance, prominence and frequency of its usage. Metaphors can also be used to help learning. To a certain extent, this resembles many aspects of visualisation. The irony is that users are frequently coming across metaphoric visualisation, as exemplified by Figure 1, but they rarely have the tools to create metaphoric visualisation. The purpose of this work is to provide a tool, with which users can create and experiment with metaphoric visualisation.

We are interested in carrying out further research in metaphoric visualisation. In particular, we plan to conduct a study on the usefulness of metaphoric visualisation in helping improve visualisation literacy (e.g., learning advance visualisation concepts) and plan to research into the feasibility of developing a tool to ease the creation of new metaphors and further experiments with time-dependent data.

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