

REPRESENTING UNCERTAINTY IN VISUALISATIONS OF FUTURE LANDSCAPES

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ABSTRACT:

The use of computer-based visualisations to depict landscape futures is increasingly common in environmental decision-making, particularly where information must be communicated to a wide and non-expert audience. Continuing technological development makes it possible to use real-world data as a base for such visualisations, with modifications made to the landscape data as appropriate depending on the scenario to be illustrated. The effects of factors such as the level of realism in the images produced and the capability for viewer interaction with the scene are beginning to be addressed by researchers, but relatively little attention has been given to the representation of uncertainty. The complexity of environmental systems means that uncertainty always exists to some degree when illustrating possible or proposed future states for any landscape, and it is essential that this be communicated to stakeholders, decision-makers and other audiences. Cartographic techniques exist and have been used to illustrate error and other quality issues relating to spatial data, but there has been no large-scale application to landscape visualisation. Options for communicating levels of uncertainty are being explored using a study area in Norfolk, in the eastern part of the UK. This work first considers sources of uncertainty; it then moves on to examine various illustration methods in terms of technical feasibility and data needs as well as audience reaction and perception. In helping visualisation producers to illustrate uncertainty in the clearest and most accessible way, the results of the study have the potential to enhance environmental decision-making processes.

KURZFASSUNG:

Computerbasierte Visualisierungen von zukünftigen Landschaftszuständen werden immer häufiger eingesetzt, um Umweltentscheidungen zu treffen, insbesondere, wenn Informationen mit einem breiten Laienpublikum ausgetauscht werden müssen. Die fortschreitende technologische Entwicklung macht es möglich Real-World-Daten für solche Visualisierungen einzusetzen, wobei entsprechende Modifizierungen der Landschaftsdaten in Abhängigkeit von den darzustellenden Szenarien vorgenommen werden. Wissenschaftler beginnen damit Auswirkungen von Faktoren wie Realitätsnähe der erzeugten Bilddaten und die Fähigkeit der Interaktion der Betrachter mit diesen Bildern zu untersuchen. Wenig Aufmerksamkeit wurde dabei bisher der Darstellung von Unsicherheiten gewidmet. Aufgrund der Komplexität von Umweltsystemen bestehen bei der Darstellung von möglichen oder vorgeschlagenen Landschaftszuständen immer zu einem gewissen Grad Unsicherheiten und es ist unabdingbar, dass diese Interessenvertretern, Entscheidungsträgern und anderen Zielgruppen verdeutlicht werden. Kartografische Verfahren existieren und werden genutzt, um Fehler oder andere Qualitätsgesichtspunkte in Bezug auf räumliche Daten darzustellen, aber es erfolgte bisher kein großer Einsatz in Bereich der Landschaftsvisualisierungen. Möglichkeiten zur Verdeutlichung der bestehenden Unsicherheiten werden bezogen auf einen Untersuchungsraum in Norfolk, im östlichen Teil von England, erforscht. Diese Arbeit berücksichtigt zunächst die Quellen von Unsicherheiten; darauf aufbauend werden verschiedene Illustrationsmethoden in Abhängigkeit von technischer Umsetzbarkeit und erforderlichen Daten sowie die entsprechenden Reaktionen und Wahrnehmungen der Zielgruppe untersucht. Durch den Einsatz der Ergebnisse der Studie können Unsicherheiten in einer klaren und höchst zugänglichen Form dargestellt werden und so zu einer Verbesserung von Umweltentscheidungsprozessen führen.

1. INTRODUCTION

The environmental decision-making process increasingly involves the visualisation of spatial data in one form or another. In particular, landscape visualisation is recognised as a useful tool for communicating large amounts of environmental information, especially when working with the non-expert groups now beginning to participate in decision-making (Craig, 2002). Recent example applications of such work in the UK include the presentation of coastal management options (Jude et al, 2002) and the impacts of climate change on rural landscapes (Lovett et al, 2003).

However, as visualisation and display methods become more sophisticated, users have control over an increasing number of aspects of the output, such as lighting, the colour and texture of surfaces and objects, and the opportunity to add elements such as labels and overlays. Attention is therefore beginning to turn

away from merely representing the visible landscape and towards adding value to that representation by including more subtle and complex factors such as uncertainty.

2. UNCERTAINTY IN ENVIRONMENTAL DECISION-MAKING

Environmental decision-making processes naturally deal with predictions or proposals relating to future environmental states. Some level of ambiguity is inevitable in any future scenario due to the combination of various sources of uncertainty, including natural environmental variability, data uncertainty, knowledge uncertainty, and model uncertainty (Willows & Connell, 2003: 49). Our understanding of natural systems is imperfect; to this is added the impossibility of completely predicting human actions and reactions on either an individual or collective scale, and issues of measurement including accuracy and precision.

Multiplication of these error sources means that any visualised landscape can only ever be said to be a possible future, one of a great number of alternatives.

Although there is a desire to reduce uncertainty, stemming from a end-users' and decision-makers' demands for information that is certain (Foody & Atkinson, 2002), it is clear that it can never be eliminated. We must therefore find ways to communicate scientific uncertainty in a clear and honest way, particularly when dealing with the public, so that the most appropriate decisions are made. However, care must also be taken not to overwhelm the viewer by adding excessive or overly complicated information about uncertainty – the purpose of the visualisation is, after all, to increase the accessibility of environmental information. To date, little research has been done to address this issue.

Previous work with planning professionals (Appleton & Lovett, in press) has suggested that uncertainty should be carefully considered when visualising a scene for the environmental decision-making process, in order that viewers' (and managers') time is not wasted in commenting on uncertain or representative aspects of a landscape future as if they were certain and specific. For example, showing an visualisation of a future rural scene which includes wind turbines may elicit detailed comments on their size and location, when in fact they were only included as an indication of increased reliance of renewable energy in the scenario shown. Furthermore, futures which appear more certain than they really are may be accepted by the audience as a foregone conclusion rather than questioned, explored, and commented on.

One potential barrier to finding a simple and effective way to represent uncertainty is that uncertainty itself is very difficult to define. For example, we could attach particular level of uncertainty to a landscape as a whole, or to the various elements within that landscape; we could be trying to show that one outcome is simply more or less likely than another given certain conditions, or we may have more quantitative information on the overall probability of different futures. We may be asking for preferences or suggestions relating to choices about the landscape, or trying to communicate the consequences of different courses of action that the viewer could take. Exactly what is to be communicated will necessarily affect the suitability of the various methods detailed in the following section.

It may even be that the passive presentation of uncertainty is not enough for some uses. Couclelis (1992) urges that data quality information should grab the attention, forcing the viewer to assess quality, although such methods could prove confusing for the type of non-expert audiences that visualisation is usually intended to bring into the decision-making process.

It is worth noting that to some extent, anecdotally at least, where visualisation technology is capable of creating highly detailed images these capabilities are used without question in the belief that "more realistic" visualisations are "better". However, it is arguable that the "best" visualisations are in fact those that give the viewer the truest picture of the future in question – scientific uncertainty included. It may be, therefore, that detail and visual realism should not be the overriding concerns, and careful attention should be paid to the overall message conveyed by a visualisation. One thing is clear – a visualisation cannot simply be presented as a fait accompli if the audience is to make meaningful decisions based upon it. Somehow, the idea that a future landscape is just one possibility

must be communicated if more participatory environmental decision-making is to fulfil its potential.

3. PREVIOUS WORK

Perhaps the simplest ways of expressing uncertainty relate to numerical information, where it can be conveyed using error margins and ranges rather than single figures (although these too have their problems (Gigerenzer, 2002)). Such methods are, however, largely inappropriate for visual and/or spatial data where there is a large variation in uncertainty over the dataset. Research has therefore also examined ways of showing data quality and error when using 2D or 3D cartographic methods; indeed, uncertainty as a whole has been an important research topic in geographical information science for the past decade (Atkinson & Foody, 2002). There are broadly three strands of research relating to uncertainty in geographical information: reducing uncertainty, characterising sources of uncertainty, and providing information to users about the uncertainty of a particular dataset. It is the latter of these that provides information relevant to the work described here, but as stated by Hunter & Goodchild (1996), that investigation of the presentation of uncertainty could still be said to be sparse. This is particularly true for the field of landscape visualisation, due to its relative newness.

Existing literature mostly focuses on error in spatial databases, and usually includes separate maps of error (for example a colour gradation) to overlay or combine with the original data in some way. A common example is 3D draping, whereby a surface is generated to represent a variable over a certain space, with that surface then coloured according to the error at each location. Cartographic techniques lend themselves to variation in representation, e.g. point clouds, thick or braided lines, or fuzzy features to represent uncertainty of location (Hunter & Goodchild, 1996). As well as visual methods, there are suggestions of animation and sound-based solutions, but they seem to be little used in practice so far (Beard et al., 1991; Krygier, 1994). The applicability of these tools to current landscape visualisation methods is discussed in Section 5.

It is also important to note that there is still little guidance as to how a given degree of uncertainty might be inferred from the use of a particular technique. Visual techniques are generally indicative rather than quantitative, giving users information quickly, but not necessarily clearly (Hunter & Goodchild, 1996).

4. CURRENT TOOLS FOR VISUALISATION

The way in which uncertainty is represented in any landscape visualisation is governed to some extent by the choice of visualisation method and output type.

Still images offer the greatest levels of realism, as there is no limit on the time taken to draw a scene – it may take several hours to render, but once completed it can be shown many times. One example of software that produces this sort of output is Visual Nature Studio (3DNature, 2004) Interactive methods are still behind in terms of the detail that can be shown (although the gap is narrowing as available computing power increases), as their content needs to be rendered many times a second to keep up the illusion of movement through a scene. For instance, the terrain modelling software TerraVista (Terrex, 2004) can be used to produce models which can be explored in

realtime with a joystick or mouse. Animations may be derived from either method, by compiling a sequence of stills or by recording an interactive navigation.

Portability is another important issue for many visualisation methods. Simple still images can easily be reproduced and distributed in a variety of ways, but cannot be modified, for example to remove the uncertainty information. Interactive methods, and some animation techniques, sometimes involve the use of particular applications or plug-ins (e.g. Audition for OpenFlight realtime models, or Flash for multimedia content on the internet), which may allow customisation and thereby the addition of some degree of user control. Such methods, however, limit the distribution and use of visualisations to those with the appropriate computer software, hardware, and possibly network connections, which may go against the desire to open up decision-making to a wider audience.

5. POTENTIAL METHODS FOR REPRESENTING UNCERTAINTY IN LANDSCAPE VISUALISATION

Many of the techniques in Section 3 do not immediately seem to be directly applicable to the issue of uncertainty in landscape visualisation, as they can conflict with the needs of the visualisation itself. That is, changes in colour, sharpness or position in an effort to show uncertainty may be interpreted as a change in real life rather than an attempt to illustrate non-visual information (Goodchild, 1991). For this reason, altering the appearance of the landscape or objects within it (e.g. changes in colour/size, or multiple instances of items) is potentially unhelpful in any decision-making process, since responses are usually requested based at least partially on the visual appearance of a landscape.

The suggestion that complications may arise from the use of highly detailed visualisations whereby the viewer equates visual detail with certainty of prediction was brought up by planning professionals in previous work (Appleton & Lovett, in press). There, respondents put forward the idea that different elements of the image could be visualised at different levels of detail depending on their certainty. On the other hand, the results of a different research project suggest that viewers find high levels of detail helpful in imagining a visualised landscape (Appleton & Lovett, 2003), implying that it could be unhelpful to alter the level of detail in an effort to express additional information. It was also evident that there may be a “lowest common denominator” effect whereby an image is only as realistic overall as its least detailed element, perhaps throwing doubt on the advisability of varying the detail level to convey uncertainty. This is an interesting disagreement which needs to be investigated in more depth, but it does not mean that visual modifications should be discounted as useful techniques. Methods whereby the user can control the visibility of uncertainty information (perhaps using a sliding scale of transparency or some other transition), or display it in a parallel window, are possible alternatives to the permanent alteration of visualisations, with animation techniques offering the option of similar displays where interactivity is not practical (e.g. with a large audience).

The techniques which would seem to be most suitable for representing uncertainty may be summarised as follows:

- Deliberately creating low-detail visualisations (or elements within them)
- Giving a range of possibilities, if appropriate

- Altering colour, either by adding false colour or desaturating (greying out)
- Blurring
- Written information, either on labels within the image or accompanying text
- Sound

Some of the above techniques may increase the time taken to draw or display a landscape image, by adding an extra dimension of information, which is relatively unimportant for single images, but has more impact on multi-frame animations and could well affect the perceived smoothness of interactive methods by reducing the frame rate. However, interactivity also brings an important extra dimension to most of the above options. Not only does it allow visual methods to be applied without permanently distorting the image, but it could be used to control the level of verbal information displayed, perhaps allowing expert and non-expert viewers to be catered for with the same visualisation. A range of visualisations could be presented in response to the viewer’s choice of scenario or changing of one or more given parameters. Sound-based techniques could respond to the pointing/navigation device used, either representing uncertainty on its own, or being used as an alert device to draw attention to the presence of other uncertainty information. It therefore seems likely that some sort of user interface would be helpful, to allow the viewer to choose the information to be displayed, showing multiple sources at a time either in separate windows or overlaid on one another.

It is important to consider non-interactive methods as well as interactive ones for the reasons mentioned in Section 4. If the decision-making process is to be widened to include a greater cross-section of society, the visual information intended to facilitate their participation must be made available in an accessible way. This does not preclude the use of sophisticated technologies but does mean that alternatives should be considered and investigated.

The audience may also affect the choice of methods in other ways. In reaching out to more non-experts, environmental decision-making must still be useful to expert participants, and their needs and perceptions must be considered. One interesting question is whether environmental professionals might have a greater inherent understanding of uncertainty when presented with an environmental future, and therefore there is less need to draw their attention to its existence and more need to explain its sources and magnitude. Such information may be overwhelming to a non-expert viewer, but could be presented on an on-demand basis as suggested above.

6. WORK SO FAR

Preliminary work is being carried out to assess the technical feasibility of the various options for presenting uncertainty information. This phase is ongoing.

The underlying image (Fig 1) was chosen from a previous project within the research group (Lovett et al, 2003) and shows a rural, agricultural English landscape in the south-east of the country. It is based on Geographical Information Systems (GIS) data, specifically UK Ordnance Survey elevation and land use data, with the land use information being greatly enhanced through fieldwork and other sources to reflect the varieties of crops grown in the area. The GIS information was used with Visual Nature Studio from 3DNature to create a landscape

model, in which various ‘cameras’ were placed; Figure 1 is the view from one such camera.



Figure 1. The base visualisation used.

The image illustrates the landscape as it may look in 20 years’ time under a particular climate change scenario which includes efforts to reduce CO₂ emissions (wind turbines, solar panels), changes in crops to reflect differences in climate and water availability, a reduced water level in the stream, and subtle changes to the apparent health of non-crop vegetation (trees and hedges), as well as adaptation and mitigation measures. Uncertainty in this particular future state comes from numerous sources, including the nature and magnitude of climate change, the type and strength of its effects, and the financial, political and social factors driving policy change and the actions of farmers. As yet, no specific levels of uncertainty have been defined, and consequently the modified images are very much exploratory. As shown here, different elements of the landscape are given different levels of uncertainty, for example we may be fairly sure that the stream level will be lowered, but wind turbines are only a vague possibility due to the planning process, a lack of feasibility studies for that precise location, possible local opposition, and so on.



Figure 2. One way in which uncertainty may be shown using colours

Figures 2 and 3 are examples of colour and clarity modifications as applied to the image in Figure 1. Different colours as used in Figure 2 could represent different, and relatively easily distinguishable, levels of certainty, although determining those levels is a challenge in itself. A legend would need to be provided with such an image. It can be seen from Figure 3 that degrees of fuzziness are somewhat difficult to achieve, certainly more so than degrees of colour, and so this technique is probably more suited to expressing general uncertainty over a

scenario rather than differentiating between specific parts of a scene. By its nature, blurring is more noticeable on elements which were previously well-defined, such as the wind turbines on the skyline, and less obvious on features which already have a degree of variation edges such as crops.



Figure 3. An example of how blurring may be used to show uncertainty

In terms of technical feasibility, the images were modified in PaintShop Pro v7 (Jasc, 2004) using, respectively, an airbrush tool used on a semi-transparent overlay layer, and a blur filter, and while they were not time-consuming to produce, it is evident that it could prove hard to apply such effects repeatedly with any great degree of consistency. The possibility of applying such effects automatically currently seems remote, although Visual Nature Studio does include a PostProcessing facility which may be of use with certain techniques. Such a capability would be almost essential if creating animations via the compilation route, where hundreds or thousands of frames need to be altered. Post-render colouring of areas of the image according to uncertainty (which could be specified in the underlying GIS database) does not seem to be possible at present, but this may change as the software develops.



Figure 4. A sample layout for an interactive “visualisation toolbox”

Figure 4 shows a purely artistic mock-up of a possible “visualisation toolbox” which could be given to viewers to allow them to toggle different representations on and off, change viewpoints, or otherwise interact with the display. While technology already exists to put together user-selectable displays of still images and other information (such as the web-browser based system being used in the Königsutter area in Germany (Warren-Kretzschmar & Van Haaren, 2004)), a working toolbox for interactive visualisations would need to be

programmed from scratch, which is beyond the current capabilities of the research group.

7. CONCLUSIONS AND FUTURE DIRECTIONS

It is clear that there are a number of areas ripe for research in this field, beginning with the definition of uncertainty as it relates to visualised landscapes, moving through the technical feasibility of the various options for representing it (which will need to be revisited as technology develops), to the perceptions and understanding of various groups of end-users when faced with such visualisations. The first of these is vital if subsequent work is to be carried out within a valid context, and to a large extent will influence the sorts of images produced for investigation.

It would seem sensible to begin with easily-modified still visualisations in order to keep processing time to a minimum as viewers' perceptions are explored. By employing qualitative as well as quantitative research methods, further insight and ideas could be obtained from respondents; ideally such results would be used to inform and direct research into more complex animated or interactive methods. To these ends, the next steps of this project will be to carry out preliminary surveys of non-expert respondents to elicit their responses to these and other simple expressions of uncertainty in visualised landscapes.

The eventual aim of this research is to feed back into the visualisation process as it is used in real-life applications. In helping visualisation producers to illustrate uncertainty in the clearest and most accessible way, this work has the potential to improve the communication of landscape-related information and thereby enhance the environmental decision-making process.

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