A representation of everything

The vision of a "digital earth" has captured the imagination of those involved with geospatial information since a now-famous speech by Al Gore at the California Science Center in 1998. The idea inspired a government initiative, a conference series and an international journal (*The International Journal of Digital Earth*), each with the long-term goal of achieving the vision described in the speech. Gore's speech presented the perspective of a child during her interaction with a 'mirror world' – a digital copy of everything there is and has been – immersed in a virtual environment. The child's geographical exploration experience required no prior training or education, but did involve the VR technology of 1998. Given technological developments since then, the current and future benefits of a digital earth not just for education but also for the geospatial analyst are self-evident.

Since 1998, impressive progress has been made towards a digital earth. Starting with NASA's World Wind (2004), many open source, freeware or commercial virtual globes and their portal managers or geobrowsers, have come into existence, and their impact has been to revolutionise our view of our planet. The early geobrowser Keyhole was purchased by Google and released as Google Earth in 2005 and has reached 400 million downloads by 2008, ten years after the Gore speech. Geobrowsers as entry points into virtual globes are increasingly more popular, and have become increasingly more "crowded" with cartographic and multimedia detail, especially when it is user-contributed. Not only can high resolution graphic data and geocodes be produced more easily today than ever before,

Virtual globes or virtual geographical reality

A good Geo Virtual Environment implementation would provide the best digital earth approximation possible at present and host unlimited multi-sensory multimedia detail and allow for interaction as if it were the real world, with added analytical possibilities the emergence of Web 2.0 (including Volunteered Geographic Information) feeds virtual globes with rich information from the bottom-up, including images, videos, sounds and written content.

These developments have been mostly positive, however, side effects such as visual clutter (a form of this is popularly referred to as "red dot fever"), lags in data loading times, information overload, and steep learning curves for interaction hinder the power and efficiency of these candidate digital earths.

Virtual globes or virtual geographical reality

Virtual globes and their portals (the geobrowsers) have proven highly popular and they represent great progress especially in public acceptance of mapping. Nevertheless, they suffer from a few drawbacks, and, in terms of content and scope, virtual globes are a simplification and only an approximation of the digital earth. Most operate in a distributed networked environment, and so face bandwidth limitations that impede the immediate access to the extreme levels of detail required for a true "mirror world" (a prior vision of the digital earth concept). A proper mirror world should mimic tangible reality as closely as possible, indeed the experience of the Digital Earth or Earth 2.0 should be exactly that of Earth 1.0. However, the visual quality (resolution, granularity and image depth) of present day geovisualisation is limited by bandwidth instead of the abilities of the human visual system and interactions are even more constrained. Given that virtual environments can range from fully immersive true 3D experiences to 3D projections onto 2D web page renderings, current virtual globes are commonly viewed in 2.5D as opposed to the more experiential natural 3D view of the world. Disregarding bandwidth limitations, with current computational resources (equipped with inexpensive fast and high capacity graphics processing units) and high-tech displays, we can already handle finer resolutions than those used with today's online virtual globes.

A set-up that brings the latest technology for advanced visualisation and analysis is a 'virtual environment' (VE). An immersive and interactive environment where high levels of information intensity can be linked to intelligent objects has been termed a geographical virtual environment (GeoVE). A true virtual environment should fully immerse the user by stimulating all five senses – sight, touch, sound, smell and taste. Visual stimulation is most obvious, since more than 40 per cent of the human brain is dedicated to process visual information and it is safe to say that currently visualisation is the most advanced component of a multi-sensory VE. Audio is also well studied and spatial hearing leads to a more precise navigation within a virtual environment. Haptic (touch) has some promise based on hand tracking and data gloves, however it is still cumbersome and expensive, or limited to one dimension (e.g. texture). Smell printers and virtual taste experiments exist but are in nascent stages compared to the stimulation of the other senses.

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In short, a good GeoVE implementation would provide the best digital earth approximation possible at present. Ideally, the Digital Earth GeoVE should host unlimited multi-sensory multimedia detail and allow for interaction as if it were the real world, with added analytical possibilities. At present, this would come through links to the current World Wide Web, such as geographic place to Wiki page linkages. Links to video, sound etc. and place-to-place links on the digital earth would require adding further information into the system and advanced research in technology and human computer interaction, e.g. better algorithms to handle large amounts of scale-dependent data, on-the-fly data fusion (multiple sources and scales) and level of detail management. As the Digital Earth content grows, new visual analytic and display methods and theory will be necessary to link the extraordinarily dense information primitives together in currently unimaginable ways. Inclusion of deep and historical time, the oceans, the earth interior, a network of things, and human culture will challenge the next generation of geographers and cartographers.

Level of detail (LOD) management

One of the continuous challenges in dealing with rich geographic datasets has been about controlling the level of detail. How much (visual) detail does a digital earth require , then? Intuitively, one can answer this question with "as much detail as there is in the real world and more." After all, we want to create a VE in which we can go back or forward in time, explore even the vaguest of spatial links (all places mentioned in Shakespeare's plays, every place associated with the evolution of the horse), run spatio-temporal analyses or simply enjoy spatio-temporal virtual tourism. As usual, however, the question is intractable without putting it in the right context. Contexts of capturing (data collection), processing and visualisation will yield different answers. That is, we want to capture high detail where possible but selectively process and visualise the information specific to the task. This should sound familiar to cartographers, as they have been managing level of detail (LOD) quite intelligently for many centuries using map generalisation approaches. LOD management is essential, among other things, to prevent waiting for data to 'load' (latency), for helping humans reason better with the available information without extreme cognitive load and to avoid visual clutter.

Biomimicry and level of detail

The capture-process-visualise stages for controlling the level of detail for geospatial data have parallels in how human senses operate. We are psychophysically wired for a certain level of sensory input at the 'capture' stage (it is perhaps interesting to note that we do not always see or 'hear' as well as our machines, that is, we can record things that are outside our sensory spectrum). Next we selectively process and select the relevant information for the task at hand. Humans do this in real time and remarkably seamlessly. For example, we can 'channel' our hearing to listen to one person speaking in a noisy room even with many people speaking at the same time.

Some LOD management approaches are based on the limits of human perception and information processing, while others make high resolution display computationally tractable. In capturing the data (unless there is a financial or another practical reason), it is invariably best to collect the highest possible resolution. Similarly, a digital earth will require imaging across the spectrum and extensive image archiving. Then at the visualisation stage, it makes perfect sense to show only the level of detail that humans can in fact perceive and process.

In terms of visual perception, the human visual system has certain acuity and the spatial organisation of the photoreceptors (rods and cones) on the fovea provides us with a non-uniform visual field, centered on our focus of attention. Our colour perception is vulnerable to surrounding colours and simultaneous contrast. Some of the behavioural imperatives make us look at salient objects involuntarily, e.g. objects approaching us rapidly. Peripheral vision is more sensitive to motion. Stereopsis provides us with fine depth discrimination at a certain depth range. The properties of our visual systems can provide us with clues and leads to find potentially better ways to design our GeoVEs, possibly avoiding visual clutter by managing the perceptual level of detail. Additionally, simulating certain features of the human visual system (e.g. simulating depth of field) might have benefits for stereoscopic displays, which are used in almost all existing VEs.

Cognitive load is yet another issue. Most geospatial data is multivariate and it is tempting to display as many of these variables as possible, especially if the analyst wants to see the spatio-temporal relationships among them. However, humans are said to be able to keep three objects at one time in their visual working memory – this number is seven at best. Awareness of these and other human factors in designing GeoVEs is essential for finding and displaying the right level of detail for the task and for the audience.

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Earth 2.0

As Ribarsky said, we are dealing with "[...] models of unprecedented scale and detail. Successfully integrating these models into a comprehensive, integrated virtual GIS remains a major challenge." Since 2005, the first generation of geobrowsers made remarkable progress, but they are merely shadows of the potential systems to come. Furthermore, the scope and content of a digital earth that is now limited to existing imagery and geospatial data has been transformed by the Internet and systems for collecting user contributed content, indeed the citizen science and volunteered information already present is also just a shadow of what the future will deliver. With such a vision as digital earth deliverable within a decade perhaps, or at least a career, one wonders what new knowledge and wisdom about the world will be revealed to the young girl in Gore's speech during her lifetime. With luck, perhaps Earth 2.0 will be the savior of Earth 1.0.

Arzu Çöltekin and Keith C. Clarke
University of Zurich & University of California, CA USA