Digital Earth reloaded – Beyond the next generation

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Abstract. Digital replicas (or ‘mirror worlds’) of complex entities and systems are now routine in many fields such as aerospace engineering; archaeology; medicine; or even fashion design. The Digital Earth (DE) concept as a digital replica of the entire planet occurs in Al Gore’s 1992 book Earth in the Balance and was popularized in his speech at the California Science Center in January 1998. It played a pivotal role in stimulating the development of a first generation of virtual globes, typified by Google Earth that achieved many elements of this vision. Almost 15 years after Al Gore’s speech, the concept of DE needs to be re-evaluated in the light of the many scientific and technical developments in the fields of information technology, data infrastructures, citizen’s participation, and earth observation that have taken place since. This paper intends to look beyond the next generation predominantly based on the developments of fields outside the spatial sciences, where concepts, software, and hardware with strong relationships to DE are being developed without referring to this term. It also presents a number of guiding criteria for future DE developments.

1. Introduction

Besides developments in basic DE disciplines such as geoinformatics, spatial sciences or GIS research, we are currently witnessing large-scale research initiatives in non-spatial fields with strong relevance to DE developments. Examples include European Future and Emerging Technologies (FET) projects such as ‘FuturICT’ or ‘Guardian Angels’, health initiatives or even fashionable technologies [1]. An example that is closer to the DE core illustrates the concept of DE on a broader canvass. The Virtual Australia and New Zealand initiative (VANZI) is seeking to exploit the convergence of complementary technologies to create functioning systems models of the built world (http://www.vanzi.com.au/ accessed 6/6/2013). Underpinned by topologically structured spatial data, it will utilize simulation, logistics, gaming, and visualization technologies to model real world situations and optimize solutions in 3D and time stamped 4D (figure 1). The VANZI concept originated from the challenge posed by the expansion of the Port of Melbourne, Australia. Melbourne is a city of 4.1 million people. It is the biggest container Port in Australia and container movements are set to quadruple by 2035. Street congestion is already at intractable levels with some inner city urban streets hosting up to 20,000 truck movements per day. The expansion will require a radically reworked supply chain, linking sea, road and rail, and the factoring in of additional capacity at two additional small Ports within 100 km of the main hub. VANZI conceives a fully functioning virtual model, with options, drawing on a data model of single point of truth, allowing the hundreds of

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affected stakeholders to thrash out the risks and options in a collaborative environment prior to a
decision on the preferred plan. It is proposing a formal framework that enables authoritative data to be
maintained in a secure environment that will underpin transactions in the real world in the same way
that hardcopy land titles for example operate today. At base, VANZI will represent both the 3D
Physical Attributes of the real world across time, plus Legal Entitlements. These entitlements will be
based on the simple principle that: “Rights in the Authorized Virtual World = Rights in the Real
World”. To uniquely identify the ‘Authorized Data Set’ to which this principle applies, it is proposed
that a new ‘infrastructure’ of Government and Commercial Data Banks be set up to hold the ‘official
version’ of all 3D data sets for every object in the real world. These data sets would be under the
control of the ‘object’ owner, just as traditional banks hold our money under the control of the
account holder. This ‘infrastructure’ will be paid for out of fees charged to all people and
organizations engaged in the “property-sector” in consideration of cheaper, quicker and better
services. It is envisaged that the ‘official data set’ will also underpin third party uses that can access
the data that is publically available, such as for all location services, as well as the context for
economic and social data.

![Virtual Australia & New Zealand Initiative (VANZI): Using the Virtual World to design and manage the Real World](image)

**Figure 1:** Virtual Australia & New Zealand Initiative (VANZI): Using the Virtual World to design and manage the Real World

This paper intends to look beyond the next generation predominantly based on the developments
of fields outside the spatial sciences, where concepts, software, and hardware with strong
relationships to DE are being developed without referring to this term. We will not only look at the
technical components of an advanced DE but also into the importance that a DE will have on the
people living in an interconnected world. We will argue that DE needs a set of strict guiding
principles and a code of DEethics to play its envisioned role for the betterment of humankind. The
paper ends with an optimistic scenario presentation on foreseeable developments for the early 21st
century. However, to quote Niels Bohr, the Nobel laureate physicist, we are well aware that
“predictions can be very difficult, especially about the future”.

2. Core elements of Digital Earth
While many technological advances come from disciplines that are inherently non-spatial, we are
convinced that they will unleash their full potential only when married with the developments in
spatial science that is by harnessing the power of geographic location. The future DE will, however,
not only integrate technological progress but also reflect socio-economic evolution and environmental
considerations. Only then can DE truly serve the needs of humankind and be more than a
technological exercise with potentially threatening consequences.
While Gelernter’s Mirror World concept [2] was still based on computers sharing data and enabling access to a modeled mirror world, the developments that we are envisioning for the DE 2020 (see also [3]) encompasses a ubiquitous pervasive wireless infrastructure that consists of billions of sentient nodes enabling global connectivity and information sharing. Nanotechnology development will result in tiny sentient entities that can be placed on or in a human being to monitor, broadcast, and receive information into and from the future DE network. The same DE network with its pervasive nodes is the medium to conduct scientific research, provide access to knowledge and information, and to act as real-time communication system; eventually leading to a DE nervous system and related information processing spinal cord and brain [4]. For an optimistic future DE scenario, it should not only be sentient and evolving, but also self-sustained with no or very little energy consumption.

All objects in our daily lives will be uniquely identified, inventoried and connected. Central to the concept of the ‘Internet of Things’ [5] and the ‘Web of Things’ [6] is the ability to discern the identity, status and location of these objects. With these details known and accounted for, things can become active participants in our lives and business processes, and can even act autonomously on our behalf. Woven into DE is the concept of the sensor web, where sensors on objects that are active in our environments take stock of their surroundings and communicate conditions.

The complexity of such an interactive and interconnected system that merges the inanimate with the living will require the means to organize and simplify interactions. One of the easiest approaches to this simplification is the concept of real space, i.e. the geographic location, size and dimension of things. Location in time and space will be an increasingly important factor for tracking and controlling the interactions, particularly when things become sentient and begin acting autonomously on our behalf. DE will not be based on a ready-to-make grand concept but will rather evolve as a series of often small and sometimes disruptive changes. In full bloom, we foresee that DE will manage to bridge the gap between its developers and stakeholders, particularly the private citizen, and thereby stimulate further innovation and co-creation processes. Future DE applications will benefit from this opening up and exchange of ideas, software components and applications.

As DE is inclusive in nature, we have to ensure that the needs of the current ‘have nots’ will be adequately addressed. [3] suggest a country based DE index that represents the state of digital development of each country. This index is based on the relationship of the rate of energy consumption by population (which is taken as a proxy for dependency on digital goods and equipment) and the rate of internet penetration reflecting a need for advanced technology use. We propose that a more robust index be developed that is not tied to energy consumption as an indicator for economic development. Indeed we challenge an authoritative body to develop a robust and reliable DE index based on measurable criteria. This DE index could be used to regularly assess the DE development of all countries to ensure that DE is not only for the wealthy parts of the world. The DE index per country and its changes should then be published for all to see.

3. Citizen science, citizen participation, citizen manipulation

Al Gore saw the citizen as the ultimate beneficiary of Digital Earth’s ambitious goals even though, ironically, the citizen was not an active participating contributor [7,8]. Furthermore the means of interaction originally foreseen was mainly limited to navigation and the use of the visualization capacities. The diffusion of the internet and the popularisation of interactive technologies (smart phones, tablets, etc.) have created new opportunities for citizens and their role has significantly changed in recent years [9]. For example social networks and communities of practice are creating alternative source of data and information. They are freely accessible and in some cases offer real alternatives to the authoritative data provided by the Public Sector authorities and competitors to Private Data providers (e.g. OpenStreetmap vs TeleAtlas or Navteq).

However these new opportunities raise issues not yet investigated nor fully understood that can be the cause of ethical concerns. Citizen science is sometimes called “public participation in scientific research.” [10]. It includes the collection and analysis of data, development of technologies (e.g. new apps for smartphones) and the dissemination of results by individuals (including non professional researchers). In this specific sense citizens can be considered a special type of “sensor”. [11] argues that there is a long tradition of non specialists contributing to the collection of scientific information but that only recently the convergence of greater access to broadband connections, the availability of Global Positioning Systems at affordable prices, and more participative forms of interaction on the
Web (Web 2.0) have enabled vast numbers of individuals to create and share geographic information. As observed by [11], the potential for up to 7 billion human sensors to monitor the state of the environment, validate global models with local knowledge, and provide information that only humans can capture is vast and has yet to be fully exploited. It is inconceivable that the construction of an earth observing system in future will occur without the contribution of the billions of people who inhabit it.

In a broader perspective, citizen participation should also consider the need to better connect scientists to citizens. DE offers a real opportunity to better address societal challenges. In this way citizens may be more likely to improve their understanding of the forces that shape society such as measures to ensure global environmental sustainability of our planet. Scientists will be ever more strongly compelled to spend less time in ivory-towers and more time in communication, dissemination and the explanation of scientific knowledge. The technology today provides the means to address this gap but research is still needed to better understand communication sociology and visualization effectiveness and tools (e.g. how to visualize abstract concepts in space). Citizen engagement is essential to improve our capacity to observe and protect our environment. But it raises fundamental issues about the structure, access, ethics and rights of use that need to be addressed in order to assist the citizens of DE. Guiding principles are required.

4. Guiding principles and DEethics

4.1. Guiding principles for DE development
We postulate that the first principle of DE is unrestricted accessibility to DE by all of humankind whether they are individuals, government agencies, non-governmental organizations (NGOs), and for-profits and not-for-profits organizations. Defined social customs governing the accepted exchange of information will be challenged by this approach because the move to unrestricted access does not sit comfortably with all nationalities, spiritualities, jurisdictional and other defining belief systems. Security, privacy and commercial confidentiality must also be respected. This principle then is never likely to be completely fulfilled in reality due to the demands for a reasonable and acceptable degree of privacy and confidentiality.

The second principle is that DE should be developed for the purpose of progressing the needs of society and humankind as a whole. It should be capable of supporting the four obligations of a good government first articulated by Edmund Burke in 1795: public peace, public safety, public order and public prosperity [12]. The Brundtland report’s definition of sustainable development reflects a similar but more contemporary sentiment that of humankind’s obligation to respect the integrity of all of earth’s interrelated human and non-human systems and processes: “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [13].

The third principle of DE is that it will always be 'on', immediate, with known precision, comprehensive and fully interactive. It will offer access to information from 'blue sky to bedrock' in immersive 3D at everybody’s finger-tips anywhere, anytime. To the individual it will be sentient; offering advice, warnings and guidance, by being aware of the individual and relating place to circumstances. It will, for example, increasingly be drawing on each individual’s health records to do this, just like Google or Amazon are drawing on our search preferences now.

4.2. Code of ethics
There are a number of issues, however, that need to be addressed to avoid negative developments which are already visible in our current internet such as cybercrime, unwanted profiling, spam, security breach, and non-approved monitoring. DE advocates are almost evangelical in support of a connected world and promote a “sink or swim” policy with a future where technology will ultimately handle things better than the human mind. You might be able to adapt the pace of the lifestream to your needs but you have to stay connected.

There are others, however, that are more sceptical of the “brave new world” of the future fearing that commercial and political interest as well as the human wish for connectedness may generate a streamlined new culture where ultimately man and machine algorithms will merge in a complete digital world: the profile becomes me [14]. We cannot rule out that we are in the position of being the
sorcerer’s apprentice but without the sorcerer that can come to our rescue. It is increasingly difficult if not currently not impossible to separate the “trusted inside from the untrusted outside” [15]. What is therefore needed is that the technological advancements have to be accompanied by the development of a DE code of ethics that ensures privacy, security and confidentiality in a world where everybody can be connected to everybody else and everything all the time. Without solving this critical dilemma and allowing people to decide whether or not they want to be connected and how much of their thoughts and emotions they want to share, the dream of a wonderful virtual future may well turn into DE nightmare.

Similar to the evolution of bioethics and geoethics, we foresee the necessity to propose a set of underlying principles for the development, implementation, and use of DE, the DEethics so that DE can deliver the anticipated benefit for all humankind. DEethics should be follow generally established ethical principles such as Kant’s Categorical Imperative ethics [16] which could be summarized as:

- Act only according to that maxim by which you can also will that it would become a universal law.
- Act in such a way that you always treat humanity, whether in your own person or in the person of any other, never simply as a means, but always at the same time as an end.
- Act as though you were, through your maxims, a law-making member of a kingdom of ends.

Consideration should be given the DEethics code being developed by a ‘steward’ or a ‘group of stewards’, ratified by a reputable body such as the United Nations.

5. DE 2100?

Can there be something of a DE 2100 vision? How much will environmental and societal changes have impacted our life on Earth? Will a DE (or the term ‘DE’) still be around in 2100? It is safe to say that the authors of this paper will not be around to see the year 2100. Building on the 2020 vision [3,9], however, we speculate that we will witness the emergence of a sentient DE which will be an unconscious presence in our life. The rate of observed progress in the development of artificial intelligence, nanotechnology, wireless communication, data storage, knowledge dissemination and other yet to be conceived technologies lends weight to this speculation. In the end, we can only make predictions based on past and present experiences; practice will reveal all. Community dynamics, that is individuals and society at large, will continuously shape DE and its applications in unexpected ways, both, negative and positive.

Digital Earth will be time stamped and topological. It will play out scenarios as genuine simulations of the world that maybe or was, at any speed, and discover consequences that can be quantified, verified and risk managed in ways not possible today. The increasing danger of ‘believing’ one scenario will be tempered by our need to validate the outcomes with competing scenarios, and new protocols will be necessary to protect the users from themselves.

As humans we are not consciously aware of the individual neurons that make up our brain. A new intelligence is emerging from the increasing complexity that is DE. Could it be that the artificial nodes and connectivity of DE might bring forth a totally new form of intelligence. A DE is built on ethical principles, we believe, should yield great benefits to all members of society. It will, however, be a changed society that will live in a DE subsisted world; a society that cannot be separated from its digital counterpart, and vice versa.

We know that forecasting scenarios and visions of future developments are always risky and often times plainly wrong. There is no master plan for Digital Earth. Progress often appears in areas where hardly anybody would have expected it. This applies especially to our vision of what will happen in the future both near and far.

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