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# The Europe's Lost Frontiers Augmented Reality sandbox: Explaining a 2.5 million Euro project using play sand

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## Abstract

The subject area of the Europe's Lost Frontiers project, the submerged landscape of Doggerland, is inaccessible and the data by which we can understand it is complex and hard for the non-specialist to understand. In order to be able to present the project at public events, an Augmented Reality sandbox was constructed, which records the shape of sand in a box, interprets it as a landscape inhabited by humans, animals and plants, and projects this simulated land back on to the sand. Different software packages can be used to highlight the effects of climate change or provide examples of the different types of evidence available to archaeologists researching submerged landscapes. The end result is an interactive, accessible display which attracts all ages and can be used as a starting point to conversation regarding the project's archaeological, scientific and technological aspects.

## Keywords

Augmented Reality, Doggerland, agent-based modelling, submerged landscapes, climate change

## Introduction

Europe's Lost Frontiers (ELF) is a five year (2015-2020), multi-disciplinary project to investigate the Holocene landscapes of the Southern North Sea, funded by a €2,500,000 ERC Advanced Grant. It uses data from seismic geophysics and core samples taken from the seabed in order to study the environmental changes that occurred within the inundating landscape and the possible effects these might have on the human population. As the project data consists of seismic geophysics and core samples (Figure 1), presenting the project to the public involves overcoming some significant obstacles. The seismic data involves very large data sets and is often difficult to interpret. The core samples are visually unimpressive, hard to transport, and are required to be in controlled conditions to preserve the integrity of samples taken from them for analysis.

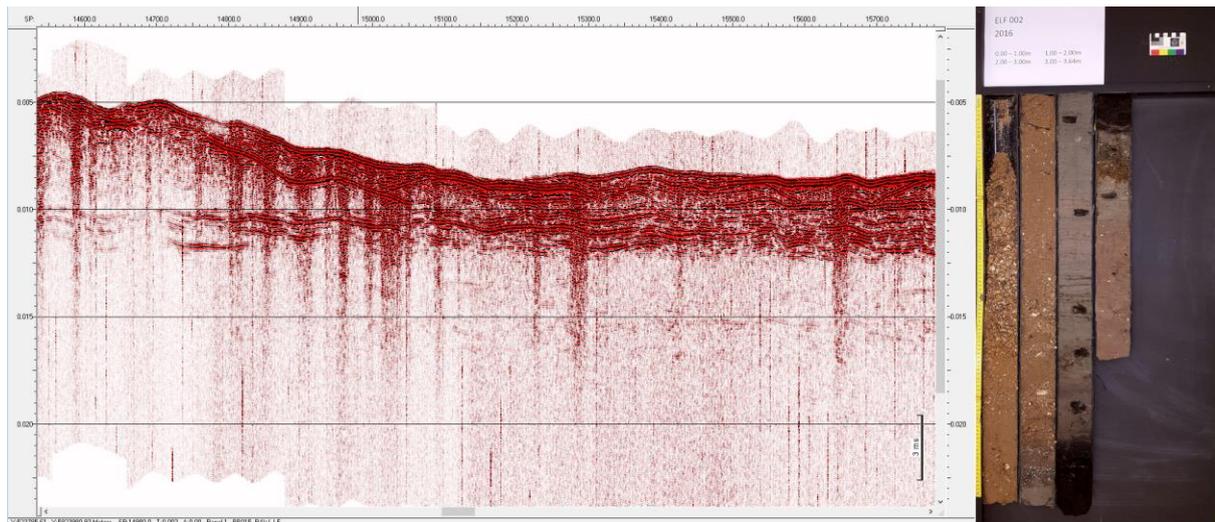


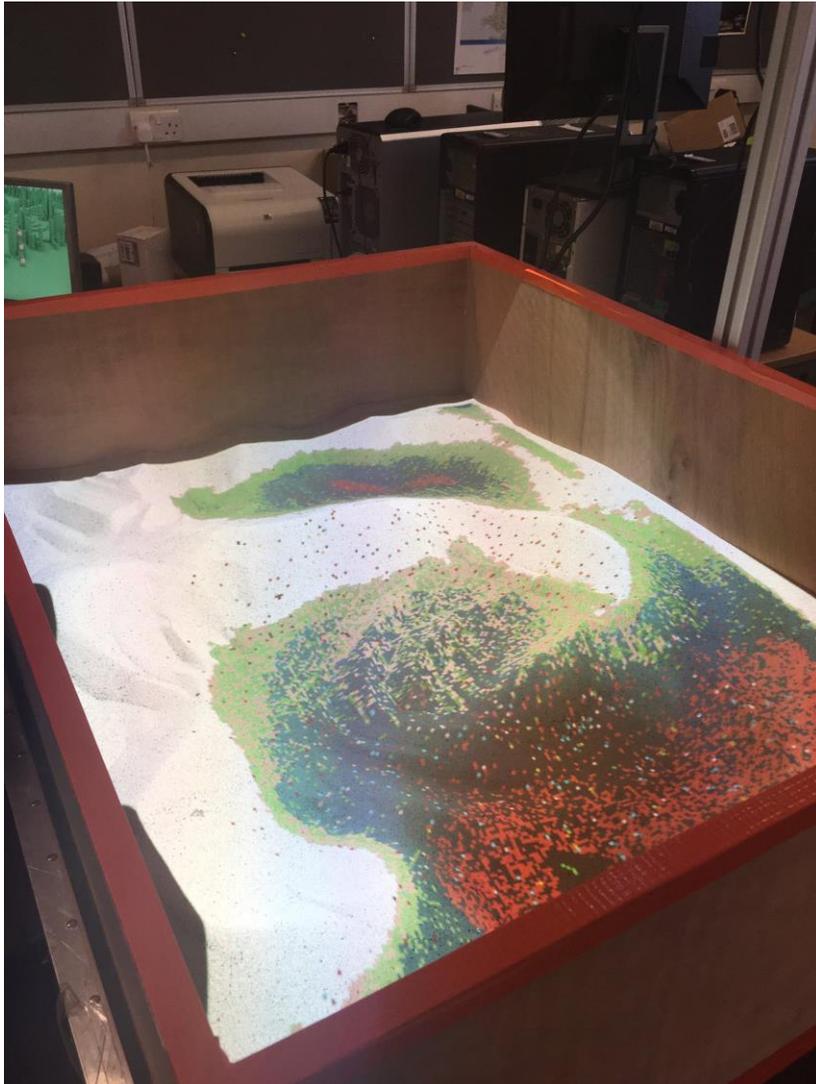
Figure 1: 2D seismic data and a photo showing a cross section of core ELF002

The project also contains a computer simulation component, where models are made to test hypotheses regarding the inundated Holocene landscape of the southern North Sea, an area known as Doggerland, and its effects on the human population. Computer simulation provides a way to bridge the gap between the large-scale seismic data and the small, but data-rich, points obtained from coring. These computer models allow the incorporation of relevant data collected from other periods and areas to provide a testing ground for our hypotheses. We can put together a model of a landscape and its environment and subject it to the effects of different models of climate change to assess the differences in the effects of each one. We can then look for signals in the seismic and core data that may indicate how the environment of Doggerland may have changed through time.

These models, however, are built with specific purposes in mind and are often not meant to be interacted with in real time. They also do not need to be visually interesting or accessible to non-specialists. Their primary aim is to answer scientific questions, not look good or be fun. This means that, between the simulations, the cores and the seismic data, the project has no obviously engaging way of presenting our research to the public beyond traditional methods such as illustrated talks.

In 2015, some members of the Europe's Lost Frontiers team were working as part of the Stonehenge Hidden Landscapes Project and presented a display as part of the Royal Society Summer Science Exhibition. As part of this display, an Augmented Reality (AR) sandbox was used to illustrate the effects of different types of geophysics. This proved very popular with a whole range of visitors, from school children to pensioners and from scientists to those with no previous knowledge of geophysics.

This success prompted the creation of another AR sandbox (Figure 2) for the Europe's Lost Frontiers project to enable our participation in public events and to act as a starting point for discussion about a range of different aspects of the project. We wanted to be able to use the visual appeal of the AR sandbox across all ages that had previously been noticed at the Royal Society Summer Science Exhibition to communicate the role of computer simulation within the wider Europe's Lost Frontiers project. The addition of a visually interesting, interactive exhibit was intended to allow us to take part in public events we might otherwise have little to contribute to.



*Figure 2: The AR sandbox running the ELF Dynamic System*

## Background

AR differs from Virtual Reality (VR) in that it contains a physical component, coupled with the virtual. These can either be directly combined, as in the projection of data onto the sand of the sandbox, or virtual objects can be mixed with video footage of the real world, as in mobile applications such as Pokemon Go. Although considered a relatively new technology dating to the 1990s (Berryman, 2012), as a concept it has been around since at least the 1940s, with the first recognised augmented reality system being developed in 1968 by Ivan Sutherland (Sutherland, 1968).

An early example of such an approach, although using clay instead of sand, is the 'Illuminating Clay' interface, where the manipulation of the clay allows for the change in the depth projection (Piper et al., 2002). The clay model is placed on a platform in the centre of the projection space, with the remaining outer areas being used to project cross sections, and landscape analysis tools which also update as the clay is manipulated. Landscape analysis functions include slope, view-shed, least cost path, water flow and erosion.

The AR sandbox was first developed by the University of California-Davis, to simulate water flow across landscapes (Kreylos et al., 2016). In teaching and learning the use of AR sandboxes have also

been applied to soil science, for example at the University of Wyoming, as part of introductory soil science labs. This use as a teaching aid in the geosciences is a popular use of AR sandboxes, as they enable students to understand the links between 3D objects, and their 2D counterparts, acting as an interface between what is viewed on a computer screen and physical models (Woods et al., 2016). Although uses thus far are limited, and are mostly used for demonstrating hydraulic action across a landscape (S. E. Reed et al., 2014), their uses and applications are expanding. It has been suggested that present numbers exceed 150 globally, which is perhaps a conservative estimate (Kundu et al., 2017). AR sandboxes are also being developed for entertainment and therapeutic purposes (Roo et al., 2017).

From an archaeological perspective the use of AR generally is becoming more commonplace, especially in the cultural heritage sector, with an early example being *Archeoguide* (Vlahakis et al., 2002), tested at Olympia, allowing the users to view 3D reconstructions of the archaeology which include audio narration, and virtual avatar animations. However, there are only a few instances of AR sandboxes with specifically archaeological content. The *Archaeological Sandbox* is one example which was developed to be used as an interactive user interface to investigate the contexts where artefacts have been recovered on sites supplementary to museum exhibits. A map of the archaeological site is projected onto the sand, with locations marked as hints. Digging at these will reveal information on that location and artefacts recovered (Biefang et al., 2017).

## Methodology

### Hardware

The design of the sandbox hardware follows the blueprint set out by the UC Davis AR Sandbox (S. Reed et al., n.d.). The equipment consists of a Microsoft Xbox Kinect v1 controller, a Benq short-throw LCD projector, a PC, a box containing play sand and aluminium framing that allows the Kinect and projector to be suspended over the sand (Figure 3).



Figure 3: The AR sandbox on its trolley

The Kinect is attached to the aluminium framing by a bespoke 3D printed part produced by the University of Bradford's Visualising Heritage team. The projector is attached via a standard projector ceiling mount and is positioned by two wooden spacers to take some of the strain from the mount (Figure 4).



*Figure 4: The mountings for the projector and Kinect*

The equipment is mounted on a sturdy trolley for easy transportation. The aluminium struts holding the Kinect and projector can be easily removed from the box to facilitate transport as the whole apparatus is too tall to fit through regular office doors otherwise. Two large bags of play sand were used to provide enough depth in the box to enable interesting landscapes to be produced. The UC Davis team added a small amount of water to their sand to facilitate modelling but we found that dry sand worked well for our purposes as the softer slopes of dry sand created land surfaces which were smoother and presented fewer registration problems between the image and the sand. We also avoided having to seal the wooden elements of the box to prevent mould growth. The lack of necessity for a registration setup procedure, as is present in the UC Davis sandbox software, simplifies the software and shortens the setup time. There are areas in which the image does not perfectly line up with the sand, but these seem to go largely unnoticed by users.

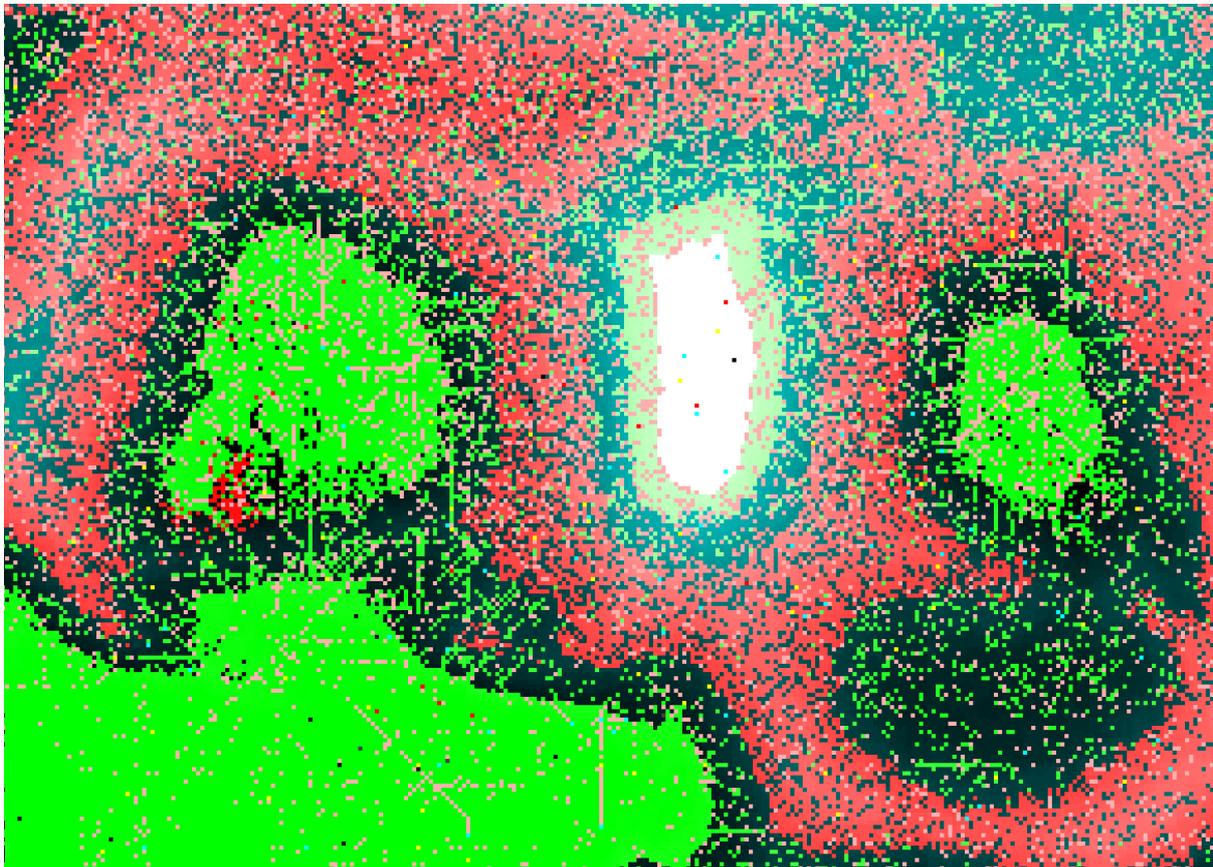
The sand can be emptied in around 10 minutes using a scoop into heavy-duty plastic bags, but these are heavy and awkward to transport and this is only done when transporting the sandbox offsite. The whole equipment fits easily into a small van.

## Software

The software running on the PC consists of several different elements. Our PC is a HP desktop with 8Gb RAM, a 230Gb HDD and an Intel Core i5 650 processor running at 3.2GHz. It runs Windows 7 as an operating system and contains the following software packages:

- Java SE SDK v8u161
- The J4K Java library (Barmpoutis, 2013)
- Eclipse SDE
- The ELF Sandbox software

The ELF Sandbox software is available via a publically available Github repository (<https://github.com/ELFdev001/ARSandbox>), and is written in the Java programming language and requires the J4K library to communicate with the Kinect sensor. There are two versions of the ELF Sandbox software detailed below but they both share a similar base. The Kinect provides a range of depth values that are treated as a Digital Terrain Model. This is a two-dimensional array of heights that is treated the same as any other terrain dataset. This provides the shape of a landscape that the ELF Sandbox software uses to create a simulated environment.



*Figure 5: ELF Dynamic System. Large areas of bright green, reddish pink and dark grey represent the predominant plant type in a cell. Areas of white represent snowy areas with no plant growth. Individual dots of red, yellow or dark blue represent humans. Individual dots of pale blue represent deer. Individual dots of black represent the remains of deceased deer or humans.*

### *ELF Dynamic System*

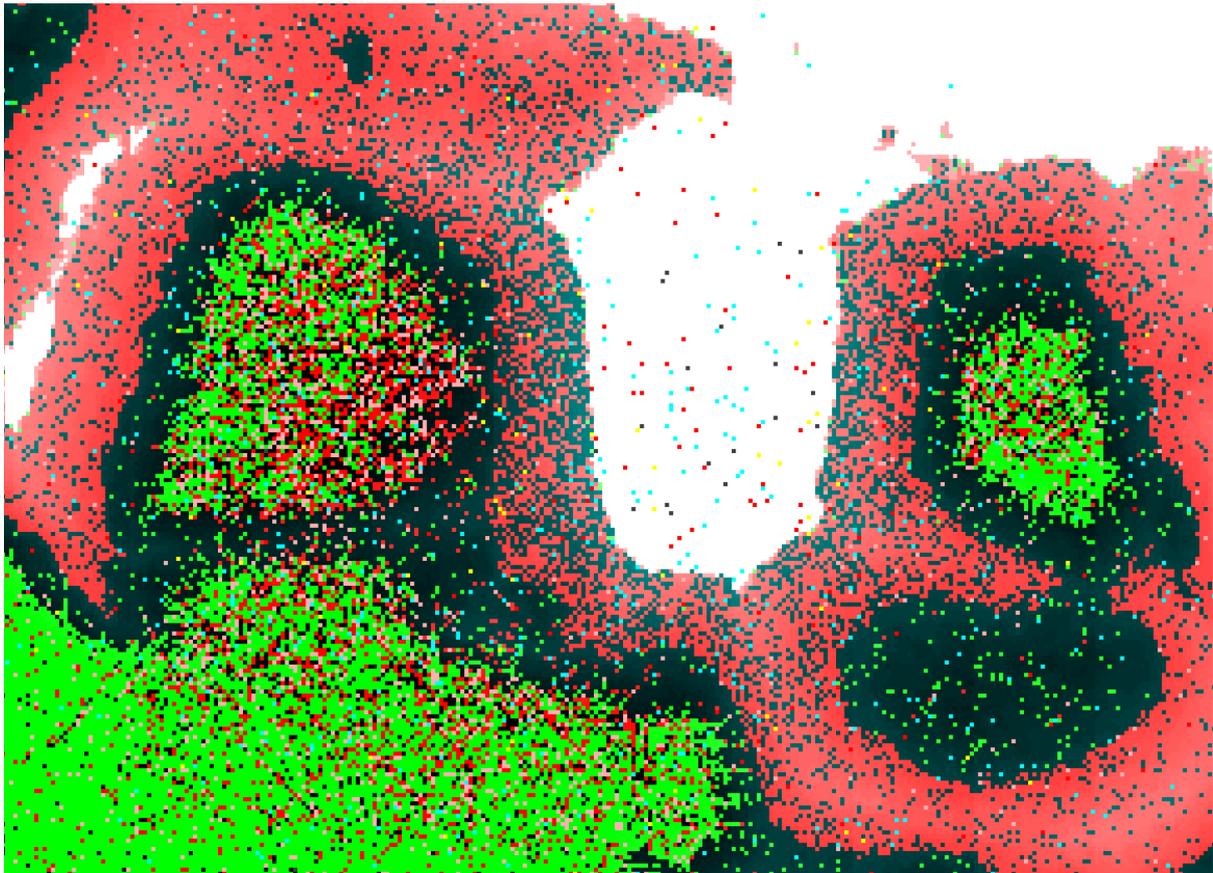
The ELF Dynamic System (Figure 5) comprises all the main elements of the project's computer simulations, albeit in a much simplified form. These are:

- Environment

- Climate
- Flora
- Fauna
- Humans

#### Environment

The terrain is split into three areas, depending on height. All areas above a set level are interpreted as above the snow line. No plants will grow here although humans and animals may cross. All areas below a set level are interpreted as underwater. Humans and animals may cross water but only humans may harvest marine resources, animals may not feed on water. The level of the snow line and the water line are determined by the temperature.



*Figure 6: ELF Dynamic System with lower temperatures. Note the larger areas of snow and different plant growth despite this being the same landscape as Figure 5.*

#### Climate

The climate is represented by a simple temperature which varies based on keyboard input. The temperature is static unless manually increased or decreased by the operator. The temperature affects the growth of plants and the height of the water line and snow line. Lower temperatures will increase snow cover and affect the growing areas of plants (Figure 6). As the temperature increases, so do the levels of the water line and snow line (Figure 7).

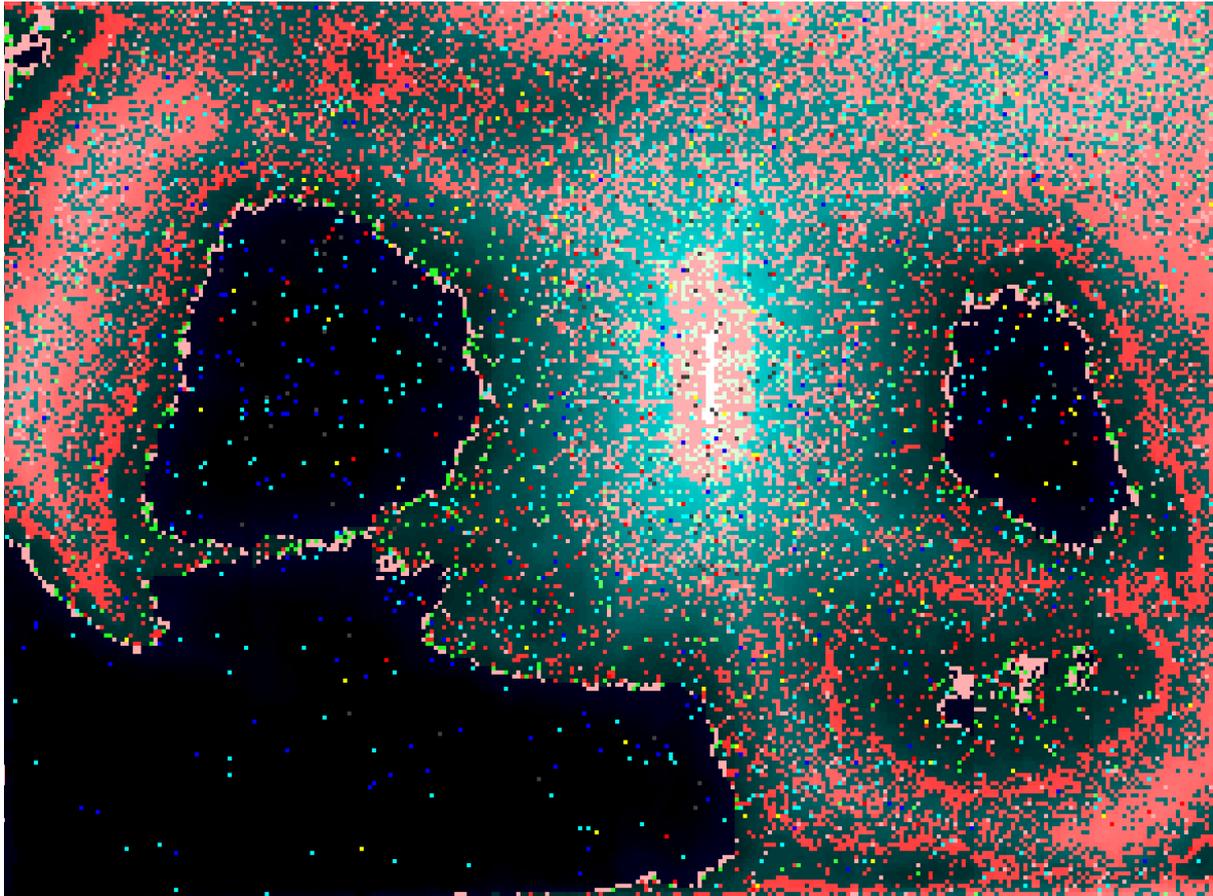


Figure 7: ELF Dynamic System with higher temperatures. Very dark blue areas represent areas under water.

#### Flora

There are three types of plants in the simulation that each occupy their own niches in the environment. Each plant type has its own height range within which it will grow. These are relative to the water line and so change as the climate does. Plant #1 is edible to humans, plant #2 is edible to animals and plant #3 is edible to both. Plants have a certain percentage chance to grow on each tick of the simulation.

#### Fauna

There is one species of animal in the simulation. This is named 'deer' in the code but its behaviour is that of any medium-sized herbivorous species that is prey to human hunting. The deer will select a random location on the landscape that is neither snow nor water. It will then move to that spot and, once it reaches it, it will select another random location. Along the way it will eat plants if it is not already satiated and there are plants of either type 2 or 3 in its current location. This increases the animal's food level by the amount of that plant in the location, up to a maximum. Each movement will expend energy, which in this simulation just decreases an animal's food level. Each animal has a highly abstract food value of 0-255 and if an animal reaches 0 food level it dies, leaving a black dot to indicate its decomposing corpse.

#### Humans

Within the simulation, humans behave a bit like deer in that they select random points in the landscape to move to, eating along the way if required and food is available. Humans can either eat plants of type 1 or 2, harvest marine resources if in a water location or will attempt to kill a 'deer' if they are in the same location. Humans start with a poor chance of killing a 'deer' but each success

will increase this chance. Like animals, each movement will expend energy, and also like animals, they have a maximum food level of 255 and will die if their food level reaches 0. The humans are coloured depending on which food they have recently eaten most of, yellow for plants, red for animals and blue for marine resources. This provides an easy indication of changing human behaviours.

#### *In use*

When the ELF Dynamic System is running, it commonly starts out as a stable system that the user can play with by rearranging the sand to create different patterns of plant growth. Initially there is no water and little snow at the highest areas of the landscape. This allows users to become familiar with the system before introducing climate change to show how this effect the system as a whole. Once the operator increases and decreases the temperature, the users can see that the plant distribution changes which then affects the humans and animals. The system is a complex system of feedbacks in which changing one thing affects the others, thus providing an opportunity to observe complex interactions between agents and a changing environment.

#### *ELF Activity Traces*

The second simulation, named ELF Activity Traces, is intended to demonstrate the different techniques required to investigate a submerged landscape of hunter-gatherers and to show how different proxies can give radically different impressions. This, like ELF dynamic system, is a highly simplified simulation designed as a starting point for discussion. It comprises of three subsystems:

- Biomes
- Humans
- Investigation techniques

#### *Biomes*

ELF Activity Traces splits the landscape up into different biomes based on set level boundaries in the code. Like ELF Dynamic System, the temperature can be changed by the operator which increases or decreases the height boundaries for each biome evenly across all biomes. The biomes can be seen in Figure 8 as different colours, with snow as white and water as blue, as in the previous simulation. Aside from snow and water, which can be traversed but not settled or used to find food, the biomes are there to indicate different environments but do not specifically related to specific, real world, environment types.



Figure 8: ELF Activity Traces. Different biomes are represented by blue (water), white (snow), and yellow, bright green and dark green (abstract terrestrial biomes). Red dots represent humans and black squares represent settlements.

### Humans

Humans can be seen in red on Figure 8. A set number are generated and they then find an appropriate settlement to live in, shown as black outlined squares in Figure 8. A settlement is associated with the biome that it occupies and humans living in that settlement can only support themselves from that particular biome. Thus, when the climate changes and the area around the settlement changes biome, the people can no longer support themselves where they are and move to a more suitable settlement. If a settlement has no inhabitants it disappears, being replaced by a randomly generated settlement elsewhere on the map. If there is demand for a settlement of this type, humans will move to it and it will flourish, otherwise it too will disappear and be replaced.

This pattern of biomes, humans and settlements is merely present to generate a landscape that has activity and that changes over time depending on the climate. This activity results in traces being left in the environment that can then be examined by several investigation techniques.

### Investigation techniques

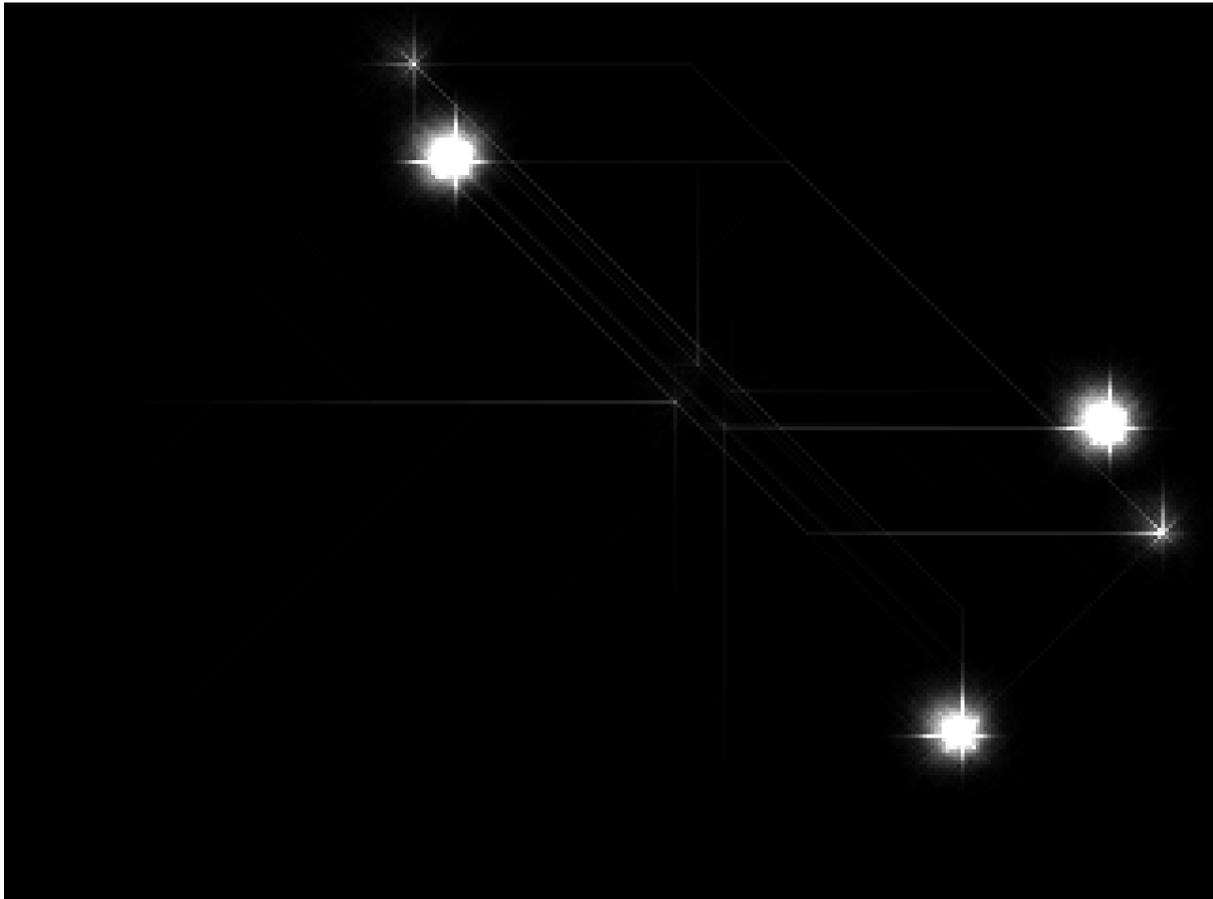
There are three investigation techniques in ELF Activity Traces:

- Soil geochemistry
- Pollen
- Magnetometer survey

It should be stressed that these work in a very simplified way compared to their real-life counterparts and their primary purpose is to illustrate how different the data from Doggerland can be and how fragmentary its nature is.

### Soil geochemistry

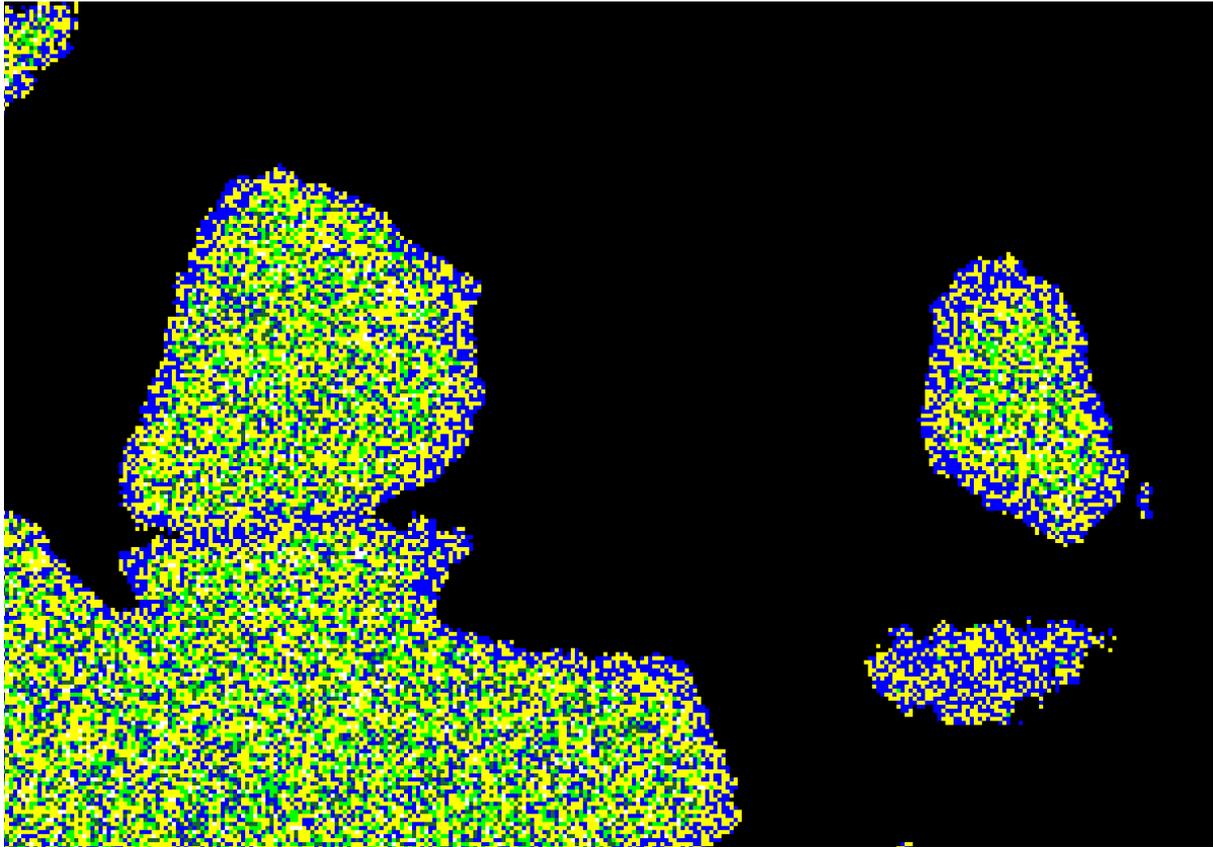
The Europe's Lost Frontiers project's environmental analysis segment includes the analysis of the geochemical components of the deposits contained within the core samples. This has the capability to detect certain markers of human, animal or plant activity. Within this simulation it stands as a representative of any technique that can detect traces left behind by any kind of activity. When displayed, it shows an activity heatmap for the landscape (Figure 9), showing which areas are likely to preserve evidence of activity. As can be seen, the areas around settlements have the highest density of activity but certain pathways between settlements are also used by humans travelling between settlements in the process of changing their home base.



*Figure 9: ELF Activity Traces, soil geochemistry data. Lighter areas represent areas of higher human activity.*

### Pollen

Pollen data preserves best in wetland environments. To reflect this, the pollen view shows the areas that have been inundated at some point with a representative sample of the biomes in the area during the period that the area was under water (Figure 10). This preserves some data about the environment but no data regarding the human activity, unlike real pollen data which may contain markers indicating the nature of human changes in the landscape.



*Figure 10: ELF Activity Traces, pollen data. Black areas have no surviving pollen data. Coloured areas represent the biomes represented in the pollen in that particular cell.*

#### Magnetometer survey

Magnetometry is a form of geophysics that detects changes in the magnetic properties of the ground. This is commonly used in archaeology to detect buried features such as brick walls and hearths which have a high degree of contrast with the underlying geology. For this reason, the magnetometer survey view shows the settlement sites standing out against a background related to the terrain (Figure 11).



*Figure 11: ELF activity traces, magnetometer data. Black dots represent the locations of all settlements, former or current. The background is a greyscale representation of the landscape.*

#### In use

This simulation offers a rare opportunity to see simulated human activity and switch between that and the results of three different types of archaeological landscape survey. It also highlights some deficiencies in survey techniques. The settlements visible in the magnetometer survey give no indication of whether they are populous and long-lived or transient. This information is more apparent in the soil geochemistry view, but the more transient settlements do not show up well at all in this view. The natural environment is much more visible in the pollen view but although this is a good record of the presence of wetlands, it is quite hard to reconstruct a full environment from this data.

These different types of survey are obviously drastic oversimplifications of much more complex techniques, but the basic message is that the more proxies that are available, the more of a complete picture we get of the landscape. The drawbacks in one technique may be mitigated by the strengths of others. Nevertheless, all these techniques put together are insufficient for anything other than a blurry reflection of the original system.

#### Discussion

Dissemination to experts and the general public. The problem of forcing 4D data into a 2D format.

The ELF AR Sandbox occupies an unusual position related to the challenges of dealing with 4D data in an academic landscape that is still more focussed on producing, disseminating and rewarding 2D outputs. The outputs of the Europe's Lost Frontiers project will include monographs, along with articles in academic journals. These formats are two-dimensional, consisting of static words and

images on paper, and increasingly, on computer screens in very traditional formats. The 4D data and processes used within the project's computer simulations are difficult to convey in the 2D environment of traditional academic publications.

Yet these 2D traditional academic publications are the most valuable output for gaining credit for research, whether from universities, peers or funding bodies. Journal impact factors are important but instant impact on the general public that fosters the understanding of research is so far untracked.

4D environments like the sandbox provide a 4D method of explaining 4D data. Using narrative and diagrams to describe the interactions of a system that involves plants, animals, humans, terrain and climate can lead to results that are verbose, difficult to understand and, to put it bluntly, boring for many audiences. The sandbox creates a low-friction interface into a 4D world that requires no instructions and little explanation. As of yet, plenty of people have failed to understand how the sandbox was created or the specific data values used in the simulation, but no one has failed to understand the basics of how it works. They put their hands in, move the sand, see the changes and they almost automatically know how to change the simulated world in front of them.

### Reception

The sandbox has been used at a variety of different public events, including:

- EU STEAM Researchers night
- Edinburgh Science Festival
- British Science Museum Lates at the Bradford Museum
- Various University of Bradford Open Days

There has always been great interest in the sandbox, with few opportunities for a rest for those manning the sandbox during public events. Children so young they have had to be dangled over the edge of the box by their parents have loved playing with the coloured sand. More mature participants are interested but usually want to know why we are presenting the sandbox at a particular event. This leads to a brief overview of the project and why we use computer simulation to examine Doggerland. This then allows participants to proceed in whichever direction they are most interested in. Some focus on Doggerland while some are more interested in the sandbox itself. Teenagers often recognise the Kinect and claim to have one themselves.

The sandbox initially had a mechanism by which the software stopped after 15 minutes and had to be restarted. This was quickly rendered redundant from a software development point of view but was kept in the version taken to public events as children, especially those around 8-12 years of age, had a tendency to play with the sandbox seemingly endlessly, and the stopping of the software provided a natural break for them to turn their attention elsewhere. It also enabled the simulated world to be reset, avoiding it heading off in any non-typical directions.

Media interest has resulted in photos of the sandbox on the Royal Society's social media accounts, an appearance on the Naked Scientists podcast and an article in Bradford's local paper, the Telegraph and Argus. The sandbox is used in both undergraduate and postgraduate teaching as part of lectures and seminars on archaeogaming and treating landscapes as four-dimensional objects.

Our main aim for constructing the sandbox was to use the sandbox to explain the computer simulation aspects of the project but it has actually proved to be a useful starting point for discussing all aspects of the project. As it contains technology, visualisation, an archaeological context, a changing landscape and an inundating world it has aspects relevant to all work packages within the

project. This was to a certain extent unintended, but it has been a welcome outcome of the AR sandbox programme. It engages more visitors as it allows an introduction to speak to the sandbox operators about any aspect that they find interesting. Although the sandbox was designed with a specific purpose in mind, members of the general public feel free to use it as a springboard to talk about issues that they are personally interested in. As computer simulation becomes a more common component of a variety of disciplines, this has wider implications for science communications. The fact that publicly accessible simulations can allow an element of flexibility in how users engage with them, developers of those simulations may find that the aspects which they find of most interest are not those in which the public is most interested. This has advantages and drawbacks that would require a separate study to fully explore.

## Conclusion

For a cost of around £600, the sandbox has proved to be a popular way of engaging with the general public and talking about the project. With a project that touches so many areas including environmental archaeology, the Mesolithic, climate change, computer science and data visualisation, the ability to present a visually interesting exhibit which allows conversation to digress into any of these areas has proved very successful. It has enabled the project to be present at public events that we otherwise would have nothing to show at. It has enabled us to have short discussions about topics whose direction is to a great extent determined by the interests of the user. These discussions have taken place with hundreds of members of the general public and counting, and have allowed us to present the work of the project, the university and the ERC in ways that are user-led and easily digestible.

## Acknowledgements

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