# Welsh Mathematician walks in Cyberspace

## (the cartography of cyberspace)

extended abstract

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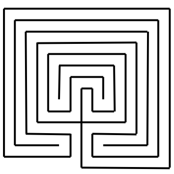
## ABSTRACT

This talk examines some models of 'space' and things in space drawing from diverse areas: mathematics (my first love), architecture, cognition as well as those developed specifically for VR; and shows how these impact and inform virtual space. Also important is the human geography of virtual space and the Internet which has been particularly important to me recently with my company hat on – mapping the interrelationships between communities of users and service providers in the Internet (we call it market ecology). This is in turn related to recommender systems, virtual communities and e-commerce. Models of 'space' from physics are not the same as those from our day-to-day experience, and neither has stayed constant through time. cyberspace challenges these models more fundamentally still, not just virtual reality, but all forms of mixed reality, mobile and ubiquitous computing. By understanding some of these models of space we may be able to better understand and better design the space of tomorrow.

## Keywords

Cyberspace, virtual reality, hypertext, web navigation, space, maps, mathematical models, mazes, myth, magic.



## Space the final frontier

Far from family and familiar things, far from home and country, Vietnam PoWs swapped stories, not of wives and children, or of childhood memories, perhaps these things seemed too close. Instead, half-remembered episodes of Star Trek were pieced together. As well as the most famous split infinitive of all, the opening words evoke links between the vast emptiness of space and the opportunities of the North American plains. Whereas the wildness of the latter is now fixed in a matrix of mile-square lots and grid roads, the former still stands untamed and unending.

Although it was the wildness and endless continuance of outer space that lent mystery to these early series of Star Trek, more recent incarnations: New Generation and Voyager have explored the deeper mysteries of space and time itself. Along with other science fiction writers, parallel universes, bent space-time, wormholes and bubbles in time have been investigated and explored. But more pertinent and perhaps even less comprehensible, has been the interrelation between the physical world and the digital: transporter technology that shifts matter into bits and back again – allowing mixing, duplicating and loss of identity; holodecks that allow cyber-reality to impinge on physical life; and beings inhabiting the electronic world, robots and digital images, becoming sentient and touching humanity at an emotional as well as at a physical level.

Looking back through history, our models of space and time are not fixed, but have changed as knowledge, society and technology have shaped human models of reality. Maps dating back four millennia capture the world on paper, ancient Egyptians built pyramids with embedded three dimensional passage ways and used complex geometry for feats of civil engineering that still cause wonder today. With the Greeks we see the formulation of 2D Euclidean space, perhaps space as we know it, but also with the Greeks the first evidence for a curved earth, destroying the perfection of flatness and denying the universality of "up". Possibly even this physical reality of space has not entered our subconscious understanding of space, let alone 19$^{th}$ century discoveries of alternative geometries and modern understanding of curved space–time.

## Information and cyberspace

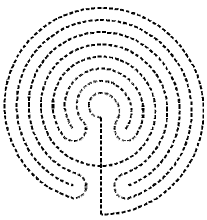
More dramatic than these scientific discoveries has been the effect of society and technology. The world for a Roman citizen was far different than that of a Pict or Goth beyond the borders of the Empire, and their knowledge different than it would have been had the Roman Empire not existed. Sea travel, the telegraph, flight, the telephone and television have all reshaped our fundamental understanding of who we are and how the world fits together. It is not simply that we know more of the world, but that the world we know is different.

Both organised society and technology have reshaped the world, not because, like a potter, they have moulded the fabric of space, but because they offer information. To this extent all these geomorphic effects are cyber-realties – the world having existence through information not through mere substance. As we struggle to create cyber-technologies for work, pleasure and collaboration, we need models of space, things in space and the way we inhabit space in order to make sense of our experiences and create worlds that are meaningful and useful for those for which we design.

## Linear space – threads through the labyrinth

Perhaps the simplest model of space is a straight line. Although this sounds a little too simple, it is surprisingly close to the truth. When shopping in a department store, a colleague of mine will walk around turning this way and that, up and down escalators, and then, when she decides it is time to leave, she will simply turn round ... even when the doors are immediately in front of her. Although this is a source of friendly jokes, it is also a very sensible and rational strategy. The department store is a highly complex space with few long vistas, full of complex angles and of course fully three dimensional with lifts and stairs. In such an environment the simple rule "go back the way you came" may not be optimal in all circumstances, but is usually far quicker than apparently more 'rational' approaches.

Following a trail backwards is a powerful method in other complex spaces – Ariadne gives thread to Theseus so that he can find his way back out of the labyrinth after defeating the Minotaur; Hansel and Gretel leave bread crumbs to mark their way through the forest; explorers blaze the jungle tree trunks with a machete to mark their passing.



In fact, some quite complex spaces are simply linear. Many early mazes and labyrinths follow a single path (Fisher [1990] calls these unicursal). Even simpler is the spiral, which has been part of primitive art since the earliest times (about 2000 BC in Egyptian art [Mackenzie]). Although perhaps too simple to be called a labyrinth or maze, it too is traditionally a focus for puzzles and confusion. When King Minos is trying to trace Daedalus (who designed the Minotaur's labyrinth), he sets a puzzle to thread a seashell, which Daedalus solves by tying a thread to the leg of an ant, thus revealing himself.

The virtual information space of hypertext and the web is no less complex with tortuous paths, dead-ends and poorly signposted junctions resulting in the well known 'lost in hyperpsace' problem. It is not surprising that the 'back' button is the most widely used form of navigation after simple link clicking [Tauscher and Greenberg, 1997]. Indeed, many of the same techniques used by jungle and maze explorers are used in the web: colouring of links is like the blazing of trees, the 'Go' menu or history list gives the equivalent of Ariadne's thread, recommender systems [Resnick and Varian, 1997] are like well-trodden paths. However, these different trail laying methods (thread, crumbs, blazing) have slightly different properties, especially when the trail crosses itself.

Consider the path in figure 1. If you are following thread this is no problem, but if you use crumbs or stones to mark the way, you may have problems. You start at X and want to get to Y. You follow the path from X through A to B leaving a trail as you go. When you get to B you don't know which path to take, so follow the left-hand path, which takes you to C and then D (i). At D you cross your own trail, and turn left again (ii). Eventually you get to Y (iii). You then need to get back home to X, so you turn round and start to pick up your trail (iv). When you get to B you go straight on, but of course a double trail of crumbs is just the same as a single trail and so you pick up all the crumbs, leaving no trail behind when you get to A (v). At this point you have a choice of trails and turn right (vi). You follow the trail back through D and C to B again (vii), but now there are no crumbs left and you don't know which way to turn (viii).

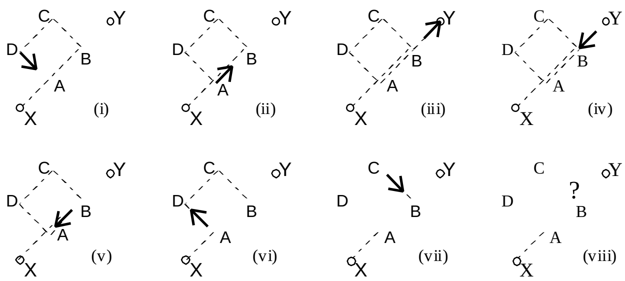



**Figure 1.** picking up crumbs

Although this is a somewhat convoluted path, it is precisely what happens when you revisit the same node in a hypertext. Sadly, when the back and history mechanisms in several hypertext, help and web browsers were being formally modelled, it was discovered that most had confusing behaviour when nodes were revisited [Dix and Mancini, 1997]. In particular, two systems had precisely this 'picking up crumbs' problem. In one the history path after visiting the nodes X-A-B-C-D-A-B-Y in that order is in fact X-C-D-A-B-Y, removing 'old' duplicated entries. In another (HyperCard 'recent' card), the history after the same journey is X-A-B-C-D-Y. In other systems the history list has a finite size so the trail disappears after you follow it back for a while. This is rather like Hansel and Gretel finding the crumbs had been eaten by birds.

## Symmetry of movement and one way streets

In natural physical space if you can get from A to B, you can also usually get from B to A. Sometimes it is harder one way than another (e.g. if A is the top of a mountain), but usually possible. This symmetry of movement we take for granted until it is broken. In particular, it makes it possible to explore options in a speculative fashion, knowing we can always step back and try another way.

In constructed spaces we often lose this symmetry, in particular many cities have one-way systems which mean that it is impossible (legally) to turn around and go the other way. Just like mazes your destination may be very close, but may you have no idea how to get there, or how long it will take. Not surprisingly, many people find one-way systems confusing and disorienting.

Whereas in physical space we need to work hard to establish asymmetry (by laws, turnstiles, valves etc.), in virtual space we have to work in order to ensure it. Some hypertext systems do make all links symmetric and standard design advice for the web or any hypertext is to have links that enable users to find their way back to 'higher level' pages [Yale, 2000]. Whilst this is possible within a single web site, we of course have no control beyond its borders. Formal link exchange schemes and informal contacts mean that many sites do mutually reference one another (there are over 40 'web rings' about dragons alone [ExistingPhantom, 2000]). However, one cannot normally expect to be able to get back once one has followed an external link.

The browser's 'back' button and history mechanism can be seen as a way of restoring the symmetry of virtual space allowing movement backwards as well as forwards, although only insofar as they are comprehensible and predictable.

## Maps and landmarks

In some ways maps represent an objective view of the world (although what is and is not included is far from objective). If you ask people to draw a map of a well-known town, it is unlikely that their map will reflect that of the typical cartographer. Most often the map will consist of patches resembling the 'proper' map, linked via main streets or landmarks, but the relative orientations of the individual patches are apparently arbitrary. The landmarks effectively establish a personal orientation more significant than that of global compass directions. Similarly, tourist maps, designed for non-expert map-readers, often include small pictures of crucial landmarks. Ask someone directions, and the explanation is littered with references to pubs, cinemas, or shops.

Likewise in cyberspace establishing landmarks to which people can return, or can use for navigation is essential. Home pages in hypertexts and webs partially satisfy this role (although this is a bit like walking round a town where the only landmark is the town-centre cross).

## Mathematical models

For over 2500 years mathematicians have analysed and modelled space. Euclid has already been mentioned, and we still talk about Euclidean space. Descartes also gave his name to a model of space and the arbitrary, but universal orthogonal Cartesian co-ordinates have been one of the most powerful tools in the physical sciences. It took many years before Euclid's models of flat geometry were challenged with various forms of non-standard geometry: spherical geometry (positive curvature) – the geometry of an orange skin, and hyperbolic geometry (negative curvature) – the geometry of a curly-leafed cabbage.

These are not simply mathematical abstractions, for example the flight paths of the planes that bring delegates to CVE2000 will follow the dictates of spherical rather than flat Euclidean geometry as they take great circle routes across the earth. Perhaps stranger is the discovery that gravity makes space and time curve in a hyperbolic fashion meaning you age faster on the top floor of a building than on the bottom. Non-standard geometry has even found its way into commercial software with the hyperbolic browser developed at Xerox Parc [Lamping and Rao, 1996] and marketed by Inxight.

Although 3D visualisation and virtual environments are often heralded as offering natural ways of understanding and manipulating information, it is important to note that we are:

(i) good at seeing meaningful 3D objects like people

(ii) but poor at more abstract ones like spheres and cuboids

(iii) experienced at moving our hands and bodies in 3D

(iv) but only used to walking and navigating on 2D ground

Walking in 2D we make use of the Poincaré property of flat worlds – if you keep on turning left you eventually cross your own path or spiral in or out for ever. 3D space has no such property.

A different strand of modelling has looked at properties of the world unchanged by stretching and moulding. Metric spaces and topological spaces (sometimes regarded as the geometry of the rubber sheet), formalise worlds where distance is less important that connectivity and continuity. In a world where you may enter a chat room with friends from other continents, but hardly speak to the family next door, perhaps this has lessons for us.

Hillier's models of architectural space, in buildings and cities, share some of this topological view of space – connectivity, not distance [Hillier, 1996]. What rooms look into what other rooms? How many road turnings are there between point A and point B? Similarly, the awareness models of Benford et al. [1995] and the related graph-based awareness model of Rodden [1996] make use of some of the metric or topological properties of space, but intermingle this with issues about the mutual foci of the participants in collaborative virtual environments.

Tom Rodden, others at Lancaster and I have also been working to create computational models of space, suitable for constructing mobile and ubiquitous systems, based on these and other models of space [Dix et al. 2000].

## Time and space–time

Although I started this abstract with Star Trek, for me as a child the defining science fiction, and formative influence was Dr Who. I was so pleased to see Dalek's on the CVE2000 web site! At a social level, Dr Who is a technologist, who doesn't just wear round wire spectacles and a white coat (although the first Doctor was very much the aged professor), but is also the protagonist and hero. There are few positive role models for academically inclined boys (and perhaps fewer still for girls). At a scientific level, Dr Who's Tardis travelled through time and, by the distortion of space–time, was bigger in the inside then on the outside. Despite this apparent global strangeness, locally, at the Tardis' door, there was a seamless transition between the spaces. In modelling curved space, mathematicians have found it useful to cover the space with a series of near-flat patches with smooth transitions between them. For cyberspace also, we can aim to have easily navigable realistic parts, with smooth transitions between them. It can be possible to sacrifice global consistency so long as the local virtual space behaves as expected.

It is not surprising that I have found the interplay of time and space fascinating as I have examined the visualisation of 3D and dynamic structures [Dix, 1996a]. If you consider static paper and dynamic electronic visualisations, we again and again see time mapped onto space (e.g. time–distance graphs) or space mapped onto time (e.g. a moving cross-section through the visible human body). In fact, at a previous keynote at a conference on visualisation, I examined the consequences of considering non-visual senses, sound and sound, and how aural and nasal interfaces give different 'cuts' through space–time [Dix, 1996b].

In the cyber-world, space and time are also more confusing. In physical space, at the distances we usually work, light travel is effectively instantaneous – to work side-by-side with someone establishes simultaneity of experience. In contrast, a virtual world may involve network delays so that the person controlling the avatar next to me sees an event seconds before or after I do.

## Myth and magic

In Welsh myth and folk tale the boundary between the physical and the 'fairy' realm is quite thin and the two co-exist. In contrast, in many mythic systems the two are very distinct (e.g. the Greek Pantheon on Olympus). As a parallel to experiences in cyberspace, the Greek model is rather like traditional VR – you go into a special place, don the 'sacred' clothing (VR goggles, gloves etc.) and then 'enter into' another realm. The Welsh model is more the experience of ubiquitous computing, augmented reality, tangible bits etc. with continuity between the physical and the digital.

In general magic worlds may be a better model of cyberspace than the physical world. If we are to leverage the power of computational environments, then simple realistic environments may be too impoverished. If the shape of the world and things in it change dynamically, then metaphors of physical reality only confuse, whereas magic makes this comprehensible. Note however that magic worlds are not arbitrary worlds, but have their own order and logic and, in particular, are predominantly like 'normal' reality, differing only when magic 'happens'. This means it is important to maintain a deterministic ground, a base of fixed and comprehensible aspects of the space.

## Things

Physical entities exist at a single location at any moment of time. Virtual entities may exist at several locations (copies of a file on different computers) and may even cease to exist for periods. Many of the attributes of a physical entity are fixed or continuously changing, whereas a virtual entity may change suddenly and totally (the file that was a letter last week is a memo this week). To see parallels of this we need only look again to the world of magic – the frog prince, one moment a frog, the next, after a single kiss, a handsome prince! The virtual world often seems to bear a closer resemblance to this than to physical entities.

## People

In magic worlds it is often people who define the structure of things, opening doors between places, times and worlds. Similarly one of the lessons of special relativity is that space and time are not global absolutes, a continuum through which we move and exist, but instead are things that we carry with us, only acquiring common meaning as we interact with one another. Think too of places that seem 'close' to you. Are they the things at hand as you read, or are they places associated with events in your life and with people you love. Cyberspace is also defined as much by people as by its own internal structure. At aQtive we have been mapping the interrelationships between groups of customers on the Internet, which we call 'market ecology'. Recommender systems establish a metric on the world that measures distance not by absolutes, but by common interest. On your desktop, network locations are brought close by your whim and beckoning.

Space is no longer what it is, but what we wish it to be.

May we wish well.

## More …

For a more references, a more detailed time line, copies of slides from the talk, etc., please look at:

`http://www.hiraeth.com/alan/topics/cyberspace`

For more on magic as a metaphor and similar bits and pieces

`http://www.magisoft.co.uk`

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## models of time and space – a short timeline

| | |
|---|---|
| Egyptians | pyramids – complex planned 3D structures<br>surveying geometry |
| Bible | a day is as a thousand years |
| Zeno | paradox - discrete time/space |
| Euclid | axiomatisation of 2D "Euclidean" space |
| Eratosthenes (and others) | ancient Greek round earth measurements, challenges preferred 3D direction |
| St Augustine | timeless God |
| various folktale | magic hills – worlds within hills |
| various | missed time stories, Ossian, Rip Van Winkle etc. |
| Mabinogion | parallel faerie world |
| mediaeval | early distance time graphs |
| Columbus | round earth |
| Copernicus, Galileo, Newton | no fixed centre |
| Descartes | universal but arbitrary coordinates |
| measurement | standard units, standard time,<br>longitude/latitude – 'global' coordinate system |
| Poincaré and others | topology, metric spaces – 7 bridge problem |
| Bolyai and Lobachevsky | non-standard geometry – Euclid's flatness gives way to curves |
| Einstein – special relativity | no universal Cartesian time/space, the "interval" |
| Einstein – general relativity | non flat time/space, differential geometry |
| recent | many worlds hypothesis, parallel dimensions, "hyperspace" |
| modern folktale | Star Trek, Dr Who |