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A Space Syntax Analysis of the Earth's Oceans

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ABSTRACT

To test if space syntax can be applied at a geographical scale we drew an axial map of the earth's oceans in which great circles were substituted for lines of sight. We found that axial line lengths were distributed hyperbolically so that the map was scaling. The oceans are better served with long-range connections than any city is by roads illuminating Buckminster Fuller's model of the earth having a single ocean. An estimate of how polar melting will change the connectivity of that ocean was made. Our analysis helps explains why long sea journeys seemed so daunting before good maps were available making Columbus's achievements all the more impressive.

INTRODUCTION

Our Space Syntax 6 paper, *The Double Fractal Structure of Venice*, compared axial maps of streets and canals in Venice, (Crompton Brown 2007). Having, so to speak, allowed space syntax to leave the shore it seemed a natural question to ask, what would happen if the second map were extended from the Venetian Lagoon into the Adriatic and then to all the oceans of the world? We here present that extended map.

An axial line can be drawn along a canal as it can along a street provided its edges are bounded by buildings, but what counts as a route in open water? In the past sailors sailed between landmarks close to the shore but since we do not know what these were this historic study remains to be done. Our strategy was to treat the oceans as convex zones connected by great circles these being the shortest distance between two points on a sphere and the equivalent of a straight line on a plane. Our map was not influenced by established shipping routes and took no account of the location of ports. Its shape was a function only of the shape of coastlines. Nevertheless this geometrical exercise did tell us something about how the world is connected, as will be seen.

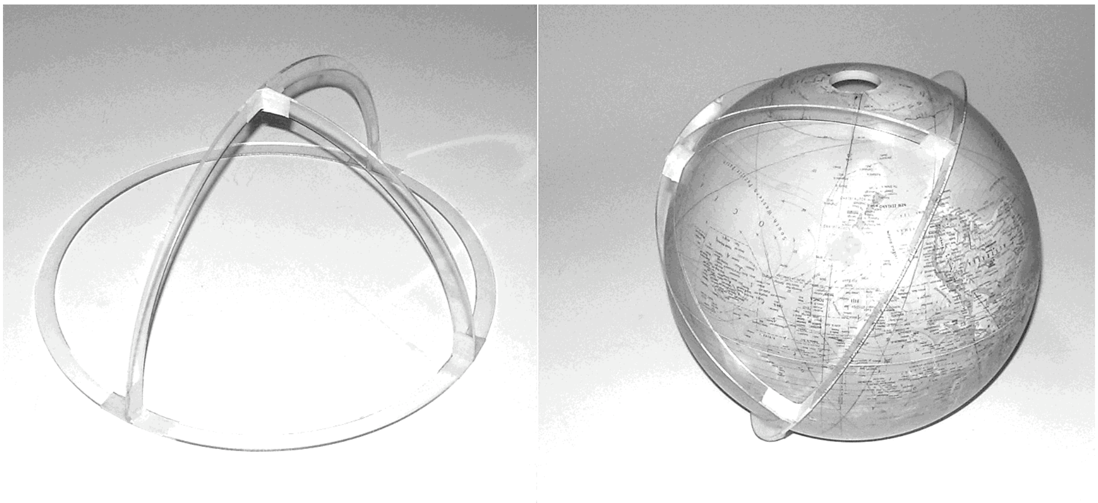

FIGURE (1) Photograph of globe and cradle used to draw the axial map.

METHOD

Our map was drawn in pencil on a school globe whilst consulting the *Times Atlas of the World*. Lines were constrained along great circles by an acrylic cradle shown in figure (1). Their end co-ordinates were entered into a spreadsheet where their lengths were calculated using the Vincenty formula. For complicated regions such as the Mediterranean, Caribbean and South China Sea, it was more accurate to work on photocopies of maps provided that long lines entering these regions had first been drawn on the globe. Lakes and inland waterways were ignored except for the Suez and Panama Canals. Two versions of the map were prepared, the first with lines ending on winter ice in the Arctic and Antarctic, the second for a world with no sea ice. We treated the oceans as a single space broken into convex zones by features such as island chains like the Aleutians or by landmasses approaching each other, like Africa and South America defining the North and South Atlantic. Axial lines were drawn to join these zones in the usual way. We ignored islands smaller than Iceland except in the Mediterranean which was studied in greater detail because of its connection to Venice. For this reason the Mediterranean was analysed separately from the rest of the oceans.

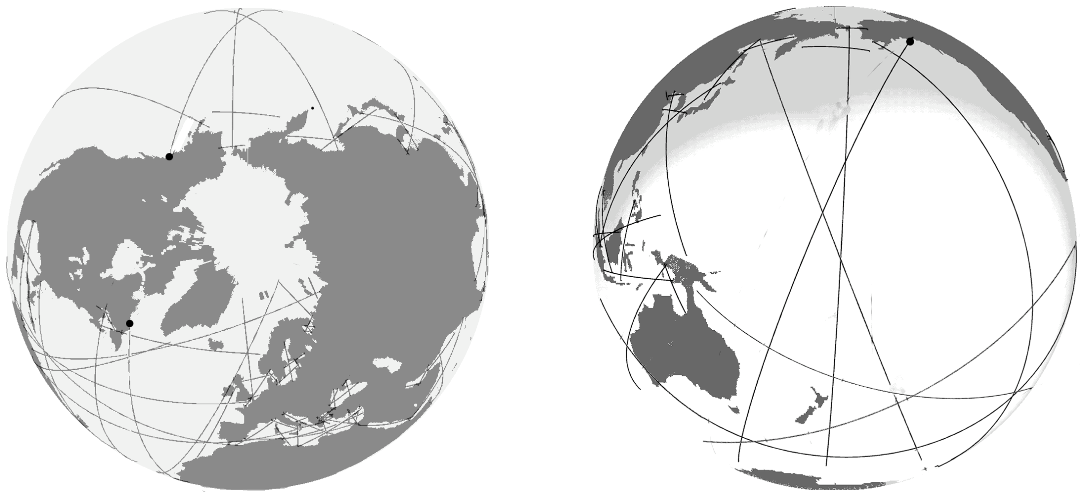

FIGURE (2) Axial maps, (orthographic projection), with the longest circle marked with dots.

RESULTS

Our map had 128 lines, 30 of them in the Mediterranean. It was redrawn as a 3-D model in VectorWorks. A rendering of it looking down on the North Pole is seen in figure (2). The longest line we could find goes from Newfoundland to the Gulf of Alaska en-route making glancing contact with Senegal, Antarctica and Tasmania. It is 36,350 km long, 90% of a complete great circle, and is marked with dots in figure (2). Although it is seldom mentioned axial maps have a kind of beauty perhaps because they economically evoke a trace of familiar shapes such as city plans. In our map the shape of the Mediterranean could be recognised in thirty lines.

DEPTHMAP ANALYSIS

Steadman (1983), considered the possibility of an axial map on a sphere, although he did not show how to analyse it. Rather than reconstructing Space Syntax on a sphere from first principles we chose to turn our map into an equivalent pattern of straight lines that could be analysed by Depthmap. An exact conversion of great circles to straight lines is impossible because circles can cross each other. Our approximate method imagined that the surface of the earth had been peeled off from a hole in the Pacific and stretched flat replacing circles with straight lines intersecting with the same lines as they did on the globe insofar as this was possible. In the distorted Pacific region some extra lines had to be introduced to retain the continuity so the process was topologically accurate only for the lines close to the Mediterranean. Adding five extra lines in different ways to the distorted perimeter of the hundred-line map tested the influence of this approximation. We found that doing this made no difference to the results of the Depthmap analysis for the areas of interest, namely the North Atlantic and Mediterranean regions where the connectivity of our planar map was correct.

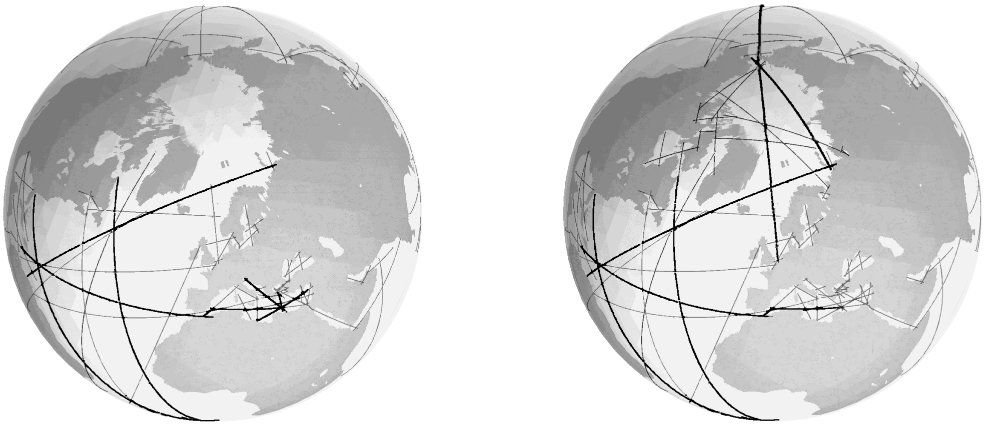

FIGURE (3) Axial maps of frozen and unfrozen arctic compared. Top 10% fast-choice lines highlighted.

Axial maps for a world where lines end on winter sea ice and for an ice-free planet are shown in figure (3). Comparing them we can get some idea of how connections between oceans might change if global warming opens the Northwest Passage. The highlighted lines show the 10% most frequently used lines on shortest journeys found using the Depthmap Choice algorithm. When the Arctic Ocean is open routes around Africa either via the Cape or through Suez are joined by routes to the Far East via the North Atlantic. A connectivity map, (not shown here), indicated that when the Arctic melts the most connected lines in the Mid-Atlantic and Mediterranean through Suez are joined by a line across the Arctic at the expense of the Cape route to Asia. Whilst this is hardly surprising it is reassuring to see that what Space Syntax tells us agrees with common sense.

SCALING IN THE AXIAL MAP

We found that the distribution of lengths of axial lines was scaling over the range 500 to 20000 km for oceans outside the Mediterranean. If axial lines are ranked in order of length, l metres, with the longest having rank r = 1, then a Zipf plot of log (l) against log (r) will be a straight line if the lines are scaling. Figure (4) superimposes Zipf plots for (i) streets in Venice (ii) canals in Venice, (iii) the Mediterranean, (iiii) the rest of the oceans. In these graphs points on the left represent long axial lines.

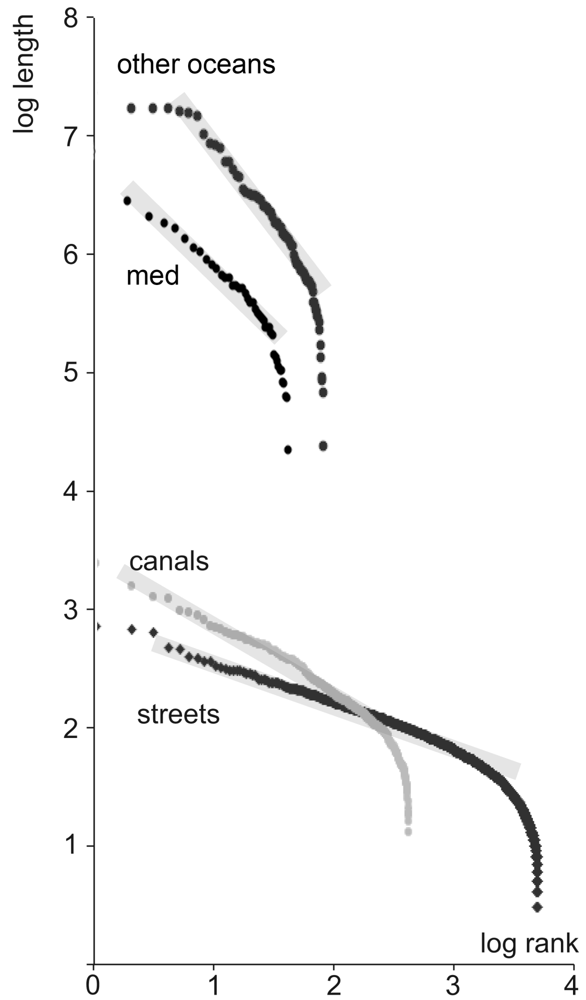

FIGURE (4) Zipf plot of axial line lengths in metres for (i) streets in Venice, (ii) canals in Venice, (iii) the Mediterranean, (iii) rest of the world.

In the shaded regions of figure (4) log (l) and log (r) are linearly related, so:

$$\log(l) = -(1/a)\log(r) + \text{const.} \qquad [1]$$

-1/a is the gradient, so expressed to match the notation of Carvalho & Penn, 2004. If $Pr(L > l)$ is the probability that a random variable L is bigger than l it follows that:

$$Pr(L>l) \qquad = \text{const. } l^{-a} \qquad [2]$$

Equation [2] has the form of a hyperbolic relationship, distributions like these are often found in nature, see Salingaros & West, (1999). The value of a is determined by the distribution of line lengths and is an intensive rather than an extensive variable. Carvalho and Penn, (2004), measured the value of a for thirty-six cities and discovered that there were cities for which $a \approx 2$ and those for which $a \approx 3$. They hypothesised that cities with $a \approx 2$ possessed open space alignments crossing the whole city, whereas cities with $a \approx 3$ did not. The lowest values of a they found were for cities with the most extreme open structures, namely Las Vegas and Chicago.

The gradients of the lines in figure (4) show that in Venice the values of a are 3.0 for streets and 1.72 for canals. Venice can be thought of as being formed by the intersection of two scaling fractal circulation systems, a closed one for everyday life and an open one for commerce. We can now see that it joins to a third scaling circulation system, namely the Mediterranean itself.

Figure (4) gives values of a of 1.0 for axial lines in the Mediterranean and 0.66 for the rest of the world past Gibraltar. Carvalho and Penn's model tells us that oceans of the world are connected by large scale structures. The lowering of the parameter a as one goes from streets in Venice to the canals and then to the sea is a measure of the great expansion of space that occurs in making that transition. Our map had 5274 lines on land in Venice yet all the oceans in our simple map had only 128. The transition from street to canal to sea to ocean involves not only a change of scale but also a change in connectivity.

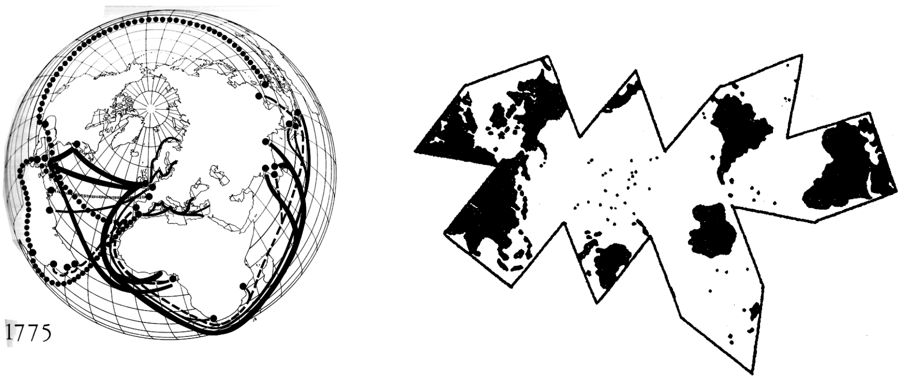

FIGURE (5) Fernand Braudel's map of world trade in 1775, (Braudel 1984, 28-9), compared to Buckminster Fuller's Dymaxion world map showing one ocean, (Mellor 1972).

An historian who acknowledged the physicality of cities in contrast to their social and political aspects was Fernand Braudel. He illustrated the Eighteenth century expansion of trade from the Mediterranean to the whole earth with curved lines, (figure 5), remarking that that the British trade network appeared to have had the world in an octopus grip. Would Braudel have reached for this predatory image had he used a map centred on the oceans rather than one centred on the land? Figure (5) compares his map with Buckminster Fuller's Dymaxion projection that maps the globe onto an cuboctahedron opened out to show all the worlds oceans connected as one, In a similar way space syntax has potential to show connections at a global scale. Applied to the oceans we see a network with emphasis, a system of possibilities. Space syntax may offer a fresh way of visualising global relationships.

WHY ARE THE OCEANS SCALING?

A complete explanation of why axial lines in a city are scaling has not been given, we believe. However if cites are fractals, (Batty and Longley 1994, 228-73), then it is plausible that a measure of them should also share this property. A similar rough argument can explain why oceanic axial lines are scaling based on Mandelbrot's observation that coastlines are fractal. Suppose a bay can be read as a convex region so that it has an axial line (Hillier, 1987). The number of bays, n, we can find of width, d, will be related to the number of steps it would take to walk round the coastline with dividers set at d. Mandelbrot, (1983) observes by experiment that n and d are related by a power law, therefore it is to be expected that the number of axial lines of length is related to their length in the same way.

CONCLUSION: THE BRAVERY OF COLUMBUS

Hyperbolic distributions lack a well-defined average. For distributions with values of a that are close to unity, as with Mediterranean line lengths, the average depends upon both the upper and lower limit of line lengths that we are willing to consider in calculating it. Sailors who spent their life in the Mediterranean could conceivably develop a sense of the distribution of axial line lengths and know that the probability that the length L of the line they were following was longer that l is given by

$$Pr(L>l) = const. (1/l) \quad [4]$$

This hyperbolic distribution has a long tail and is far from Gaussian. It has no centre or average value beyond which high values become vanishingly improbable. There is always a finite probability that very long lines will occur. Let us put ourselves in the minds of the experienced sailors who crewed Columbus's ships. If they had an intuitive grasp of the distribution of axial line lengths in the seas they knew then they had very good reason to be fearful when their journey past Gibraltar did not quickly find land. Their fear was not founded in superstition but on common sense founded in experience.

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