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Embracing the "Tyranny of Distance": Space as an Enabling Constraint

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Abstract

Architectural design is typically limited by the constraints imposed by physical space. If and when opportunities to attenuate or extinguish these limits arise, should they be seized? Here it is argued that the limiting influence of spatial embedding should not be regarded as a frustrating "tyranny" to be escaped wherever possible, but as a welcome enabling constraint to be leveraged. Examples from the natural world are presented, and an appeal is made to some recent results on complex systems and measures of interaction complexity.

Introduction

Complex natural architectures, be they termite mounds, neural networks, or patterns of lichen, are embedded in physical space. Until recently the same was true of most human-designed architectures. However, the ubiquity of this spatial embedding is such that it is often overlooked as a substantive factor influencing both form and function. This is perhaps most readily seen in the use of network diagrams to represent system organisation, where nodes are used to represent parts, and edges between them represent interactions. Rather than depict such systems with the nodes organised to reflect their spatial location, it is common to re-arrange the nodes, relaxing their location on the page in order to best convey their *logical* connectivity, at the expense of their physical organisation.

Where the ramifications of spatial embedding are considered they are often regarded as frustrating limitations on design, mitigating against freedom of organisation. Consider the job of a micro-chip designer, attempting to place a set of components on a wafer of silicon and wire them together such that the connections between components do not interfere with one another and their lengths are minimised. The job would be made slightly easier if the components could be embedded in a three-dimensional medium. A four-, five-, or six-dimensional space would relax the constraints on design even more. If no spatial embedding were imposed, the task of organising components would evaporate. More generally, the constraints imposed by spatial embeddings do appear oppressive: they guarantee that some places or people are more remote than others, that there may be a central core and a more isolated periphery, that not everyone can be together, that to change the intimacy of two parts will cost time and energy. Consequently, it is not difficult to see why escaping the shackles of space might appear attractive, especially to those somehow disadvantaged by it. Australia, for example, has reflected on its perceived remoteness from world commercial and cultural activity, with Blainey (1996/2001) coining the phrase the "tyranny of distance" to convey the challenge that nature has presented to the antipodes, a challenge that was met head on by airlines such as Qantas (Gunn, 1985; Rimmer, 2005).

In fact, some commentators have been predicting the "death of distance" since at least the end of the last century, quoting globalization, cheap travel and the world-wide information and communications technology revolution as forces capable of shrinking the world to ever more manageable dimensions. And with the advent of "virtual space" comes the possibility of dispensing altogether with the limitations imposed by the physicality of the environment, perhaps delivering something of a *coup de graĉe* to distance.

This paper argues that to dispense with distance is to do damage to a valuable source of inherent order. It is true that space must be regarded as a constraint, but it can be understood as an *enabling constraint*, one that brings about spontaneous correlation and organisation that is the fuel of complex coherent interaction.

How Might Distance be Dying?

The phrase "death of distance" is most strongly associated with Frances Cairncross (1997/2001). She has argued that the rise of information technology, telecommunications and the internet, has brought people and places closer together than ever before. As a consequence, she imagines a not-so-distant future in which geographic location will be far less meaningful in terms of its determining influence on our ability to work, communicate, trade, learn, and play with other people. Alternative phrases such as the "annihilation of distance" have also been used to express the same conviction, appealing, for instance, to high-speed transportation as a factor in shrinking the world, or common language and culture "bringing people closer together" (but see, e.g., Heidegger, 1971/2001).

But how exactly are these technological advances "killing" or "annihilating" distance? It is clear that the effective distance between locations has reduced as increasingly rapid and cheap means of transportation and communication have been created. However, this "shrinking" of the world has not extinguished distance entirely. Some places are still further apart than others. While the new effective distances are not perhaps exactly correlated with the older effective distances (just because *A* was "closer" to *B* than to *C* before the advent of British motorways, does not guarantee that the same relationship will hold today), distance can hardly be said to have been annihilated. It would also appear that the notion of effective distance must be subjective, since whether one has access to a car or broadband internet will influence the extent to which reduced distances are experienced. Consequently, while technological advances may attenuate the influence of distance, the rhetoric of destruction and annihilation seems overblown.

A second sense in which the world's distances might be side-stepped is offered by the small world notion (Watts and Strogatz, 1998). Informally, the idea can be expressed by pointing out that in certain systems all parts are in some sense close together despite each part only being directly linked to a small clustered fraction of the total system. In such small world systems, the physical remoteness of system components from one another is no obstacle to system synchronisation or agreement or co-ordination as any two components within the system are separated by only a small number of intervening components, irrespective of their (lack of) physical proximity. Interestingly, this small world concept was originally employed, amongst other things, to explain how a population of crickets distributed over a wide area might come to synchronise their chirruping songs despite the fact that each cricket is only within ear-shot of a few others. In this example, the physical distances between individual crickets was in some sense spontaneously extinguished by the effective organisation of the network representing which crickets are within earshot of each other. Despite this, the influence of physical proximity is still reflected in the organisation of this network and spatial location will determine, for instance, the nature of the transient behaviour prior to synchrony being achieved.

A third case of the "death of distance" is perhaps most deserving of the sobriquet. Virtual environments, by virtue of existing as logical rather than physical organisations, have no need to respect the constraints of Euclidian space. In particular, two of the axiomatic properties of Euclidian space can be dispensed with easily. Spatial *symmetry* demands that the distance between *A* and *B* is identical to the distance between *B* and *A*. Since links, routes and relationships in virtual environments are directed, there is no guarantee or requirement for this kind of symmetry. My page may link to yours, without yours necessarily linking back. The *triangle inequality* is slightly more involved in that it demands that a route from *A* to *C* via *B* cannot be shorter than a direct route from *A* to *C*. If *A*, *B*, and *C* do not have a spatial location and routes do not have a spatial extent, this inequality need not hold. Finally, it is also typical to consider that architectural components spatially *exclude* one another in that two objects may not occupy the same location. Again, this need not hold for components of a virtual architecture where different elements may share the exact same set of relationships with their neighbours, thus achieving indistinguishable locations within the system. Giving up spatial constraints on relationships between system elements allows for a wider design space of virtual organisations. While the fact that my neighbours live in homes that are close to mine implies that they live in homes that are close to each other, the same need not be true of our *home pages* where correlations of this type are not imposed by the medium, but may only arise and be maintained as a consequence of explicit or implicit design processes (Thrift and French, 2002).

Case Study: The Evolution of Brains

Whether or not the death of distance is actually taking place in the forms described above is a matter of some debate (see, e.g., Mejias, 2007), but is not the topic of this paper. Here we are concerned with whether the attenuation and in some cases the eventual extinction of spatial constraints on design should be taken, uncritically, to be a boon and a blessing. First, we will consider the evolution of neural systems as an instructive case study. The following descriptions draw heavily on the work of Buckley (2008).

Initially, simple multi-cellular creatures did without brains, relying on chemical messengers to achieve co-ordinated behaviour. For such systems, functional unity of the whole demanded close anatomical proximity of the parts. As the size and complexity of these early organisms increased the ability of one body part to signal to another with efficiency and rapidity over larger distances became paramount. These factors selected for a series of evolutionary innovations culminating in the kind of circuit-like nervous systems employed by higher organisms today. First, proto-neurons arose that combined chemical and electrical activity but communicated only locally via gap junctions. These were assembled into nerve networks in which sheets of such cells mutually stimulate each other, as exemplified today by some jellyfish. Subsequently, the evolution of localised ganglions of cells enabled directed point-to-point communication, and, ultimately, increasing encephalisation brought about a central nervous system built from components "wired" together by fast, efficient, point-to-point neurotransmission (Buckley, 2008).

To some degree this story offers an analogy for the development of our own communications and transportation technologies, which can also be understood to have allowed for functional organisation over larger group sizes and more extensive geographic ranges: from societies organised locally via word of mouth or the ability to readily assemble in particular significant locations, to societies governed via a network of devolved control executives linked by rapid transport, to national and ultimately trans-national organisations reliant on telecommunications, inter-continental travel and shared languages and cultures.

However, it is becoming apparent to neuroscientists that the advent of modern neural circuitry did not lead brains to give up the spatially constrained chemical communication and control systems that pre-dated neural networks. In fact *neuromodulation*, the use of such chemical signalling within the brain, is increasingly thought to play a critical role in organising, tuning, reconfiguring and stabilising brain functionality to the extent that it may be responsible for the majority of the information processing in the brain (Katz and Harris-Warwick, 2005). Rather than conceive of nervous systems in terms of electrical circuits comprising wires and components, then, it may be more apt to consider a "liquid brain" (Changeux, 1993) in which "electrical" neurotransmission is one process embedded within a spatio-chemical medium that is itself active and implicated in control and communication. Why might evolution have chosen to employ mechanisms severely constrained by spatial embedding to effect these important roles?

Space as an Enabling Constraint

There is ample evidence that spatial embedding influences the organisation of natural systems in a significant fashion. This is true whether we are interested in the way that populations of termites construct their impressive mounds (Ladley and Bullock, 2004, 2005), the way in which species of plants compete for light (Clark and Bullock, 2007), or even the way in which genes are packed onto linear strands of DNA (Quayle and Bullock, 2006). Moreover, we are beginning to understand that this influence is not neutral, but can sometimes be positive, with spatially embedded systems enjoying advantages in terms of their improved ability to effectively organise in order to support useful functionality.

A key example is offered by Boerlijst and Hogeweg (1991) in their work modelling the tendency of molecules to organise into mutually self-reinforcing "hypercycles" (Eigen and Schuster, 1979). A hypercycle consists of a set of different molecular species, where each species supports the persistence of some of the others and, in total, they achieve the persistence of the entire set. While such organisations appear to offer a route by which persistent co-operative collaboration might arise spontaneously, they can be vulnerable to *parasitisation* where an additional free-riding molecular species benefits from interacting with some member(s) of the hypercycle, but does not support the hypercycles's persistence in return, essentially leaching energy from the hypercycle. In Boerlijst and Hogeweg's model co-operative hypercycles could be undermined by this type of exploitation and were not stable in a well-mixed non-spatial population of molecules. However, when the same system was spread across a two-dimensional lattice such that molecules could only interact with their close spatial neighbours, hypercycles arose that resisted invasion by parasites and as a consequence were able to persist in the population indefinitely. This was achieved through the co-operating molecular species spontaneously organising in space in the form of rotating spirals. Parasitic infections that arose within such a structure were driven to the edge of the spiral where their impact was minimised. Here, a system incapable of achieving persistent functional organisation is enabled to spontaneously achieve and maintain such organisation in the face of exploitative disturbance by the mere fact of introducing spatial embedding. It is interesting to note that such spiral formations are in fact often observed in nature in the form of patterns of lichen or other simple sessile creatures.

Figure 1. A spiral pattern of lichen on a rock. (Jan-Eric Nyström; Creative Commons Attribution-ShareAlike 3.0 License)

A second example is due to Di Paolo (2000), again in the context of trying to understand how biological populations might evolve to exhibit co-operative tendencies, but this time at the level of evolving populations of simple creatures rather than molecules. First, a particular kind of altruistic behaviour is shown by Di Paolo to be unstable in a well-mixed non-spatial model: exploitation quickly undermines any tendency towards co-operation. However, the same altruistic behaviour is prevalent in the same model when individuals are distributed across a two-dimensional plane. In this latter variant of the model, individuals spontaneously organise into spatially organised clusters of altruistic individuals, each surrounded by a halo of non-altruists. Just as in the hypercycle example, spatial embedding enabled the population to structure itself in such a way as to maintain co-operative functional organisation through exploiting the "useful" asymmetries that space introduces into the ecology of interactions.

The results described above resonate with a number of diverse design challenges: how to organise housing such that community coherence is consolidated rather than fragmented; how to arrange social care processes such that they are vital and integrated; how to build a business organisation that has a healthy culture of reporting both unacceptable and commendable behaviour; how to achieve sustainable cities, an accountable polity, global governance, etc. Space does not solve these problems, but it may, as in the examples above, allow and encourage individuals to organise in a way that makes solutions easier to achieve, mitigating against the well-documented problems that beset non-situated social organisations: groupthink, diffusion of responsibility, the bystander effect, etc (e.g., Aronson, Wilson and Akert, 2007).

But just what is it about spatial embedding that gives rise to these properties? Recent theoretical work attempts to construct an account capable of explaining the capacity of spatial embedding to encourage sophisticated system organisation (Buckley and Bullock, 2007; Barnett, Buckley, and Bullock, 2009; in preparation). The starting point is a measure of interaction complexity originally proposed by a team of neuroscientists (Tononi, Sporns, and Edelman, 1994). The measure attempts to capture a feature of neural systems that appears to underpin their ability to subserve complex functionality: a balance between functional integration and functional segregation. At a fine scale, the dynamics of the components that comprise the brain (i.e., individual neurons) are *segregated*. This allows different parts of the brain to handle different jobs, processing auditory rather than visual stimuli, for instance. However, at successively coarser scales, the interactions between components (e.g., neural assemblies, functional modules) can be observed to be more *integrated*. This allows a nervous system to achieve functional unity at the level of the whole organism. Auditory and visual pathways, for example, combine and influence one another in order to direct behaviour in a systematic, unified and holistic fashion. In order to evaluate this relationship between integration and segregation, their measure assesses the degree to which knowledge of the behaviour of different components of the system, large and small, can allow prediction of the behaviour of the remainder of the system - i.e., the degree to which components share mutual information (Tononi, Sporns, and Edelman, 1994; Barnett, Buckley, and Bullock, 2009). Functionally segregated components will behave independently, while functionally integrated components will behave *inter-dependently*, to the extent that the behaviour of one will tell an observer much about the behaviour of the other.

As such, unlike many metrics that purport to evaluate system complexity, the measure is not explicitly tracking the *structure* of a system. Rather, it is directly concerned with the *interactions* amongst components at various scales within the system and *not* the mere structural connections between components. Neural systems score highly on this measure (Sporns, Tononi and Edelman, 2000), as do artificial neural systems evolved to achieve a cognitive task (Seth and Edelman, 2004). What is most relevant here is that analysis of the measure demonstrates that it is maximised for systems that have strong reciprocal and cyclic connectivity amongst their components (Barnett, Buckley, and Bullock, 2009; in preparation), thus establishing a link between spatial embedding and functional complexity. In a well-mixed non-spatial population, each pair of individual components is as likely to interact as any other. In a spatially embedded population this is no longer true. Space introduces correlation structure (Barnett, Di Paolo, Bullock, 2007). Specifically, amongst other things, space introduces clustering and cyclic or reciprocal interdependencies between a system's parts. These structural correlations encourage regularities and asymmetries in the history of interactions between some of these parts, and between some groups of these parts, and between some groups of these groups, etc. In bringing about and maintaining these correlations, space scaffolds and stabilises interesting, persistent functional organisation that may be measurable in terms of interaction complexity.

It is in this sense that space should be considered an *enabling* constraint. By limiting the degrees of freedom within a system in such a way as to encourage some types of reflexive and reciprocal interaction amongst its parts, space may canalise system design into regimes that spontaneously exhibit useful order. This type of self-organisation, or "order for free", has been described carefully in the context of non-spatial networks (Kauffman, 1993), but has also been studied in natural systems where spatial organisation is foregrounded (e.g., Goodwin, 1994/2001), and has even influenced the ideas of those trying to understand the nature of sound architectural form (Alexander, 2004).

Designing Spaces

How should or could these observations inform design?

First, they may help us to make sense of existing design tendencies. In digital spaces, where freedom from physicality might lead us to expect to see alternative organisational forms, we continue to see a reliance on the familiar tropes of physical space as a means of organising digital objects and our relationships to them (Thrift and French, 2002). On-line interactants ask after each other's "a/s/l" (shorthand for "age/sex/location") as they roam virtual worlds organised to ape real worlds. Social networking sites with a global reach encourage participants to construct a "space", rather than a page. On-line groups organise around shared geographic location. Google offers to augment its maps with geographically organised icons linking to relevant Wikipedia pages, allowing the on-line encyclopaedia to be searched *spatially*. On the one hand this could be argued to stem from a lack of imagination, or a desire to impose a recognisable structure on a potentially alienating digital world. However, it may be that projecting the enormously high-dimensional logical connectivities that characterise the relations amongst digital objects (and ourselves) into a low-dimensional *space* confers useful organisational constraints that facilitate sophisticated persistent interaction.

As an example, consider the design problem faced by "on-demand" computing (Bullock and Cliff, 2004). Rather than deliver computing power in PC boxes that sit on people's desks, one alternative is to locate the computational power off-site (perhaps in vast data centres containing many thousands or millions of individual processors) and deliver it to the user as needed, in much the same way that water and power are currently provided. While this model offers many potential advantages in terms of cost and efficiency it poses the problem of efficiently co-allocating each demanded computational job to an appropriately configured machine with sufficient free capacity. With many thousands if not millions of nodes involved in such a system, it is unrealistic to expect this co-allocation job to be handled by a person, a team of people, or even a fast computer, yet it is also impractical to rely on a free for all in which every node constantly communicates its availability to every other.

Surprisingly, ants and termites solve an analogous problem at an impressive scale without the use of a "central executive" by employing a communication and control strategy that relies on slowly diffusing pheromone chemicals. As the insects go about their jobs, they secrete the pheromones which diffuse to the surrounding area alerting nest-mates to the presence of (re-)building work to be done, predators to be attacked, food to be collected, etc. Critically, this approach relies upon the spatial medium within which it is embedded. Pheromone signals diffuse through space, impinging only on near-by insects. This prevents an entire colony from switching from one behaviour (say foraging) to another (attacking a predator, say), when it would be more appropriate to deploy a proporionate division of labour. By exploiting the colony's spatial extension, its functional organisation can achieve a balance between local functional segregation and global integration (Gambhir, Guerin, Kauffman, and Kunkle, 2004; Jacyno and Bullock, 2008).

In order to achieve something analogous in a computational ecosystem populated by virtual rather than corporeal agents, a typical approach is to cleverly program the software agents to converse, negotiate, debate, and discuss *en masse*, relying on the ease with which the digital world supports all-to-all communication and rapid information processing. But perhaps it may make more sense to impose upon these agents an "artificial space" that, while non-physical, shares the physical world's Euclidian axioms and low-dimensionality. As a consequence, such a spatial embedding will restrict which agents may interact with each other, introducing the asymmetries and correlations enjoyed by ants and termites. If the agents tend to "move" in this space until they tend to find themselves "close" to those that they have some reason to repeatedly interact with, then the problem of achieving multiple simultaneous patterns of co-ordinated mass action that themselves are sensitive to each other's presence and character may be solved without recourse to expensive and time-consuming ratiocination (Jacyno, Bullock, Luck and Payne, 2009).

The digital arena is, of course, not only populated by pieces of software. Dreyfus (2001) offers an important account of what we might lose as people as we apparently move to embrace a non-spatial, non-corporeal, distanceless life of on-line interaction. He follows Heidegger and other continental philosophers in arguing that without embodiment and co-location there can be no co-presence, and that without co-presence the risk and responsibility of meaningful interaction are precluded. For Dreyfus, a world without space, without near, far, here and there, is a world without meaning and consequently one in which we cannot learn, communicate, or take responsibility for our actions. While Dreyfus sees little hope of the Internet overcoming these problems, the deliberate, designed introduction of spatial embedding may yet attenuate them.

Conclusions

In an era in which we are increasingly being asked to simultaneously "live local" and "think global", the relationship between our local spatial organisation and the global systemic behaviour that it gives rise to deserves our attention. Designers may be increasingly free to consider architectures, systems, organisations that transcend spatial constraints and break free from their associated tyrannies. But before we rush to embrace these possibilities, we should pay attention to the systemic properties that spatial embedding encourages. While the task faced by a designer is not diminished or obviated by the influence of spatial constraints, sensitivity to their presence and their affordances may enable efficient, co-operative, complex behaviours to persist robustly where they would otherwise break and fail.

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