How the individual, society and space become structurally coupled over time.

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Abstract

How are we to understand the ambiguous nature of a space: the simultaneous possibility of standing still, moving around it or moving through it? To answer this question requires 'seeing' the configuration through the eyes of the human subject. Taking the phenomenological formulation of the subjective 'lifeworld' and bringing to it our knowledge of spatial properties identified by space syntax techniques, it becomes possible to conceive of an individual's interpretative horizon as possessing an identifiable morphology, developed historically through situated social practices, which brings forth reality for the embodied subject.

Space syntax theory rejects the man-environment paradigm, positing instead an emergent socio-spatial configuration that generates the co-presence and movement necessary for social existence. However, the question of precisely how the human subject engages in re-embodying the spatial configuration remains opaque. One reason for this is the absence of a clear understanding of what it is meant by 'embodiment' in space. Consequently, the generative, 'bottom-up' nature of the spatial configuration appears absent from analyses more concerned with its top-down functioning. In effect this privileges the structural and generic over the historical and contingent aspects of the space-society relation.

This paper reasserts the role of the individual actor embodied in space. We present an empirically grounded definition of 'embodiment' based on information theory and structural coupling to provide a bottom-up account of the emergent congruence between space, the individual and society.

Embodiment, so defined, implies that human subjects' relation with their 'environment' is multi-faceted; that the emergence of a relational socio-spatial system consists of agents coupling with the environment and with each other, developing relationships through the transformation of their internal structures.

2. Introduction

This paper revisits the question of the man-environment paradigm from a perspective that draws on Maturana and Varela's work in systems biology and discusses some of the implications of this for Space Syntax research (Hillier and Leaman, 1973; Hillier 1986, p.384-391). It explores the relevance of the notion of 'structural coupling' to the ongoing debate concerning the relation between individuals and the built environment. We suggest that structural coupling can provide an account of how discrete organisms embodied in time and space generate an 'interpretative horizon' through a process of embodied engagement with their environment. In outlining our theoretical approach we hope to show how structural coupling could provide a basis for the analysis of the phenomenological aspects of space from the perspective of the situated actor. Turner has already successfully experimented with structural coupling to create 'ecomorphic environments' using agent-modelling techniques, in which agent and environment are formed reflexively through interaction. He asks "how can we quantify phenomenology?" (Turner, 2003, p.15.2). We suggest that it may be possible to do so, even in the case of real-world socio-spatial situations, through appeal to embodiment and structural coupling.

3. Revisiting the man-environment paradigm from the 'bottom-up'

The paradox of the man-environment paradigm lies in the fact that it advances two contrasting theorisations of society: the mechanistic and the phenomenological, as a single explanatory model. Hillier and Leaman characterised these as "two mutually exclusive epistemological positions-that of the organism looking out into the environment, and that of the environment bearing in on the individual" (Hillier and Leaman,1973, p508). The former offers no explanation of agency beyond that defined by society, the latter no account of society beyond the individual.

As Hillier has noted more recently, the man-environment paradigm has remained remarkably persistent de facto because sociological research traditions tend to remain divided between 'social physics' and phenomenological approaches to space (Hillier, 2003a, p. 1.18-1.19). One is concerned with the 'objective environment', the other with 'subjective phenomenology'. Hillier asserts that the objective nature of the subject and the subjective nature of the object must be the central concerns of a 'unified paradigm of the city'. This is reflected in his approach to space syntax at the individual level of analysis. The apparent 'alliocentric' properties of human spatial cognition are proposed as the generic "determining link" between the built environment and the living city (Hillier, 2003a, p. 1.6; Hillier, 2003b, p. 6.24-6.33).

However, Hillier is less concerned with the social and the historically particular, than with the creation of the generic human city by the cognitive subject, which he believes to be a more important question (Hillier, 2003a, p. 1.4-1.5; Hillier, 2003b). While not disputing this, we believe that the structuralist approach, needs to be balanced with a perspective more sensitive to variations in socio-spatial identities generated over time through social interaction. A cognitive predisposition must still be enacted in the world for any social organisation or architectural form to emerge.

In the Social Logic of Space Hillier and Hanson argued that social relations must be "constantly re-embodied in social action". They continue that this will require a considerable effort to social transfer resources "from the local to the global, from the spatial to the transpatial, and from everyday life to the perpetuation of descriptions" (Hillier and Hanson, 1984, p.45).

We suggest that without an improved understanding of the reflexive and historical nature of the structural dialogues between the environment and the individual in space there is no explicit mechanism for 're-embodiment' of social ideas in the world and therefore no satisfactory account of how progression from one spatial form to another occurs. The plasticity and inter-relatedness of the embodied entity and the environment emphasised by the structural coupling approach significantly undermines the traditional man-environment paradigm.

4. Embodiment and structural coupling

There is a common theme underpinning what might be called 'the embodiment perspective' in Artificial Intelligence, Robotics and Cognitive Science research (Brooks, 1991; Hendriks-Jansen, 1996; Clark, 1997) recognising the significance of a system's sensorimotor co-ordination-typically but not necessarily referring to non-symbolic and non-representational mediation between sensory input and effector output in relation to an environment in which it is directly present, in contrast to purely abstract or rational reasoning. This perspective draws on the interaction between a system or entity and the environment in which it is present occurring through the sensorimotor 'coupling' arising from performance properties inherent in different sensors and effectors operating in particular operational contexts and with internal structural components mediating between sensory information and effector action in terms of the behavioural phenomena and strategies that are made possible as a consequence of these relationships.

We characterise embodiment in a relational way, as a state of being that enables perturbatory influences to flow between some entity and the surrounding world or 'environment' in which it is embodied. Embodiment is thus said to enable, at the most basic and fundamental level, interaction between a system and its environment-such as a person and a physical space. Note, we henceforth use the term 'system' rather than 'entity', denoting a set of one or more components with relationships between them, conceptually grouped together as such by an observer.

In explicating this relational notion of embodiment and the interaction processes that it enables, we draw on Maturana and Varela's work (Maturana, 1980), particularly the notion of 'structural coupling' first introduced by Maturana (Maturana, 1975) and later developed further by Varela as a basis for understanding the roots of cognitive phenomena (Varela, 1979; Varela 1991). Specifically, we define embodiment to underpin structural coupling, in turn providing an explanatory basis for the phenomena of interaction and adaptation over time and specific momentary interaction. Figure 183 left illustrates the conceptual relation of embodiment and structural, coupling to the cognitive development of the 'interpretative horizon' in the socio-spatial world.

In his Principles of Biological Autonomy, Varela defines 'structural coupling' as a process involving perturbatory interaction between the structure of a system and its environment, as follows (where 'structure' refers to the components that make up a system and the relationships between them):

...the continued interactions of a structurally plastic system in an environment with recurrent perturbations will produce a continual selection of the system's structure. This structure will determine, one the one hand, the state of the system and its domain of allowable perturbations, and on the other hand will allow the system to operate in an environment without disintegration. We refer to this process as structural coupling. (Varela, 1979 p.33)

Structural coupling is a process with explicit diachronous and synchronous elements. How a system responds to and is changed by an environmental perturbation at a moment in time (such as an agent encountering a space) is determined by its structural state at that moment. A system's state at a given moment in time is a product of its history of internal dynamics (if any) and interactions with its environment. Similarly, a given moment's interaction then exerts an influence on subsequent internal dynamics and interactions. This is important because, while emphasising the ongoing process of coupling, it also explains how deep structural simplicities are reproduced, but explicitly puts these into temporal

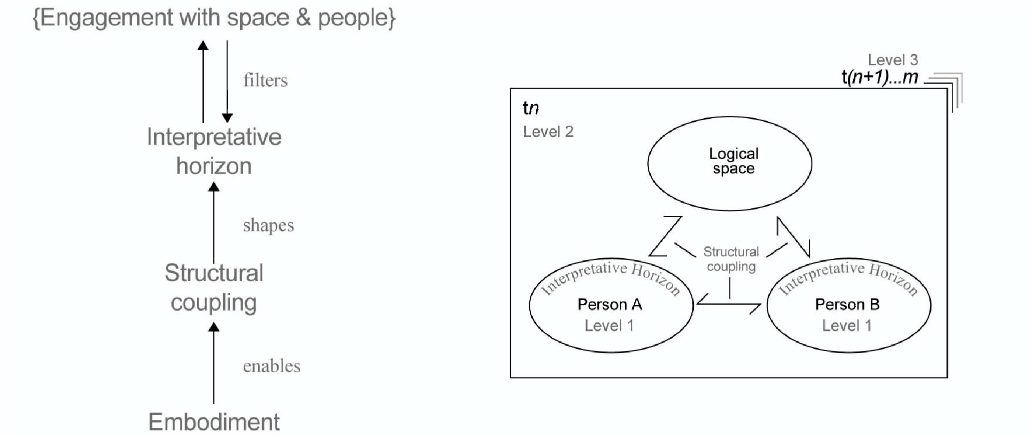

Figure 183: LEFT: Hierarchy of key concepts. RIGHT: Levels of analysis: the relation of the individual, social group and society to space

contexts which admit of great variability in how social space is actually experienced at any given time.

We use the following formal definition of embodiment:

A system X is embodied in an environment E if perturbatory channels exist between the two. That is, X is embodied in E if for every time t at which both X and E exist, some subset of E's possible states have the capacity to perturb X's state, and some subset of X's possible states have the capacity to perturb E's state. (Quick, 1999a; Quick 1999b)

This expresses a fundamental relationship between embodiment and structural coupling, describing the conditions that are necessary and sufficient for mutual structural coupling between a system and its environment to occur.

The process of structural coupling, enabled by embodiment, in turn produces an 'interpretative horizon'. This refers to how a system's structural state, produced over time, determines at any given moment in time what environmental events it responds to, how it responds to them, and how it is changed by such events.

An individual's interpretative horizon can be thought of as possessing a spatial quality that is developed over time through the performance of situated social practices. We suggest the spatially focused part of the interpretative horizon, perhaps a "morphological lifeworld", engages with the world at a particular time by invoking a history of such spatial interactions.

We are concerned with establishing how local, everyday social interaction in space is enacted and how this relates to the emergence of broader socio-spatial trends over time. Figure 183 right expresses this position in terms of levels of analysis: level one refers to individual subjectivity which, through the interpretative horizons produced by structural coupling between individuals and space generates the second level of analysis, that of the particular social situation in 'logical' (socially knowable) space. The third level of analysis concerns the emergence of society and the spatial configuration over time.

5. The ambiguity of space

The process of structural coupling provides a crucial mechanism for the re-embodiment of social relations in space but in so doing raises the difficult question of the subjective interpretative horizon. In spatial terms we articulate this as the 'ambiguous' quality of space, implied in the freedom of the individual subject to walk through, move around or stand still a space at any given time.

Space syntax research has shown that, with regard to generic function, the linear extension of a space tends to generate movement around the urban grid-walking through. Investment of space to increase convexity is more associated with social and cultural performance-standing still, moving around (Hillier and Hanson, 1984, p.96; Hillier, 1996, p130-32). At the generic level therefore, we can say that the cognitive decision whether to see and go, see and stay or see and move around is itself implicated in the creation of socio-spatial identity.

Using space syntax terminology we are able to express the ambiguity of space as the co-existence of convex and axial qualities to some extent in all real-world spaces. The ambiguous nature of space itself implicates the interpretative horizon in bringing forth a living city.

In any particular situational context, movement patterns are likely to be diverse even if analytically consistent with the generic functioning of space overall. The complex and multifaceted interaction of people with each other and with the built environment could be expected to produce variations which, if not significant generically, are significant as a basis for historical explanation and the interpretation of particular socio-spatial contexts.

In the structural coupling model, we consider axial and convex spaces as containers of potential perturbatory events (i.e. information sources) for an individual embodied within them. (We will expand on these ideas below, in section 7). Here we assert that the spatial qualities of the interpretative horizon are formed at the second level of analysis, according to the properties of the local space and the nature of spatial, linguistic and other situated forms of social interaction.

6. The structural nature of communication between agent - environment

Varela illustrates the process of structural coupling using a simple Cellular Automata (CA) that engages in environmental coupling, which he calls 'Bittorio' (Varela, 1988; Varela, 1991). The basic CA model involves a 1D array of cells that can be in one of two states. The system's states update synchronously at each time step over a period of time, with each cell's next state being based on the application of a simple update function that describes the next state based on the cell's current state and the current state of its neighbours (Gardner, 1970; Wolfram, 1983).

Varela adds a simple extension to this basic model, whereby his CA is sensitive to binary states in its environment. He shows how a particular cell update rule results in the system coupling to the environment in such a way that odd sequences of encounters leave its state modified, whilst each even numbered encounter effectively resets it. Thus through the interplay between the system's dynamics and its environment, the system become an 'odd sequence recogniser'.

In a very simple way this shows how the process of structural coupling in an operationally closed system (one that determines its own states over time), creates or 'brings forth' an interpretative horizon for the system, defining what environmental events it is sensitive to and how it responds to them. In effect, Varela shows with a simple concrete example how a 'lifeworld' comes to be from the coupling relationship between a system and its environment. In the words of Merleau-Ponty, quoted by Varela in The Embodied Mind: "The environment (Umwelt) emerges from the world through the actualisation of the being of the organism" (Varela, 1991, p. 174).

7. Measuring embodiment using information theory

Using metrics from information theory, it is possible to quantify the exchange of information between a system and environment as a means of measuring the degree of a system's embodiment, in such a way that inferences can be made regarding the structural complexity and plasticity of the system and its environment without requiring any prior knowledge of or special access to either system or environment beyond the flow of events constituting perturbation to the system from the environment and vice versa. In practice, assuming one is looking at virtual or real actors in some kind of space, this amounts to accessing sensory input and actuator output. It may also be possible to use metrics from space syntax relating to an individual in space, such as lines of sight (as sensory input) and lines of movement (as actuator output).

Shannon entropy (Shannon, 1948; Pierce, 1980; Cover, 1991), designed for measuring the complexity of streams of bits travelling via communications channels, can be used as a basis for measuring the amount of information flowing between system and environment. Shannon entropy (H), measures uncertainty or unpredictability, such that a signal comprised of a random series of events, and hence which is very unpredictable, requires more bits to encode each event and thus has greater entropy than does a constant and hence totally predicable signal. The Shannon entropy of a series of events is calculated as follows, where x is a discrete variable that takes on n different values:

$$H(X) = -\sum_{i-l}^{n} p_i log p_i \tag{19}$$

Here we sum, for each unique state in a series of state events, the probability of that state multiplied by the base two logarithm of the probability of that state. This figure is then subtracted from zero to give us the entropy value, or 'H' (Shannon, 1948; Pierce, 1980).

The string '01′has the same entropy value as the string '011100101001010101′, because both strings consist of two event types, each with equal probability. In both cases the entropy, H, equals 1, meaning we need a minimum of one bit to represent each element in each of the strings. Roughly speaking, a high entropy value for a signal implies a large number of events with a largely random distribution. Entropy thus denotes information in the sense that an event from a sequence of events with a high entropy requires, on average, more bits to encode than an event from a sequence of events with lower entropy does.

The application of entropy as a measure applied to human activities in no way implies a computational perspective on cognition. Rather, as observers we select a series of events to treat as a 'signal', then apply this relatively simple metric to it. However, the measure is sensitive to higher-level features of the information, in so far as they can impact on the probability of the events to which the measure is being applied. For example, different natural languages have different entropy profiles, due to differences in grammars, character sets, word frequencies and so on.

The initial naive measure of embodiment we use is simply the joint entropy between sensory and actuator states. We are currently in the process of evaluating more sophisticated measures, for example taking into account the 'mutual information' between channel data. Joint entropy for multiple variables is calculated in the same way as for a single variable, but as a function of the probability of values of the different variables occurring at the same time:

$$H(x, y) = -\sum_{i,j} p_{ij} log p_{ij} \quad (20)$$

There is a very close relationship between embodiment and structural coupling, such that the information metrics used to measure embodiment can be used to infer knowledge about the coupling relationship between system and environment (Lungarella, 2001; also our own research in progress using information theory as a measure of embodiment applied to an adaptive system based on Varela's Bittorio, described in Quick, 2003). The amount of information flowing between system and environment is a rough indicator of the complexity of system and environment in so far as high entropy is produced as a consequence of a wide range of 'events' occurring. We suggest that there may be a region of 'optimal' entropy between the minimum of zero, representing inactivity, and the maximum possible, representing random activity.

7. The elucidation of an embodied spatial scenario using structural coupling

In this section we take the ideas that we have presented, and suggest how they might be applied quantitatively to the analysis of space and people in space, as well as in the context of a real-world spatial situation. We are concerned to show how moment to moment human activity within a space shapes people's engagement with the space, and thus subsequent human activity in an ongoing reflexive process of structural coupling between individual, group and space.

Although we can posit a clear relationship, we cannot yet provide a detailed causal model of how the flow of information between system and environment shapes the structure and thus the observed behaviour of each. Without a full understanding of what constitutes a given system's and given environment's structure this cannot be done. In the case of human systems in a socio-spatial environment such an understanding may never be possible as it would have to take into account vastly complex factors such as the dynamically coupled neurological states of interacting human beings. However, just as Space Syntax is able to successfully analyse space using a highly abstracted representation of it, it may be that by a similar token we are able to identify broad truths and make roughly accurate predictions about ongoing relationships between individuals, groups of individuals and spaces using similarly abstracted information-theoretic analyses.

In terms of human communicative interaction with other humans, we might assume that people try to minimise the amount of 'noise' disrupting the flow of information between them. Interference to the flow of information between communicating parties reduces the effectiveness of communication, whether it takes the form of explicit sound pollution or other kinds of distraction impacting participants. Such a scenario would be relatively straightforward to model quantitatively, where people act as information sources for one another, and environmental qualities such as ambient sound levels introduce noise, thus requiring more bits are transmit a given signal.

Similarly, we might model an area of space as containing information sources that decay or become increasingly noisy over distance. The metric properties of a space will then impact on the information content available at any given point in that space, as well as over the whole space. For example, consider four spatial points, each containing an information source transmitting 1 bit per second (bps). Assume that a receiver can receive 1 bps if they are standing in the same space as a transmitter, but the amount of information received per bit sent decreases by 50% at every unit of distance away from the transmitter. If the four points were arranged on a 2x2 grid, then a receiver standing on any square would receive 2.5 bps, totalling 10 bits per second of information distributed across the whole space. However, if they were arranged in a 4x1 line, then a receiver would receive 1.875 bps at each of the end two squares, and 2.25 bps on the centre two squares, totalling 8.25 bits per second across the space. I.e. for maximum information content and distribution within a space, convexity is preferable to axiality. Note however, that if we are concerned with purely visual information that does not decay so rapidly over space, it is still the case that a single axially oriented visual field may contain more information than a convexly oriented field (See Hillier, 2003b, p.1-14).

In terms of human orientation in space we assume the opposite to be true: people seek to minimise the informational complexity of navigating between points. Generally speaking, navigating to a destination within a single line of sight (i.e. with zero depth) is preferable to navigating to one via many lines of sight An information theoretic analysis might be performed as follows. If a route consists of two directions (or lines of sight), such as ‘go north, go east’ (N,E), this can be represented as a sequence of two events of equal probability. This gives an entropy value per event of 1 bit. Multiplied by the two events, the information content of the route can be measured at 2 bits. For the three stage route N,E,N, the information content is 3 x 0.917 bits, totalling 2.751 bits of information. N,E,N,E equates to 4 bits of information, N,E,S,E,N to 7.61, and so forth. This is not necessarily equivalent to measuring depth. For example, the route N,E,N,E has 4 x 1 = 4 bits of information, whereas N,E,S,W has 4 x 2 = 8 bits of information.

In a far less abstracted world, a man walks into a pub. If he is a participant in a joke, he is not aware of it. The pub consists of a long rectangular room with the entrance at one end and the bar at the other. There are doors to the toilets roughly halfway along the side wall to his left. Figure 184 left illustrates this simple layout. Thick lines show the direct routes between entrance and bar, entrance and toilets, toilets and bar, and the area immediately in front of the bar where people buy their drinks.

The bar is virtually empty. As he is here to meet someone, he wishes to maximise his access to visual information about the contents of the room. He walks to the bar, perhaps feeling exposed in the middle of the room, a point which has least visual access to the rest of the room, but which is very visually accessible from all other points. He buys a drink and chooses to stand in a corner, at the end of the bar opposite the toilets. From this position he can acquire visual information from the rest of the room, including the entrances to the toilets, the entrance to the pub itself and a portion of the street area outside without making much effort to look around. Shortly after he arrives, people begin filling up the pub in small clusters, utilising the spaces that are not bisected by the lines between the entrance, bar and toilets.

Each group creates its own communicative unity. Some of the people in the clusters are facing a wall and occasionally glance around, re-establishing the location of the group

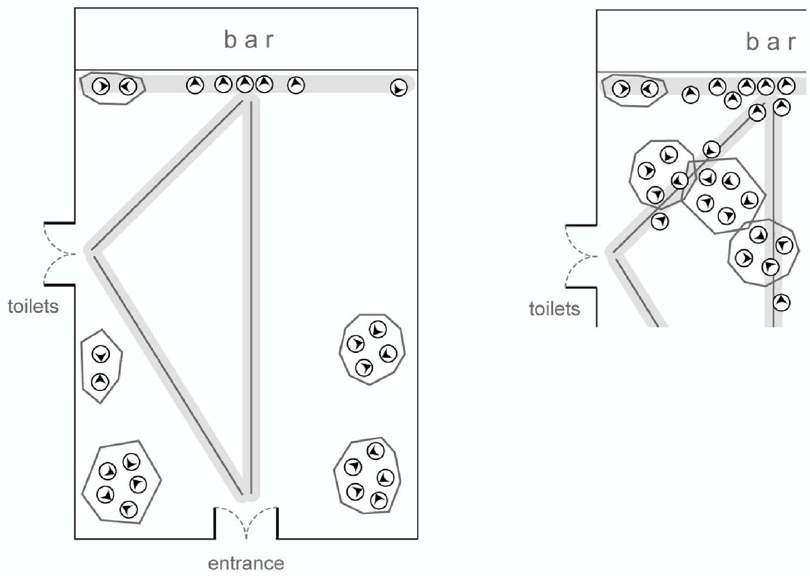

Figure 184: LEFT: The pub early in the evening: optimum information flow through space. RIGHT: The pub late in the evening: disrupted information flow through space

in relation to the pub. Members of each group who do not have their backs to walls form a symbolic social barrier to random people passing on the way to the toilet or the bar but occasionally someone is recognised and joins the group. These social barriers are represented by grey boundary lines in Figure 184 left. Typically, members of the group sit close enough together to emphasis their identity as a group, and to maximise the ease of conversational information flow.

This is not about territoriality, but rather optimising the balance of linear and social spaces maintained through the arrangement of people. The spaces formed by groups for their social interactions are maximally convex and information-rich. Linearised spaces in between mean it is straightforward to leave the group and go to the toilet or to the bar and rejoin the group and friends arriving late have no problem finding who they are looking for.

There is an architectural quality to this arrangement. People moving through the space of the pub, for example to and from the bar and the toilets, try to navigate around these physically grounded social spaces just as they would architectural physical obstacles, for they have learned that this is how one correctly responds to groups of unknown people- if possible, one should not cross the convex social boundary formed by imaginary lines between their bodies unless one is known to them. The placement of groups thus shapes both the flow of moving individuals and the placement of new groups as the syntactic and informational qualities of the space shift, in an ongoing and reflexive dialogue between people as individuals, social groupings and space.

The group tries to prevent the linearisation of this informational space as the number of people in the pub necessitates fragmentation of the linearised 'routes', as illustrated in Figure 184 right. Lines of movement, previously along single lines of sight, representing minimal informational effort now become increasingly complicated and ill-defined, greatly raising the informational effort required to navigate them. Furthermore, as these routes become fragmented, groups start to find people pushing through their space, disrupting the flow of information between them. The group strives to maintain its identity, with the members moving closer together, making the group boundary more physically impermeable rather than merely suggested. Closer proximity and an increase in speech volume between communicating parties also helps to reduce the amount of noise disrupting the information flow between them. Equally, these changes modify the environment as experienced by others in the pub. The extent to which the group is like an architectural obstacle is increased, as is the amount of overall conversation-disrupting ambient auditory noise that they contribute. The man in the corner, unable to command the space visually is distinctly isolated in his corner and decides to leave.

9. Conclusion

As an approach to the relation of space and society, structural coupling emphasises the creative role of the individual in particular spatial contexts in re-embodying socio-spatial structures. It effectively undermines the man-environment paradigm by offering a way of thinking about inter-subjectivity in a manner that does not lead to simplifications of the social either in terms of deterministic socio-economic forces or pure phenomenology. On the contrary, our argument is that the spatial properties of the interpretative horizon, formed in relation to other people as well as to particular spaces, suggest how we can understand spatial transformation as an historical context in which individuals maintain their subjective integrity and have the potential to generate, over time, change from the bottom-up. Believing that it may at some stage be possible to measure certain phenomenological aspects of space, we have outlined how information theory could be used as a basis for measuring a system's embodiment relationship with an environment, and suggested that this in turn gives us insight into the complexity of the system, its environment, and the coupling relationship that exists between them.

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