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Visible Colleges: Structure and Randomness in the Place of Discovery

The Argument

Visible colleges, in contrast to the "invisible colleges" familiar to historians of science, are the collective places of science, the places where the "creation of phenomena" and theoretical speculation proceed side by side. To understand their spatial form, we must understand first how buildings can structure space to both conserve and generate social forms, depending on how they relate structure in space to randomness. Randomness is shown to play a crucial role in morphogenetic models of many kinds, especially in spatial forms and in social networks. We argue here that it can also play a crucial role in the advance of science.

The Problem of Space According to Lévi-Strauss

In 1953, Claude Lévi-Strauss formulated the problem of space as follows:

> It has been Durkheim's and Mauss's great merit to call attention for the first time to the variable properties of space which should be considered in order to understand properly the structure of several primitive societies. . . . [But] there have been practically no attempts to correlate the spatial configurations with the formal properties of the other aspects of social life. This is much to be regretted, since in many parts of the world there is an obvious relationship between the social structure and the spatial structure of settlements, villages and camps. . . . These few examples (camps of Plains Indians, Ge villages in Brazil, and pueblos) are not intended to prove that spatial configuration is the mirror image of social organization but to call attention to the fact that, while among numerous peoples it would be extremely difficult to discover any such relation, among others (who must accordingly have something in common) the existence of a relation is evident, though unclear, and in a third group spatial configuration seems to be almost a projective representation of the social structure. But even the most

> striking cases call for critical study; for example, this writer has attempted to demonstrate that, among the Bororo, spatial configuration reflects not the true, unconscious social organization but a model existing consciously in the native mind, though its nature is entirely illusory and even contradictory to reality. (Lévi-Strauss [1953] 1967, 282–85)

A little later he adds:

> Problems of this kind (which are raised not only by the consideration of relatively durable spatial configurations but also in regard to recurrent temporary ones, such as those shown in dance, ritual, etc.) offer an opportunity to study social and mental processes through objective and crystallized external projections of them. (Ibid., 285)

It may seem natural that a "structuralist" of Lévi-Strauss' stripe would see the spatial forms of settlements as "projections" or "reflections" of "mental processes" and be puzzled when he finds it in some cases and not in others. But we find a curious blindness in his view. A short while previously in the same paper Lévi-Strauss had proposed a fundamental distinction in the analysis of social structure between what he calls "mechanical" and "statistical" models (ibid., 275–76). In a mechanical model, according to Lévi- Strauss, the elements of the model are "on the same scale as the phenomena" they account for. In a statistical model the elements of the model are "on a different scale" from the phenomena.

Lévi-Strauss illustrates the difference through marriage laws in "primitive" and modern societies. In primitive societies, the laws of marriage can often be "expressed in models calling for actual grouping of the individuals according to kin or clan." Individuals are thus categorized and brought into well-defined relationships with individuals in other categories. This degree of determination is characteristic of a mechanical model. Modern societies, in contrast, specify no such assignment of individuals to categories, and therefore no such relations to other categories. Instead, "types of marriage are determined only by the size of primary and secondary groups." A model of the invariants of such a system could therefore determine only average values, or thresholds, and therefore constitute a statistical model.

What we find curious is that in using such terms as "projection" and "reflection" to formulate the problem of space, Lévi-Strauss seems to be taking for granted that spatial phenomena will be on the same scale as the mental processes that (so he imagines) must govern them, and therefore be expressible through a mechanical model. It is far from obvious that this should be so. On the contrary, everyday experience suggests that it is rarely so, and that space more commonly possesses the attributes of Lévi-Strauss' statistical model. The differences between the type of spatial mechanical models Lévi-Strauss has in mind for such cases as the circular villages of the Ge Indians of Brazil and the type of space characteristic of modern cities seems to have much in common with the differences he has already noted between types of marriage systems. Modern urban space is for the most part interchangeable and lacks well-defined correspondences between social categories and spatial domains. Insofar as such distinctions exist, they appear to be exactly of a statistical kind and are generated by a process of social action rather than simply reflecting a mental process. Considering the full range of cases with which ethnography and everyday life present us, in fact, space seems to vary on a continuum with mechanical and statistical models as its poles.

The reason for Lévi-Strauss' unexpected conceptual blindness is perhaps that he lacks any concept of what a statistical model of space would look like. The need to formulate such a model underlies the attempted resolution of Lévi-Strauss' problem in *The Social Logic of Space* (Hillier and Hanson 1984). In that text it is argued that leaving aside issues of sheer scale, which are themselves morphologically significant, the investment societies make in space varies along three fundamental dimensions: the degree to which space is structured at all, the degree to which space is assigned specific social meanings, and the type of configuration used. Across the range of known societies, the first gives a continuum from nonorder to order; the second gives a continuum from nonmeaning to meaning; and the third gives fundamental differences in actual spatial form across a range of spatial variables (ibid., 5).

Morphogenetic Models

The only type of model that might succeed in showing a field of phenomena with these dimensions of variability to be a "system of transformations" (to use a favorite expression of Lévi-Strauss) is, it was argued in *The Social Logic of Space,* a model in which rules are conceived of not as mental entities producing projections or reflections of themselves in the real world, but as restriction imposed on an otherwise random generative process – say, a cell aggregation model, or a model generating relationships in a graph. In such a model, rules and randomness can interact to produce not only known outcomes, but also new outcomes or *morphogenesis*. Cases were shown in which a morphogenetic model based on cell aggregations randomized apart from purely local rules (i.e., specifying only relations of cells to an immediate neighbor) was able to generate – and by direct inference to "explain" something about – common global topological properties of groups of apparently random settlement forms (ibid., 55–63; see also Hillier 1985).

But computer experimentation has shown that such morphogenesis occurs only where the rules restricting the random process are few, and local in their scope. The more the rules become too many or too global (i.e., specifying relations beyond those with immediate neighbors – for example by requiring lines of sight covering groups of a certain size), the more the generative process will tend to produce reflections or projections of those rules. Morphogenesis in such systems requires, it seems, the co-presence of randomness and rules restricting that randomness.

Such co-presence can arise only to the extent that the number of possible relations that cells can enter into in an aggregation process is significantly more than those specified by rules. The higher the proportion of possible spatial relations specified by the rules, and the more global those rules, the less the process has morphogenetic potential, and the more it will conserve the form given by the rules. Conversely, the lower the proportion of possible relations specified by rules, the greater the morphogenetic potential. More succinctly, we can say that short descriptions, or "short models" as we have come to call them, inserted in random processes tend to morphogenesis, while long descriptions, or "long models," tend to conserve.

We also find that the shorter the model the larger the equivalence class of global forms that can result, and the more these forms will, while sharing "genotypical" similarities, be individually different. The longer the description required, the smaller the equivalence class and the more individuals will resemble one another. In other words, short models tend to individuation as well as morphogenesis, whereas long models tend to conformity as well as conservation.

A further refinement of this theoretical model can incorporate another significant dimension: that of social meaning. In what has been described so far, it has been assumed that the elements of a generative process are interchangeable and do not have individual identities. If we now assign individual identities – or even group identities – to individual cells, and assign individuals or categories to specific relations with other individuals or categories within the system, then the description required to restrict randomness is still further lengthened, since relations between specific elements or groups of elements need to be specified – though this time by *transspatial* or conceptual rather than purely spatial rules.

This is most economically conceived of as the imposition of "noninterchangeability" on the elements of the generative process. While appearing initially to be the addition of entities of an entirely different kind – those associated with social "meaning" – the concept of noninterchangeability shows that these can be brought within the theoretical scope of long and short models. The limiting case of such a noninterchangeable system is one in which every cell has a specified relation to all others in the system. This limit seems to be approached in the famous case of the Bororo village used (though not originated) by Lévi-Strauss (1964).

The continuum of long and short models is, we believe, the general form of Lévi-Strauss' distinction between mechanical (long) and statistical (short) models. Unifying both into a single scheme of things, one is able to see that the statistical and the mechanical, while appearing to characterize quite different research approaches to human affairs (in that sociology tends to the statistical while anthropology tends to the mechanical), are in fact aspects of an underlying continuum of possibility that runs right through human affairs in all societies.

Simple examples can be set within the model and clarified. For example, a ritual is a set of behaviors in which all sequences and all relations are specified by rules – that is, it is a long-model event. Of its nature, a ritual eliminates the random. Its object is to conserve and reexpress its form. A party, on the other hand, while it may be casually described as a social ritual, is a short-model event. Its object is morphogenetic: the generation of new relational patterns by maximizing the randomness of encounter through spatial proximity and movement.

Not the least interesting property of long and short models for our present purposes is that they appear to give good characterizations of both spatial patterns and types of human encounter (encounter being the spatial realization of the social), so that one can begin to see possible generic relationships among them. Short models, it seems, require space to be compressed because they depend on the random generation of events, and this becomes more difficult to the degree that distance has to be overcome. Long models on the other hand tend to be used to overcome distance and to make relationships that are not given automatically in the local spatial zone. Societies typically use ceremonies and ritual to overcome spatial separation and reinforce relationships that are not naturally made in the everyday spatial domain. Informality, in contrast, is associated exactly with the local spatial zone and is harder to retain at a distance. Greater space, as Mary Douglas once observed, means more formality ([1970] 1973, 101).

Looked at this way, one can see that society actually has a certain rudimentary "spatial logic" built into it, which links the *frequency* of encounters with the *type* of encounters. By the same logic, the typing of encounters between short and long models generates a need to pattern the local spatial domain to structure the range of encounter types. In this way, space as a physical arrangement begins to acquire a social logic.

This reformulation of the problem of space leads to a research program in which the object of investigation is how the two morphologies of space and encounter are patterned. Research can thus proceed without any presumption of determinism. If social encounters have their own spatial logic and space has its own social logic, and the task of research is to understand how they relate morphologically, then the naive paradigm of cause and effect between environment and behavior can be avoided. Indeed one can see that the term "environment" used in this context is in danger of itself setting up this false paradigm of the problem it seeks to address (Hillier and Hanson 1984, 1987), since it presupposes an ambient circumstance with some specific influential relation to the behaviors it circumscribes. This paradigm is unrealistic, and it has been criticized at length elsewhere. Even so it is worth uttering a word of warning that the fallacies of what has been called the "man-environment paradigm" (Hillier and Leaman 1973) can also be present in the notion of the "setting."

These theoretical ideas have been set out at some length because we believe that the analysis of the relationship between "the spatial setting and the production and reproduction of knowledge" can proceed effectively only within this type of theoretical framework. It is this theoretical framework that the methodology of "space syntax" seeks to convert into a program of empirical investigation, by first investigating space as a pattern in itself, then analyzing its relationship to the distribution of categories and labels (noninterchangeabilities), then systematically observing its use.

Before explaining something of the method and the modeling concepts it gives rise to, however, some careful distinctions must first be introduced about the way we use the word "knowledge," since these have a direct bearing on how the reproduction and production of knowledge relate to space.

Ideas We Think With and Ideas We Think Of

To study space and knowledge, we must begin by making a fundamental distinction between two everyday senses of the word "knowledge." The first is when we talk of knowing a language, or knowing how to behave, or knowing how to play backgammon. The second is knowing in the sense of knowing projective geometry, or knowing how to make engineering calculations, or knowing the table of elements.

Knowing in the first sense means knowing a set of *rules* that allow us to *act* socially in well-defined ways: speaking, listening, attending a dinner party, playing backgammon, and so on. Knowing in this sense means knowing something *abstract* in order to be able to do, or relate to, something *concrete*. Knowledge of abstractions is used to generate concrete phenomena. Let us call this kind of knowledge *knowledge A,* or *social knowledge,* since it is clear that the ubiquity of knowledge A is one of the things that make society run.

Knowledge A has several important characteristics. First, we tend to use it *autonomically*. We are not aware of it when we use it, in the sense that when we are speaking sentences, the last thing we wish to give attention to is our knowledge of the rules of language. The rules of language are *ideas we think with,* whereas the concepts we form through language are, for the most part, *ideas we think of*. It is necessarily so. To be effective as speakers, we must take it for granted that we know, and others share, the rules of language.

Second, in spite of the evidently abstract nature of such knowledge, we normally acquire it by *doing,* rather than by being explicitly taught. As we learn words and sentences, we are not aware we are learning abstract rules. On the contrary, what we are learning seems fragmentary and practical. Nevertheless, as linguists have so often noted, such knowledge must be abstract in form since it allows us to behave in novel ways in new situations – the familiar "rule-governed creativity."

Third, we should note that knowledge A works so effectively as social knowledge precisely because abstract principles *are* buried beneath habits of doing. Because they are so buried, we become unconscious of them, and because we are unconscious we also become unaware that they exist. Ideas we think with are everywhere, but we do not experience them; they structure our thoughts and actions, but we have forgotten their existence. The trick of culture, it might be observed, lies in this way of making the artificial appear natural.

Knowledge B, in contrast, is knowledge where we learn the abstract principles consciously and are primarily aware of the principles both when we acquire and when we use the knowledge. Thus we learn and hold projective geometry, or how an engine works, or the table of elements, in such a way that abstract principles and concrete phenomena seem to be aspects of each other. We might very loosely call this "scientific knowledge," making the only criterion for this term the fact that principles as well as cases are explicit and can be written down in books and taught as aspects of each other.

Now it is unimportant to our argument that there is no clear demarcation between knowledge A and knowledge B. On the contrary, the lack of clarity as to what belongs where is often an important debate. For example, in the field of space there is a theory called territoriality, which claims scientific status. We believe this theory not only to be wrong but also to be knowledge A masquerading as knowledge B. That is, we believe it to be in the main a projection into a quasi-scientific language of normative beliefs and practices that are deeply ingrained in modern Western society – ideas that have indeed become ideas we think with in architecture (Hillier 1988) and now need the reinforcement of scientific status.

The reason we need the distinction between knowledge A and knowledge B for our purposes here is that all human spatial organization involves some degree of knowledge A. How much knowledge A is involved is indexed by the length of the model that structures space. But it is not a one-way process in which space *reflects* knowledge A. In short-model situations, space can also be *generative* of knowledge A.

Examples of this range of possibilities are given in the next section. However, knowledge A is not our principle subject here. We are interested in space and knowledge B, trivially in its reproduction, nontrivially in its production. The essence of our answer is that the conditions for the production of knowledge B are likely to exist to the extent that knowledge A is absent in spatial complexes, and that the short-model conditions that permit the generation of knowledge A also have a bearing on the generation of knowledge B.

This does not mean that the absence of knowledge A in space will always lead to the production of knowledge B, or that knowledge B can be produced only when knowledge A is absent. What it means is that in the absence of knowledge A the spatial conditions can exist for all kinds of *generation* – new relationships, new ideas, new products, and even knowledge – just as in the presence of knowledge A, the spatial conditions exist for all kinds of *conservation* – of roles and positions, of social praxes and rituals, of statuses and identities.

More briefly, the proposition put forward in this paper is that buildings, which insofar as they are purposeful objects are organizers of space, can act in either a *conservative* or a *generative* mode. The place of the spatial reproduction of knowledge lies in the conservative mode. The place of the spatial production of knowledge lies in the generative mode. What this means in practice may surprise the proponents of scientific solitude.

Space and Knowledge A

The argument can be made more precise by illustrating the presence of knowledge A in some simple examples of domestic space. Social knowledge is built into domestic space in many ways, but one of the most important is through *configuration* – that is, through the actual layout of the plan. Configuration is defined as being more than mere relations, since a complete account of relations can be given in terms of a series of dyadic relations between pairs of spaces. Configuration, however, is defined as, at least, the relations between two spaces taking into account a third and, at most, the relation between all spaces in a complex taking into account all others. In other words, configurational analysis must take account of many relations at once and express them in numbers. It is configuration that space syntax analysis seeks to express in numerical and model form.

A key syntactic measure of configuration is *integration*. The integration value of a space in a complex is calculated by first representing the space complex as a graph according to one of a number of representational conventions: spaces defined by boundaries, fewest and fattest convex spaces, fewest and longest straight lines – all defined according to relations of permeability or visibility or both (Hillier, Hanson, and Peponis 1984) – then calculating the total number of spaces that intervene between each space and every other space in the complex. This gives us a series of numerical values that express how this particular configurational property is distributed in the complex.

This is initially a purely spatial measure, but it gives a configurational analysis of function as one simply looks at the integration values of the spaces in which functions are located. As soon as we can identify common patterns in the degree of integration of different *functions* or *labels* in a sample of dwellings, then it is clear that we are dealing quite objectively (i.e., in terms of the properties of objects) with cultural genotypes acquiring a spatial dimension – that is, with social knowledge taking on a spatial form.

This notion can be illustrated by simple examples. figs. 1, 2, 3 are rural farmhouses in Normandy, taken from a sample analyzed in Hillier, Hanson, and Graham 1987. To keep matters simple, in this case we will use the boundary convention in which spaces are distinguished only insofar as they have closable doors distinguishing them from other spaces. To the side of each plan is a justified graph of the minimum living complex of each house, using the outside of the dwelling as the "root." In a justified graph, a particular space is selected as the root, and the spaces in the plan are then aligned in graph form above the root in levels according to how many spaces one must pass through to arrive at each space from the root.

The justified graph is a very useful device for showing configurational properties in visual form, and also for illustrating in a visual way what is meant by the integration value of a space: the justified graph from a space will be shallow to the degree that it is integrating, and deep to the extent that it is segregated. Table 1 shows the integration values of all the spaces, in order, from the most integrated (lowest value) to the most segregated (highest value).

An inspection of plans, justified graphs, and integration values shows that in spite of the geometrical dissimilarity of the plans, all three share certain "syntactic" invariants: the *salle commune* (sc) is the most integrated space, lies on all rings in the

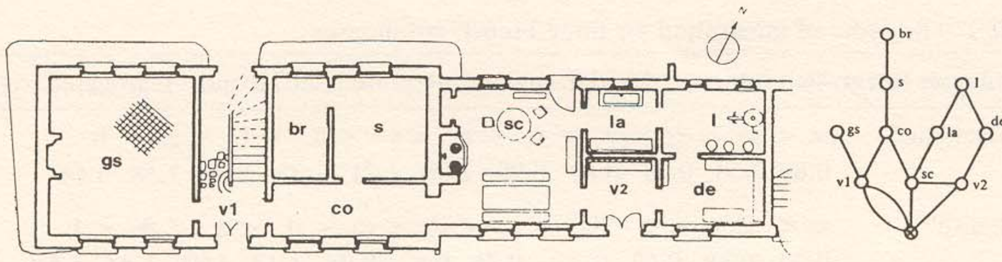

Figure 1. "La Bataille."

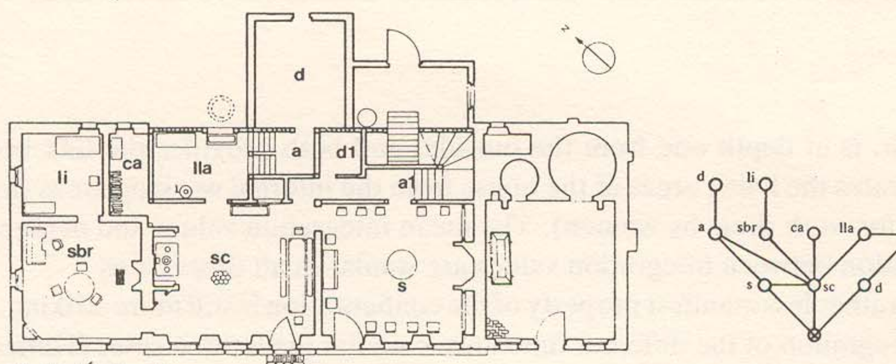

Figure 2. "L'Église."

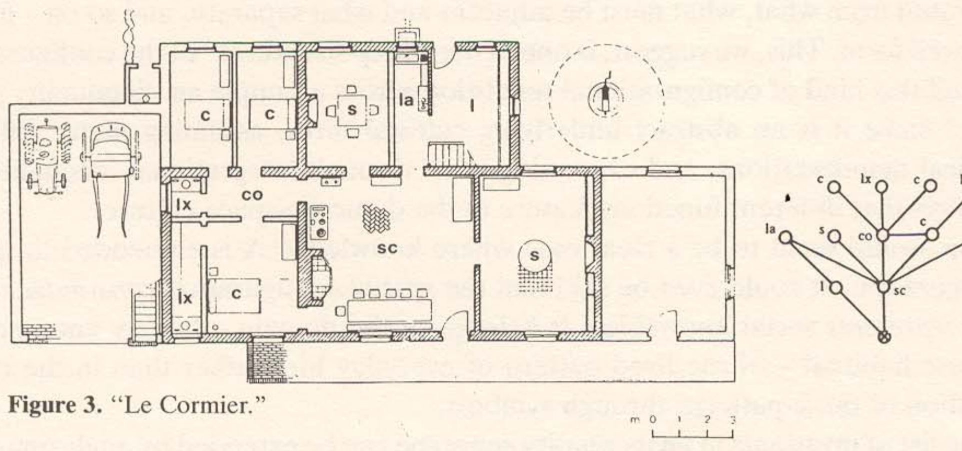

Figure 3. "Le Cormier."

Figures 1–3. The ground floor plans of three farmhouses from the Normandy region of France, together with their justified-depth graphs from the exterior space.

Abbreviations of room labels are as follows:

a	Access to upper floors (*accès*)	li	Linen room (*lingerie*)
br	Study (*bureau*)	lla	Dairy/washing room (*laiterie-laverie*)
c	Bedroom (*chambre*)	lx	Lavatory (*lieux d'aisances*)
ce	Wine and food store (*cellier*)	m	Equivalent to "*salle commune*"(*maison*)
co	Corridor (*couloir*)	s	Room where fire is not always lit, that is, not an everyday room (*salle*)
cu	Kitchen (*cuisine*)	sb	Bathroom (*salle de bains*)
d	Storage (*débarras*)	sbr	Sitting room/study (*salon-bureau*)
de	Preserving food (*dépense*)	sc	Everyday communal living and cooking (*salle commune*)
gs	Reception room (*grande salle*)	sm	Dining room (*salle à manger*)
l	Dairy (*laiterie*)	sr	Masters' dining room (*salle à manger des maîtres*)
la	Washing room (*laverie*)	v	Entrance hall (*vestibule*)

Table 1. The order of integration for three French farmhouses

Farmhouse	**Integration values** (ordered from most integrated [left] to most segregated [right])
"La-Bataille"	sc < co < ex = v < v < la < s < d < 1 < gs < b
	0.60 0.68 0.83 0.83 0.90 1.06 1.21 1.28 1.51 1.58 1.88
"L'Église"	sc < ex = s < lla = a < sbr < ca < d < a < d < 1
	0.30 0.68 0.68 0.75 0.75 0.82 0.98 1.13 1.21 1.43 1.51
"Le Cormier"	sc < co < c < ex = la < s = s < c = 1 = c < 1x < 1
	0.31 0.45 0.57 0.83 0.83 0.96 0.96 1.08 1.08 1.08 1.21 1.34

graph, is at depth one from the outside, and both provides the link between and separates the living areas of the house from the internal working areas (for the most part for work done by women). The mean integration values and degrees of differentiation between integration values are similar in all three cases.

A rather less manifest property of the configuration is still more striking. The order of integration of the different functions is similar in all three cases (Hillier, Hanson, and Graham 1987). In other words, the way in which spaces are categorized according to the ways in which culture arranges activities – what goes with what, what is separated from what, what must be adjacent and what separate, and so on – finds a repeated form. This, we suggest, is one of the "deep structures" of the configuration. We call this kind of configurational repetition across a sample an "inequality genotype," since it is an abstract underlying cultural form, assuming many different physical manifestations, and expressing itself through integrational inequalities in the ways that different functions feature in the domestic-space culture.

This would seem to be a clear case where knowledge A is embedded in spatial configuration. It could even be said that the spatial configuration *constitutes* rather than *represents* social knowables. It belongs in the domain – largely unconscious, because habitual – of the lived pattern of everyday life, rather than in the representation of these patterns through symbols.

The list of invariants in an inequality genotype can be extended by analyzing more subtle spatial properties, such as the relation between permeability and visibility among the spaces. The more the list can be extended and remain invariant – or approximately so – across a sample, the more it can be said that the genotype is a long model or a Lévi-Straussian mechanical model. In the case of the French farmhouses, the genotype is far from being a mechanical model. There is much that varies, apparently randomly, among the houses, ensuring that each retains its individual spatial character.

Set into the general theoretical scheme we are proposing, we might say that the list of invariants over the list of possible invariants across the sample would be the length of the model. For our present purposes, we will not pursue precise measurement too far, since to show the possibility in principle is sufficient. But it can easily be seen that a more stereotyped housing type – say the English suburban house, where most spatial and function rules are invariant across very large samples – will have a much longer model than the French farmhouses, where much individuation still prevails over an underlying genotypical pattern (see Hanson and Hillier 1982; Hillier, Hanson, and Graham 1987). We can also say, therefore, that the length of the models indexes the degree to which the houses, through their configuration, reproduce knowledge A. English suburban houses reproduce more social knowledge than do the French rural examples.

Strong and Weak Programs

Let us now consider two more complex examples, which take the model to its extremes. To do this we need to invoke movement. In architectural terms, movement is a very dull word for a very critical phenomenon. Although we are accustomed to taking a static view of buildings by being concerned primarily with the aesthetics of their façades, there is no doubt that from the point of view of space, buildings are fundamentally about movement, and how it is generated and controlled. The type of "inequality genotype" just discussed may be present in, say, a factory (through the different degree of integration of managers, foremen, supervisors, workers, different departments, and so on; see Peponis 1983), but it is rather shadowy and far from being the most important feature of the spatial layout and its dynamics. To understand these more complex situations we must internalize the idea of movement into our theoretical model.

Let us begin with an example of what we call a "strong-program" building. The program of a building is *not* the organization it houses. An organization, by definition, is a list of roles and statuses that has no necessary relation to a form of space, and its description – although not necessarily how it functions – would be the same regardless of its spatial configuration. We must give up the idea that it is the organization that is reflected in the layout (another Lévi-Straussian case of a mechanical expectation that is usually unfulfilled) and look for some aspect of the organization that does have some kind of spatial dimension.

"Program" is the name we give to the spatial dimensions of an organization, and the key element in any program is the interface, or interfaces, that the building exists to construct. An "interface" is a spatial relation between or among two broad categories of persons (or objects representing persons) that every building defines: *inhabitants,* or those whose social identity *as individuals* is embedded in the spatial layout and who therefore have some degree of control of space; and *visitors,* who lack control, whose identities in the buildings are collective, usually temporary and subordinated to those of the inhabitants. Thus teachers, doctors, priests, and householders are inhabitants, while pupils, patients, congregations, and domestic visitors are visitors. An interface in a building is a spatial abstraction associated with a functional idea. It can vary in its form – think, for example, of the many ways in which the interface between teachers and pupils in a school can be arranged – but the building does have to construct its key interfaces in some form or other. The notion of interface thus extracts from the idea of organization the spatial dimensions that must be realized in some way in the spatial form of the building.

A strong program exists in a building when the interface or interfaces constructed by the building have a *long model*. Take a court of law, for example, which has probably the most complex strong-program interface of any major Western building type. The complexity of the program arises from the fact that there are numerous different categories of persons who must all be brought into the same interface space in well-defined relations. The length of the model arises from the fact that spatial configuration must ensure that each of these interfaces happens in exactly the right way, and that all other possible encounters are excluded.

The interface in a court of law is, of course, static and "synchronized" – meaning that all parties are brought into the same space-time frame. But the way the interface is brought about has to do with movement. The court of law has as many entrances as categories of participant, and all entrances have the property of noninterchangeability. Usually each independent entrance is associated with an independent route, or at least with a route that intersects only minimally with others. Each category is likely also to have an independent origin and destination in and around the courtroom space.

The essential characteristic of the court of law, considered as a system of movement and stasis, is that everything that happens is programed in advance in order to structure the interfaces that must occur and inhibit all others. Movement is thus constructed by the program, and the role of spatial configuration is primarily to permit the necessary movements and inhibit others. A strong-program building is one in which it is not the layout that generates the movement pattern but the program operating within the layout. In terms of the model, it can be said that the whole space structure for stasis and movement is controlled by knowledge A: its aim is to reinforce certain categoric identities and create strongly controlled interfaces between them.

Now let us consider a contrary case: the weak-program building. Fig. 4 shows the editorial floor of a leading London daily newspaper. Impressionistically, it is the opposite of the courtroom. It appears to be a hive of activity, with a high degree of apparently random movement and static encounter. If we now analyze the space structure using the axial convention (in which the longest and fewest lines of sight and access are drawn through all the open space), then analyze its integration pattern, we find that it has an integration core (the 10 percent most integrating lines) of a type familiar from syntactic studies of urban grids (fig. 5): a semigrid near the heart of the system links to strong peripheral lines by a series of routes, keeping it shallow from the outside as well as across its width. If we carefully observe the pattern of movement and stasis, we find that integration values of axial lines are powerful predictors of the degree to which space will be used (fig. 6).

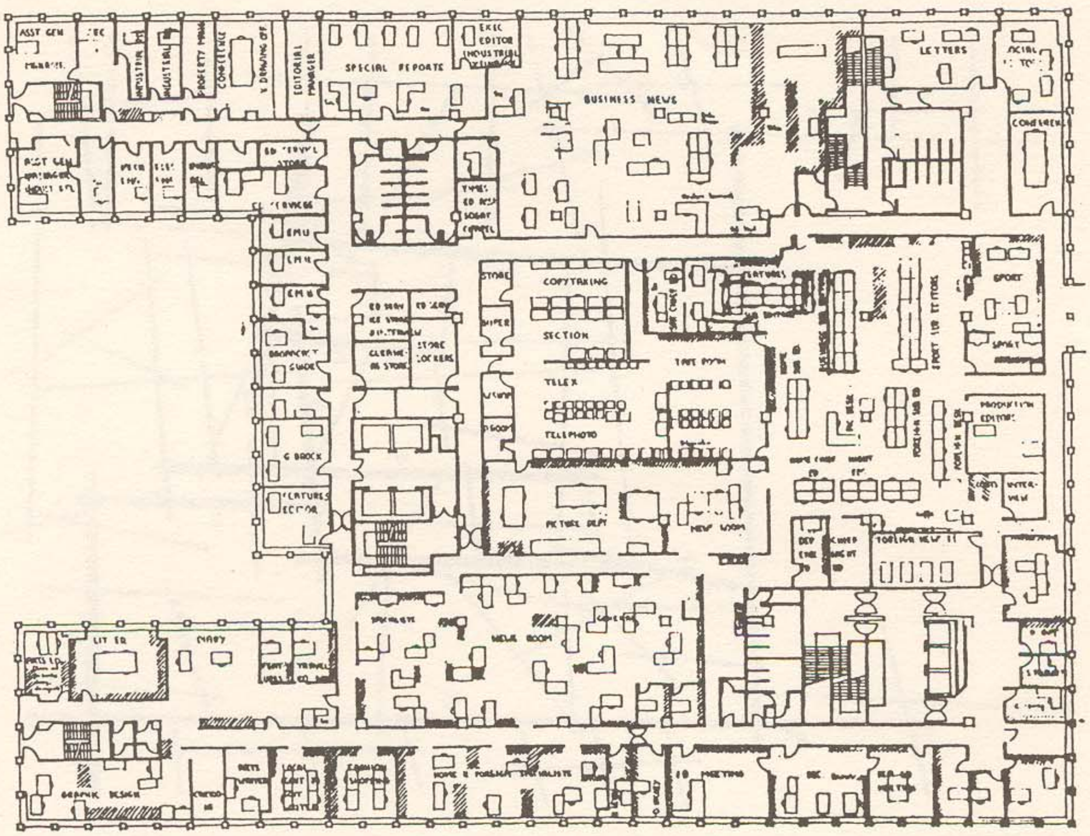

Figure 4. The editorial floor of a leading London daily newspaper, including main items of furniture and equipment.

We see here what we believe to be a general principle: as the program of the building becomes weaker and moves toward an all-play-all interface, the distribution of space use and movement is defined less by the program and more by the structure of the layout itself. This is because the high number of origin/destination pairs coupled to the integrated nature of the layout means that the by-product of movement – moving through intervening spaces – reflects the pattern of routes from all points to all other points. In this way the editorial floor comes to resemble an urban system, where movement and space use also have a weak program. In this case we can say that the grid is behaving generatively: it is optimizing and structuring a dense and random pattern of encounter, rather than simply restricting it to reflect a preexisting social knowledge pattern.

Theoretically it can be said that the editorial floor is a short-model setup; and through its integrating layout, its density of movement, and its structuring of the by-product of movement, it is generating new encounter patterns – that is, it is acting *morphogenetically* at the level of social encounter. Its content of social knowledge and noninterchangeability is weak and ever changing. The function of space is to be creative by facilitating and extending the network of unprogramed encounters necessary to the efficient running of a newspaper. Space in this sense is generative, or

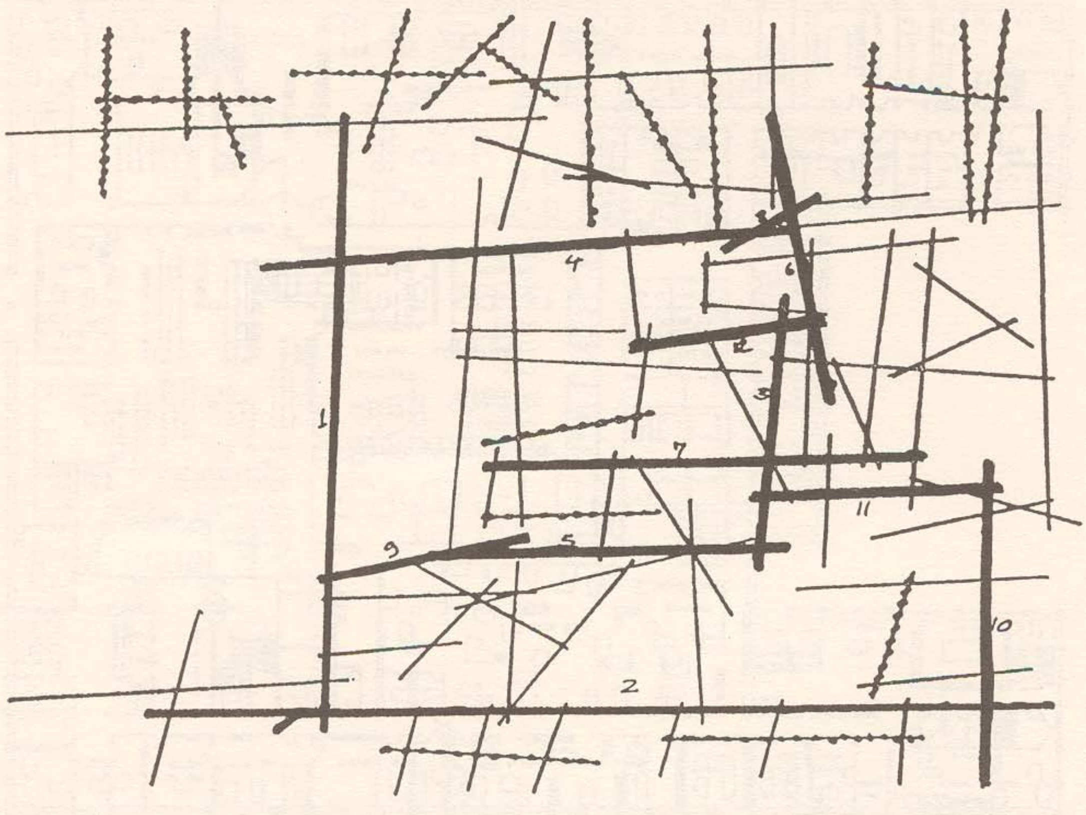

Figure 5. The axial integration core map of the open space structure of the editorial floor. The 10 percent most integrating lines are shown in heavy black, the 25 percent most segregated are dotted.

creative of knowledge A. It is generating new patterns of social relationship, which might not exist outside the spatial milieu.

This same construct can be applied to the *type* of social structure described by knowledge A. When we look for social structure in an organization one of the first things we pick on as an indicator is the division of labor. And important for our purposes here, the more obvious the division of labor, the more strongly we consider an organization to be structured. In this sense we can consider a social structure in terms of the length of the model needed to describe its division of labor. The shorter the model, the more the social structure required to carry out actual tasks will be generated through changing day-to-day needs. The longer the model, the more the division of labor itself will serve to reproduce the status quo.

In relation to knowledge A, therefore, both spatial structure and the organizational division of labor can act in either a *conservative* (reproductive) or *generative* (productive) mode, and by and large this will be determined by the length of the model governing the degree of randomness in the system.

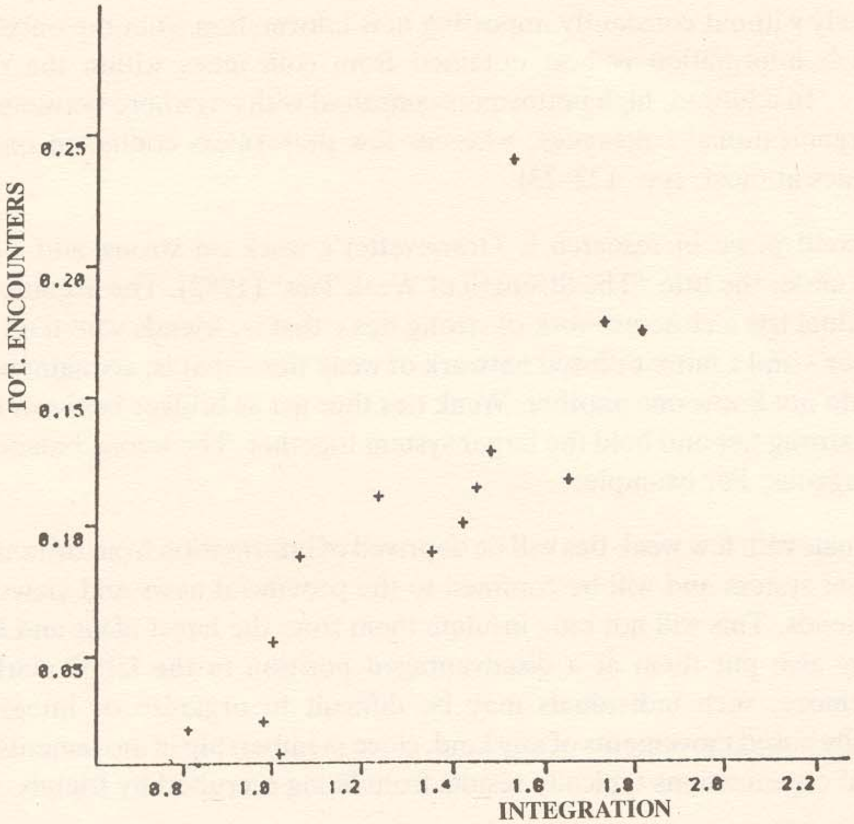

Figure 6. Scattergram showing the correlation between the integration value of a space on the horizontal axis and the observed density of space use on the vertical axis averaged over twenty observations at different times of day. The outflying point (highest use) is the photocopy space. The degree to which it is removed from the regression line of the remainder of the points indicates the degree to which it attracts use due to its function rather than its spatial location. This shows how it is possible to detect the "magnet" effect of facilities against the background of the use pattern of the spatial milieu. $r = .83, p < .001$

Strong and Weak Ties, Local and Global Networks

But what about the *production* of knowledge B – the key question? Can space influence the advance of science? Here there are no answers, but there are suggestive studies. Before describing them, we would like to present two pieces of research that, while not concerned with space, have a bearing on the matter.

The first is the seminal work of Tom Allen (1977) on communication and innovation in R&D organizations in engineering. To quote his own summary:

> Despite the hopes of brainstorming enthusiasts and other proponents of group approaches to problem solving, the level of interaction within the project groups shows no relation to problem-solving performance. The data to this point lend overwhelming support to the contention that improved communication among groups within the laboratory will increase R&D effectiveness. Increased communication between R&D groups was in every case strongly related to project performance. Moreover, it appears that interaction outside the project is most important. On complex projects, the inner team cannot sustain itself and work

> effectively without constantly importing new information from the outside world . . . such information is best obtained from colleagues within the organization. . . . In addition, high performers consulted with anywhere between two and nine organizational colleagues, whereas low performers contacted one or two colleagues at most. (pp. 122–23)

The second piece of research is Granovetter's work on strong and weak ties, presented under the title "The Strength of Weak Ties" (1982). The argument is that any individual has a close network of strong ties – that is, friends who tend to know one another – and a more diffused network of weak ties – that is, acquaintances who normally do not know one another. Weak ties thus act as bridges between localized clumps of strong ties and hold the larger system together. The wrong balance can be disadvantageous. For example:

> Individuals with few weak ties will be deprived of information from distant parts of the social system and will be confined to the provincial news and views of their close friends. This will not only insulate them from the latest ideas and fashions, but may also put them at a disadvantaged position in the labor market. . . . Furthermore, such individuals may be difficult to organize or integrate into politically based movements of any kind, since membership in movements or goal-oriented organizations typically results from being recruited by friends. (p. 106)

Granovetter's work focuses primarily on social networks in the broader community, but he also reviews work on the role of weak ties in schools by Karweit et al. (1979), and in a children's psychiatric hospital by Blau (1980).

Although Granovetter's work refers in the main to the generation of knowledge A, while Allen's refers to the generation of knowledge B, the two arguments are similar, in that both cast doubt on the long-assumed benefits of spatial and social localism (small communities, small organizations, small groups of neighbors) and point to the need for a more global view of networks. Hillier (1988) puts forward similar arguments about urban space. Recent architectural and urban theory has been dominated by social assumptions of the benefits of small-scale communities, and spatial assumptions of the benefits of localized "enclosure" and "identification." The effect of both, however, seems to be to fragment the urban space structure into over-localized zones that become empty of natural movement through their lack of global integration, and often show signs of physical and social degeneration in a comparatively short time.

All our analytic studies of the structure and functioning of urban space suggest that it is the global scale that is critical, whether to the structuring of co-presence through movement, the sense of safety, the development of social networks, or the distribution of crime. The local sense of place arises not from the existence of segregated local zones, but from different types of deformity in the global grid. The same applies to social networks. Good urban networks are not self-contained groups but distributions of probabilities within a larger, continuous system. The key to "urbanity," we have concluded, lies in the way the local and global scales of space and networks relate to each other.

All of these suggest that what is needed is a theory of space in which the relations between local and global scales and the dialectic of strong and weak ties and of structure and randomness (through long and short models) all interact. Because any spatial structure has the capability to generate patterns of co-presence through movement, it also has the potential to generate ties. Spatially generated ties will clearly in the first instance be weak ties. The more localized the tie, the more one might expect space to have the potential to help turn a weak tie into a strong tie. Indeed, in the local spatial milieu, one might well expect the spatial strategies of individuals to be concerned with the avoidance of the overstrengthening of ties – in much the same way as there are special forms of social and spatial behavior to resist the spatial pressure to make relations with one's neighbors stronger than is comfortable. The ability of space to generate weak ties lies, we suspect, in the middle ground between the immediate neighboring group and the larger-scale transspatial network that is more or less independent of space.

Probabilistic Inequality Genotypes in Two Research Laboratories

We can now look at cases. Figure 7 is the floor plan of Lab X and fig. 8 the floor plan of Lab Y. Lab X was constructed in two phases according to a single planning system, but the Lab Y building is divided into the "old building" (horizontal in the plan) and the recently added "new building" (vertical in the plan).

Both Lab X and Lab Y belong to well-known organizations, but each has a distinctive research style and management structure. Lab X is the lab of a large, well-established public charity specifically concerned with a certain range of diseases. Its director sets up and funds (according to reputation, often lavishly) teams led by eminent research leaders, whose task is to pursue specific goals laid down by the charity. The research program is thus geared to specific medical and therapeutic goals. Lab Y is oriented more to the academic production of knowledge and has a less goal-directed, more individually entrepreneurial form of organization, its members for the most part define their own research programs. Both are highly successful, but in terms of top-level performance (as measured by, for example, the number of Nobel prizes) there is little doubt that Lab Y would have to count as the higher flier.

Figures 9 and 10 show a useful way of representing the difference in the spatial layout of the two labs. In each figure, all the "free space" – that is, the space in which people can work and move freely – is colored black. This shows that in spite of the basic cellular form of each building, there are fundamental configurational differences between the spatial layouts of the new and old parts of Lab Y, and between Lab X and the old part of Lab Y. In the latter case, the differences have arisen from a protracted process of spatial mutation and adaptation.

The most important configurational difference between Lab X and the old part of Lab Y is that while both have created internal permeabilities between groups of cells,

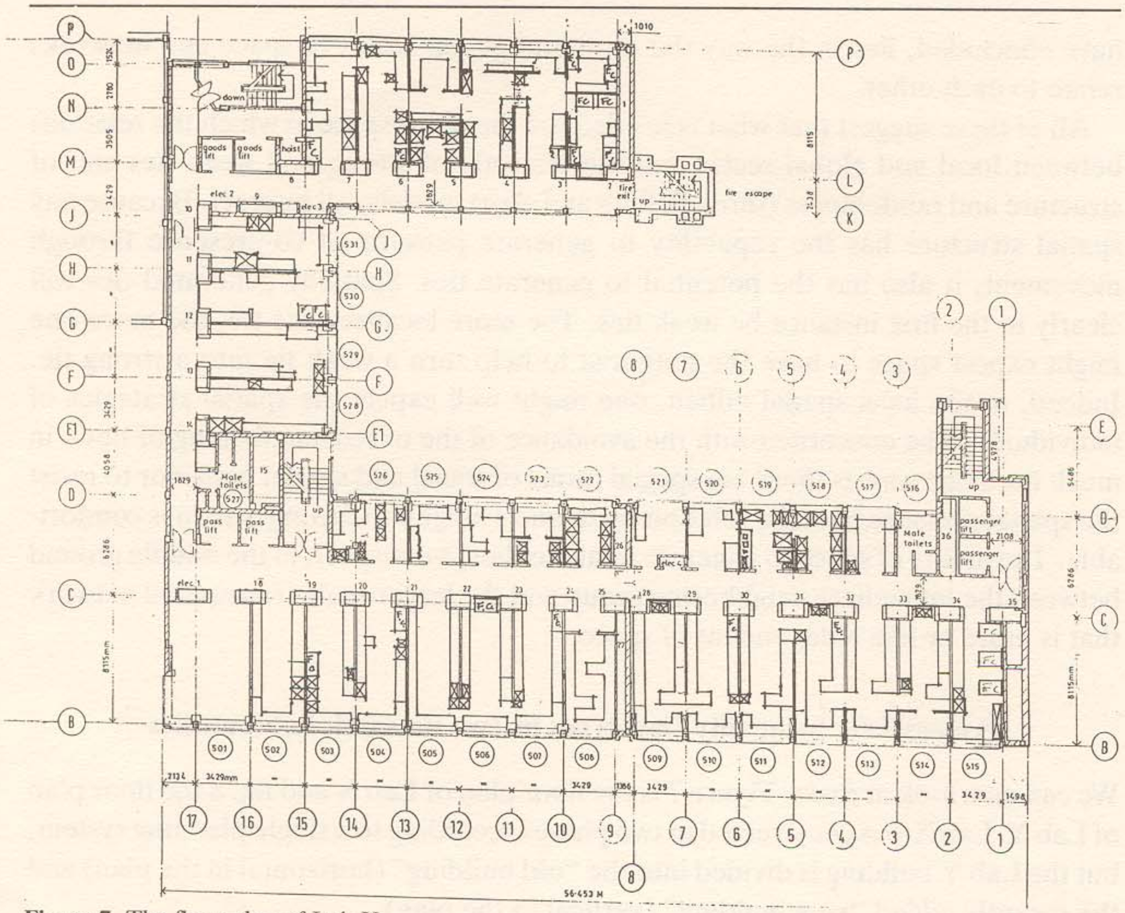

Figure 7. The floor plan of Lab X.

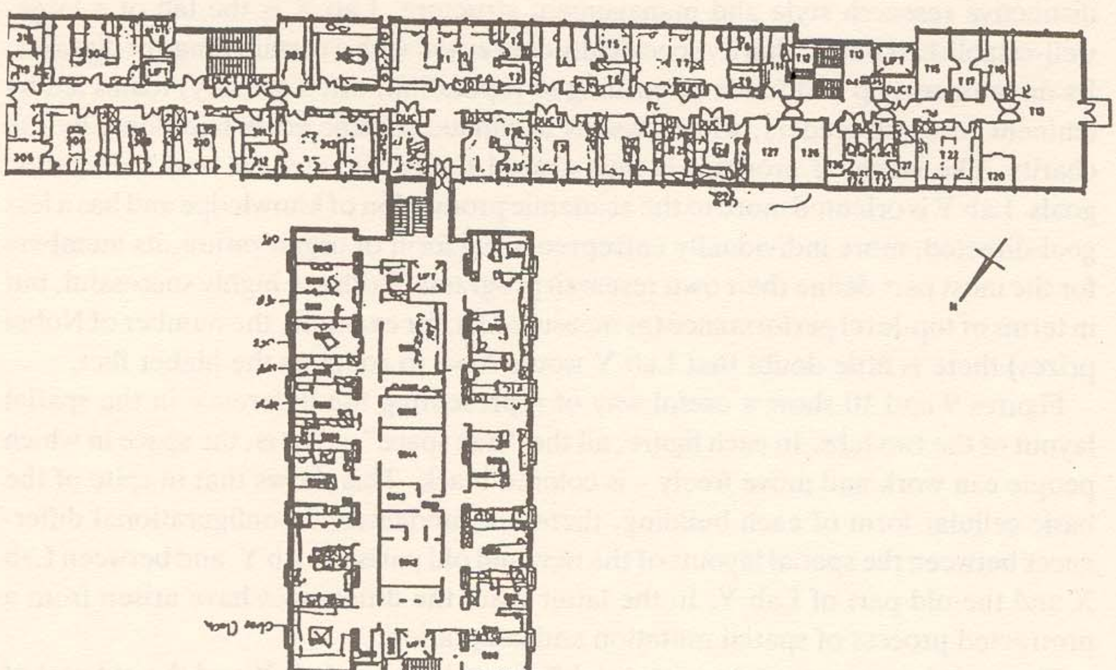

Figure 8. The floor plan of Lab Y.

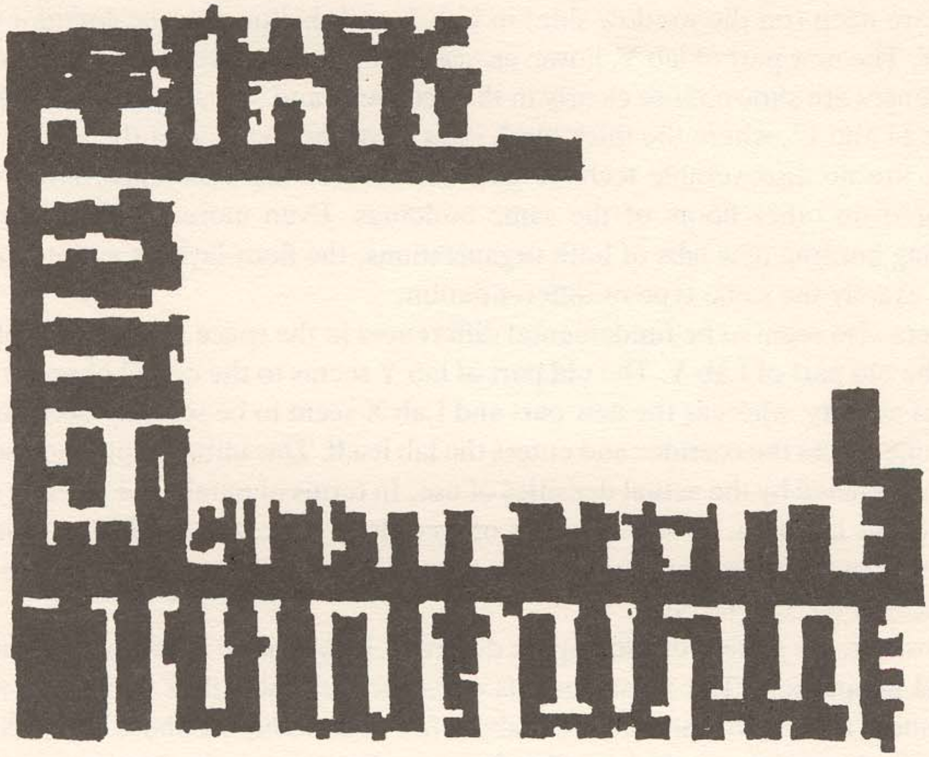

Figure 9. The open-space structure of Lab X.

and each has done it both so as to break up space into local convex lumps and so as to link these convex elements together by direct lines of sight and access, the intercell

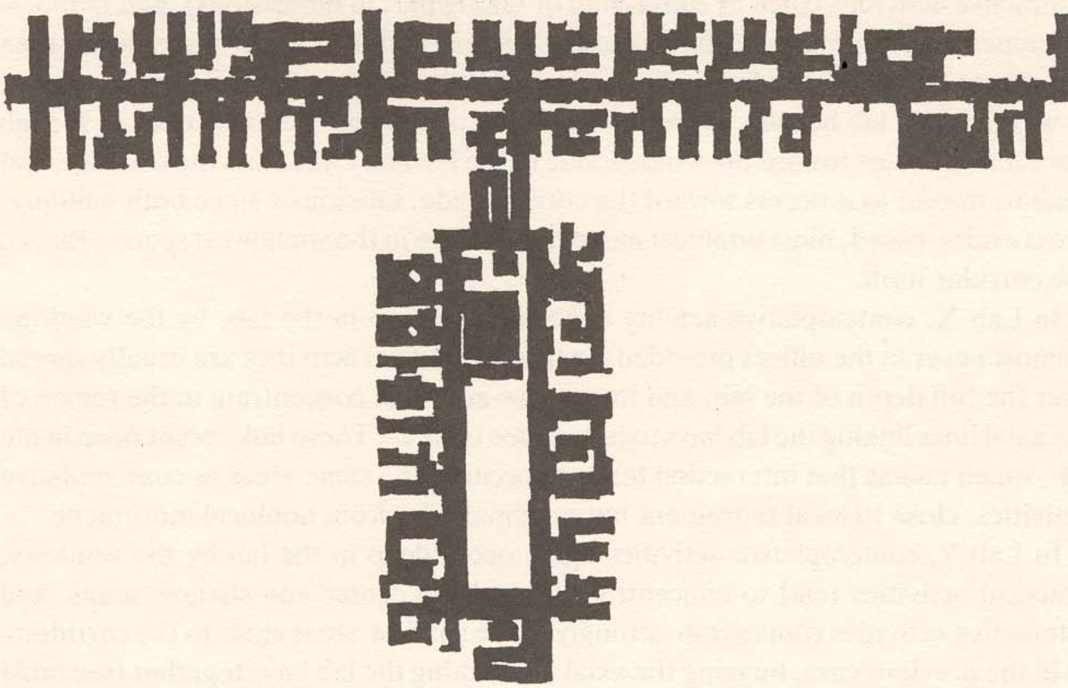

Figure 10. The open-space structure of Lab Y.

links are deep (on the window side) in Lab X and shallow (on the corridor side) in Lab Y. The new part of lab Y, however, seems to combine properties of both. These differences are shown more clearly in the "convex" and "axial" maps of each, given in figs 11 and 12, where the thick black lines show the location of the intercell links. There are no discoverable technological reasons for this difference. However it is repeated on other floors of the same buildings. Even more strikingly, in a new building housing new labs of both organizations, the floor layouts adopted by each show exactly the same type of differentiation.

There also seem to be fundamental differences in the space use patterns of Lab X and the old part of Lab Y. The old part of lab Y seems to the casual observer to be a hive of activity, whereas the new part and Lab X seem to be scarcely occupied at all until one leaves the corridor and enters the lab itself. This initial impression seems to be contradicted by the actual densities of use. In terms of number of persons divided by the full lab area, or the quantity of free floor area (the total area minus that occupied by benches and equipment) per occupant, average densities are almost identical in the two layouts.

However, the *pattern* of use is quite different, in each case following the pattern of spatial adaptation. The most obvious difference is that Lab Y has space use and movement rates in the main corridor about five times as high as those in Lab X, with a substantial component of interaction between two or more people occurring in the corridor.

We can make the pattern differences clear by dividing activities into four broad kinds: contemplative activities (such as sitting, writing), practical activities (such as working at the bench, which usually involves a certain degree of local movement), interactive activities (such as conversing or taking part in discussions), and nonlocal movement (i.e., movement that is basically linear and on a larger scale rather than describing a local convex figure, as would usually be the case for movement involved in working at a lab bench). We will describe an activity as occurring deep in the lab insofar as it occurs toward the window side of the lab and away from the corridor, and shallow insofar as it occurs toward the corridor side. Obviously since both buildings are corridor-based, most nonlocal movement will be in the shallowest space – that is, the corridor itself.

In Lab X, contemplative activity concentrates deep in the lab, by the windows (almost never in the offices provided for this!), practical activities are usually spread over the full depth of the lab, and interactive activities concentrate in the region of the axial lines linking the lab bays together (see table 2). These links occur deep in the lab, which means that interaction tends to occur in the same areas as contemplative activities, close to local movement but maximally far from nonlocal movement.

In Lab Y, contemplative activities again occur deep in the lab by the windows, practical activities tend to concentrate toward the center and shallow areas, and interactive activities concentrate strongly in the shallow areas close to the corridor – as in the previous case, hugging the axial line linking the lab bays together (see table 2). This means that interaction occurs both close to local movement within the lab, as

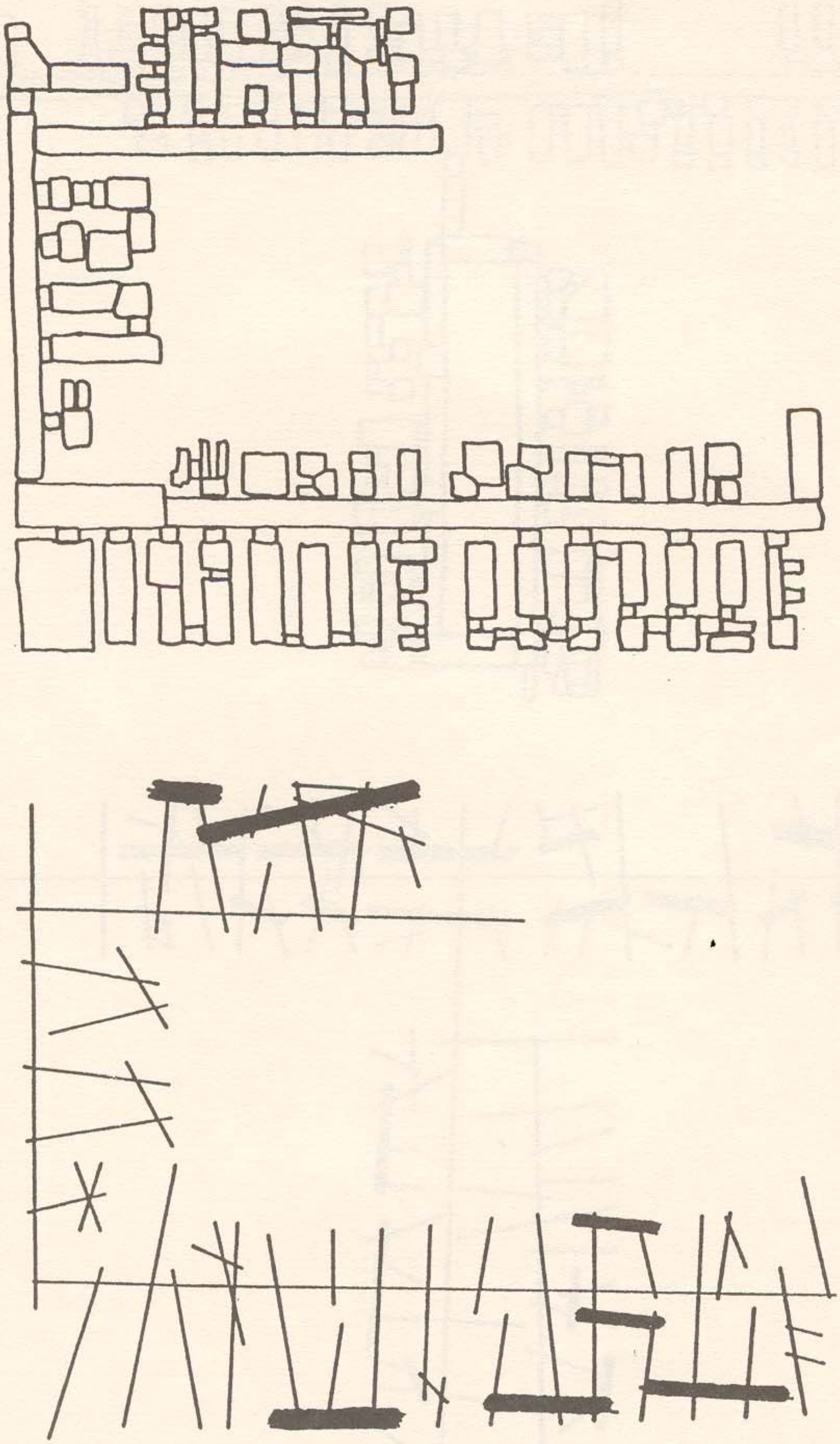

Figure 11. The convex and axial maps of Lab X. The convex map divides the free floor space of the laboratory into its "fewest and fattest" convex polygons. The axial map passes the fewest and longest straight lines of access through the free floor space. Heavy black lines mark the intercell links.

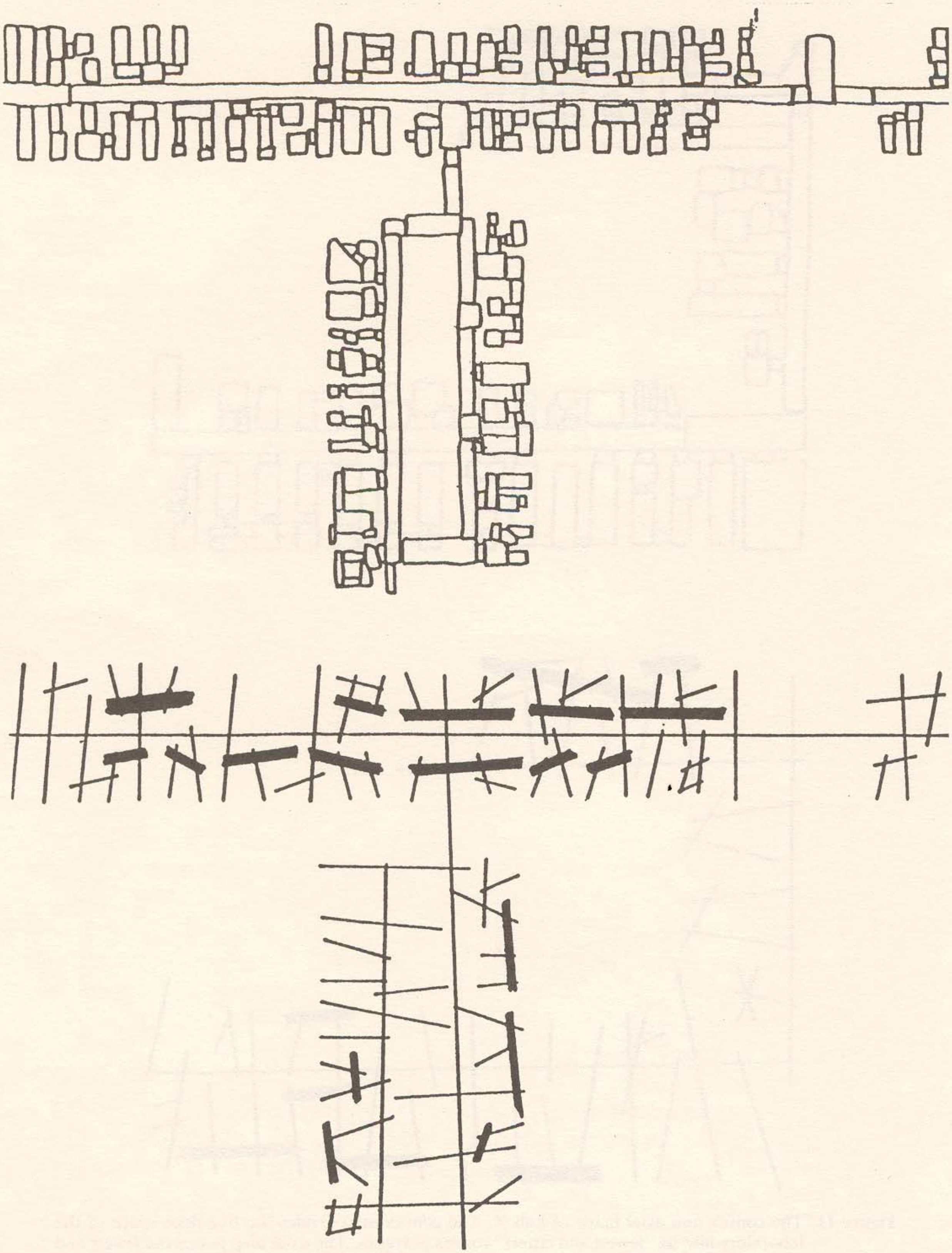

Figure 12. The convex and axial maps of Lab Y.

in the previous case, and close to nonlocal movement in the corridors, where a significant degree of interaction also occurs.

Put simply (and inevitably simplifying the real situation somewhat), we can say that in Lab Y, contemplative activities are deeper than practical activities, while interaction is shallow and close to nonlocal movement. Using the symbol "<" to mean "shallower than" we can say that in Lab Y: *movement < interaction <practical < contemplative*. In Lab X, both contemplative activities and interaction are deeper than work, and remote from nonlocal movement, so we can say that in Lab X: *movement < practical < interaction = contemplative*.

Table 2 below gives the mean distance (in meters) of each of the activity types from the local intercell links in each building. Since the distance is the mean of a large number of observations of individual workers, it provides a "statistical" picture of activity in the two buildings. This picture shows that interaction stays close to the intercell links in both buildings, but that this leads to it being close to global movement in Lab Y and removed from it in Lab X.

Table 2.

	Movement	Interactive	Practical	Contemplative
Lab X	4.9	.93	2.85	1.09
Lab Y	1.3	1.17	1.41	2.03

These formulae summarizing the spatial dynamics of each organization resemble the "inequality genotypes" noted in domestic space. But whereas the domestic inequalities were an association of function labels with integration values, and were therefore more like a Lévi-Straussian mechanical model, in the case of labs the inequalities are purely probabilistic, representing activity types rather than social categories, and therefore resemble a Lévi-Straussian statistical model.

We might call these formulae expressing differential spatial dynamics "probabilistic inequality genotypes" and note that while both are short-model they affect the dynamics of the organization differently. In Lab X, the probabilistic inequalities would seem to work to reinforce local ties and make them stronger, thus reinforcing the local group at the expense of the larger group. In Lab Y the inequalities seem to act more to create weak ties at the larger scale and link the local group to a larger-scale level of between-group contact.

We cannot yet demonstrate that these have effects on research productivity. What we can say is that the pattern exists, giving rise to a morphological concept of work organizations as something like "space use types," with suggestive relations both to organizational objectives and also to the theories of Allen and Granovetter. In terms of the organizational nature and objectives of each lab, it would seem to be a matter of how the boundaries of knowledge are to be drawn in space – that is, how the reproduction of knowledge is to be organized in support of the production of knowledge. In Lab X, the objectives are focused and defined for the group by the organization as a whole. The spatial structure of the lab and the spatial dynamics within it thus both mirror this structure and work to concentrate the efforts of a local, organizationally determined unit. In Lab Y, the more fluid organization, based more on individual initiative than on group objectives (although defined by a commonality of academic interests), has created an intensively interactive spatial milieu at the scale of the floor as a whole. In both cases, specific forms of sociality are built into the work process itself, rather than being simply added on by special-event socializing – such as going to shared coffee locations or having joint seminars (although these also occur).

So far as the production of scientific knowledge – that is, knowledge B – is concerned, we might propose that the two forms of spatial layout have radically different implications. Whereas the statistical effect of the layout in Lab X has led to the separation of interaction within a lab from large-scale movement between labs, in the old building of Lab Y the two are brought into close probabilistic contact. However, the existing state of knowledge B is defined to some degree by the organizational divisions into different research groups studying particular defined areas and physical scales of science. In the case of Lab X it is tempting to suggest that the predominant spatial milieu leads to the reinforcement of these local, preexisting boundaries of knowledge. In the old building of Lab Y, however, the tendency would be to break the existing boundaries through the random action of the spatial milieu at the large – between existing boundaries – level.

More generally – more speculatively – we might suggest that while organizations always tend to localism, the statistical tendency of the building will be either to reinforce this or to weaken its boundaries. Everything depends on the level at which the spatial structure of the building introduces randomness into the encounter field. Our instinct is to suggest that the more fundamental the research, the more it will depend on the globalizing of the generative model. In contrast to organized events, weak ties generated by buildings may be critical because they tend to be with people that one does not know one needs to talk to. They are, then, more likely to break the boundaries of the existing state of knowledge represented by individual research projects, organizational subdivisions, and localism.

We might suggest that the morphogenesis of knowledge B – like all morphogenesis – requires randomness. How can randomness be inserted into the process by which knowledge B is generated? Obviously, since science is done by human beings, it must be by randomizing the knowledge A inputs. It is at this level, it seems, that a building can operate to generate or conserve. Space is morphogenetic of knowledge B precisely because it can randomize knowledge A.

Synthesis: Creating Phenomena and Visible Colleges

There is a debate as to whether basic science is an individual or a collective activity. The evidence we are finding (and which we have presented only as examples) is that it is how the one relates to the other that is critical, at least as far as the study of space is concerned. Space, we would suggest, articulates exactly this double need for the individual and the collective aspects of research: how to combine the protection of the solitary with the natural generation of more randomized co-presence with others – the need for which seems to grow the more the objectives of research are unknown.

But it is not just that the nature of scientific work requires this kind of socialization. There is something else, we suggest, intrinsic to the nature of scientific research that gives it a spatial dynamic. It is customary to see science as a dialectic between theory and experiment, with (psychologically incompatible) theoreticians working in one corner and experimenters in another. Under the influence of such theorists as Popper and Lakatos, the late twentieth century has been preoccupied with theory (correcting an early failure to understand the deep dependence of phenomena on theory), seeing experiment increasingly as no more than the servant of theory.

Hacking (1983) disagrees, and sees experiment and theory as bound up in a quite different way. "One role of experiments," he writes, "is so neglected that we lack a name for it. I call it the creation of phenomena. Traditionally scientists are said to explain the phenomena they discover in nature. I say they often create the phenomena which then become the centrepieces of theory" (p. 220). Phenomena, according to Hacking, are not the sense data of phenomenalism. Science is not made of such. Phenomena, for scientists, are significant regularities that are useful to speculation.

Phenomena are therefore not "plentiful in nature, summer blackberries just there for the picking." On the contrary, they are rare. "Why," Hacking asks, "did old science on every continent begin, it seems, with the stars? Because only the skies afford some phenomena on display, with many more that can be obtained by careful observation and collation. Only the planets, and more distant bodies, have the right combination of complex regularity against a background of chaos" (p. 227). Because phenomena are so rare, they have to be created. This is why the creation of significant phenomena plays such a central role in the advance of theory.

Hacking, like most people in the philosophy of science, is working on big science. We are not philosophers of science and cannot offer useful comment on his propositions at that level. But we can apply his strictures to our own situation. Speaking as researchers who are trying to run a lab setup in a soft science, we know that the creation of phenomena is the center of what we do, even though we see our objectives as the creation of theory. Global spatial complexes with well-defined morphological properties, generated by computer on a restricted random process, are created phenomena. So are inequality genotypes, integration cores, and scattergrams showing correlations between integration values and observed movement or crime frequencies.

Of course, much of our discussion is theoretical. But theoretical debate centers on created phenomena, and it is created phenomena that continually destroy and generate theory. Theoretical debate survives distance. The creation of phenomena is harder to share at a distance. It is not because one discusses theories but because one creates phenomena that people cannot be absent for long without beginning to lose touch. The creation of phenomena, it seems, is more spatial than is theory.

We suspect it may also underlie the more localized spatial dynamics of the laboratory. "What's so great about science?" Hacking asks. He then suggests it is because science is "a collaboration between different kinds of people: the speculators, the calculators, and the experimenters." "Social scientists," he adds,

> don't lack experiment; they don't lack calculation; they don't lack speculation; they lack the collaboration of all three. Nor, I suspect, will they collaborate until they have real theoretical entities about which to speculate – not just postulated "constructs" and "concepts," but entities we can use, entities which are part of the deliberate creation of stable new phenomena. (Hacking 1983, 249)

The locus of this collaboration is, we suggest, the research lab. A lab is where thoughtful speculators are close to the creation of phenomena. To be absent from the lab is not to be unable to theorize, but it is not to know quickly enough or precisely enough what to theorize about. This is not of course to say that the collaboration between theory and the creation of phenomena cannot proceed at a distance. On the contrary, it is obvious that it often does. But what science cannot do without, we suggest, is the existence of lab-like situations *somewhere,* where the creation of phenomena and speculation – and probably calculation too, if our experience is anything to go by – feed off each other.

Such *visible colleges* are, we suspect, the precondition for the existence of science's ubiquitous *invisible colleges.* Where they occur, a spatial dynamic will be set up, which will mean that, for a while at least, a good place will exist in which science can happen. That good place is, probably, a *generative* building. Only when such concrete realities exist somewhere within the abstract realm of the invisible college can that peculiar form of morphogenesis that we have called the creation of knowledge B become a collective phenomenon.

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