



Discipline and the Material Form of Images: An Analysis of Scientific Visibility

Author(s): Michael Lynch

Source: *Social Studies of Science*, Vol. 15, No. 1 (Feb., 1985), pp. 37-66

Published by: Sage Publications, Ltd.

Stable URL: <http://www.jstor.org/stable/285307>

Accessed: 22/04/2010 15:01

Your use of the JSTOR archive indicates your acceptance of JSTOR's Terms and Conditions of Use, available at <http://www.jstor.org/page/info/about/policies/terms.jsp>. JSTOR's Terms and Conditions of Use provides, in part, that unless you have obtained prior permission, you may not download an entire issue of a journal or multiple copies of articles, and you may use content in the JSTOR archive only for your personal, non-commercial use.

Please contact the publisher regarding any further use of this work. Publisher contact information may be obtained at <http://www.jstor.org/action/showPublisher?publisherCode=sageltd>.

Each copy of any part of a JSTOR transmission must contain the same copyright notice that appears on the screen or printed page of such transmission.

JSTOR is a not-for-profit service that helps scholars, researchers, and students discover, use, and build upon a wide range of content in a trusted digital archive. We use information technology and tools to increase productivity and facilitate new forms of scholarship. For more information about JSTOR, please contact support@jstor.org.



Sage Publications, Ltd. is collaborating with JSTOR to digitize, preserve and extend access to *Social Studies of Science*.

<http://www.jstor.org>

● ABSTRACT

This paper is about how natural objects are made visible and analyzable in scientific research. It is argued that the objects scientists actually work upon are highly artificial, in that their visibility depends upon complex instruments and careful preparatory procedures. Instruments and laboratory procedures do more than provide a window to the world; they lay the groundwork for specific analytic operations which utilize literary resources to represent phenomena graphically. Two specific cases from biology are discussed. The first is from a popular field manual, and is used to introduce themes for analyzing a more complex case, a neuroscience project using electron microscopy of brain tissue. The discussion of both cases concerns how specimens are modified into 'docile objects' for purposes of investigation. These modifications are summarized under the headings of 'marking', 'constituting graphic space', and 'normalizing observations'. Finally, it is claimed that these practices make up an 'externalized retina' for scientific perception — a 'retina' that depends upon disciplined conduct within the laboratory setting.

Discipline and the Material Form of Images: An Analysis of Scientific Visibility

Michael Lynch

A characteristic feature of scientific activity is the production of visual displays of objects, processes, relationships and theoretical constructs. Scientific publications often include illustrative photographs, diagrams, graphs and other data displays. Visual displays are not only valuable as illustrations in scientific texts; they are irreplaceable as documents which enable objects of study to be initially perceived and analyzed. Such displays systematically transform specimen materials into observable and mathematically analyzable data.

Objects and relationships which were initially invisible become visible and palpable as a result of highly technical skills and complex instruments. What laboratory scientists perceive and work upon is thus artificial in the extent to which its appearance depends

upon such technologies.¹ Artificial features of visual displays sometimes are blamed for illusions, misrepresentations or distortions, but in fields such as electron microscopy the artificial appearance of a specimen is what enables it to be observed and analyzed in the first place.²

In this paper I analyze two cases of scientific illustration and discuss conventions used by laboratory researchers to make their objects of study visible and analyzable. The conventions produce features of visual displays which reflect the disciplinary organization of scientific labour as much as they do the organization of natural objects and relationships.

My resources for making the analysis are diverse. They include previous studies on the details of laboratory practice and scientific literatures.³ The discussion is also informed in a more general way by extant sociological and historical research on methods of order production in the human and natural science disciplines.⁴

Another source of information about visual displays are the conversations by laboratory practitioners while constructing and analyzing displays.⁵ Such conversations demonstrate that what can be seen and said of such displays varies with the situation — with the purposes of a project, the composition of a work group, and the informal methods used in a laboratory and in the field at large to establish what counts as an adequate display of an object.

What I want to address, however, is not how any particular conversation refers to a visual display or influences the further course of its production: I want to be able to characterize general features of the production process as a whole. The visual documents and conversations that appear at various stages of a project are part of a larger and more inclusive set of operations involving complex instruments, simple hand tools, manual tasks, specimens and their residues, and literary and mathematical facilities such as scales, graphs, tables, labels, indices and so forth. The process of working with such materials cannot adequately be characterized by focusing only on verbal references to an object, literary inscriptions,⁶ the relationship between written accounts and visible displays, or embodied actions at the lab bench.⁷ What I will present instead is an account of how a specimen is transformed into visible and analyzable data through the various stages of a project. I will describe the *rendering practices*⁸ which utilize a variety of modalities⁹ of action to transform the documentary form of a scientific object from one stage of a project to another.

The documents reproduced in Figures 1–5 will be used as an occasion to discuss practices of constructing scientific data. Although I believe that such documents act as an organizational focus of the various tasks that make up a project,¹⁰ I will not be discussing semiotic elements that can be inferred from the pictures by themselves.¹¹ The pictures will be discussed inasmuch as they were featured in a labour process. Some of the features of the displays which reflect that process became obvious only after I had observed laboratory work *in situ*.

The first of the two cases discussed in this paper (Figure 1) is taken from a popular field guide of reptiles and amphibians, and was chosen because of its utter ‘proto-scientific’ simplicity. Specific themes will be taken from the analysis of that case and then applied to the second instance. The second case is a series of documents used during a neurosciences research project (Figures 2–5). The laboratory that conducted the project was the subject of an ethnography I performed several years ago. During that study I examined the overt features of the lab’s graphic displays, observed the series of procedures that were used to construct them, tape-recorded several discussions while lab members were assembling and interpreting the displays, and read several drafts of a research publication that resulted from the project.¹²

I believe that the properties of graphic representation that the two cases illustrate are very common in science. This does not mean that they are universal in science, or that they are essential to science as a demarcated domain of activity. Instead, they are more like typical ‘instruments’ of graphic and pictorial representation which enjoy widespread use in many scientific fields, although science surely does not hold a monopoly on their use.

A Proto-Scientific Example

The diagram in Figure 1 is a rudimentary display of ‘scientific’ activity. It is selected for analysis here as a case which should readily be comprehended, as its reading requires no extensive training in any of the specialized natural sciences. The simplicity and ordinariness of the display makes it useful for pedagogical purposes, and, I will argue, allows us to identify elements which are common to more complex and esoteric representational procedures in science.

FIGURE 1
Map of Study Area, Showing Home Ranges of Marked Lizards

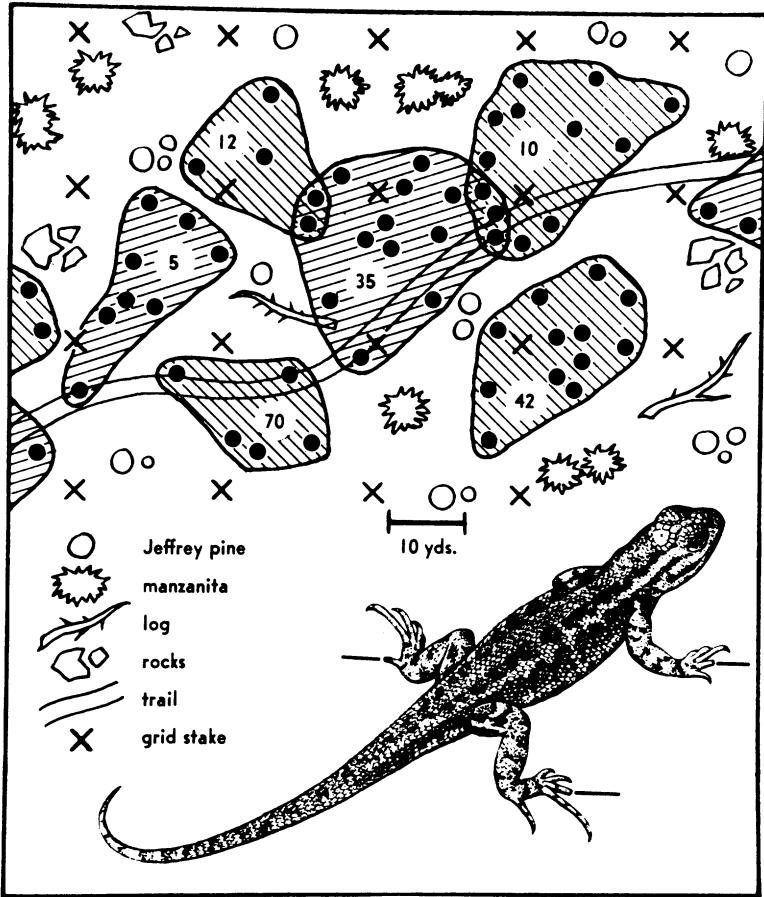


Figure [1] illustrates the kind of results that can be obtained. The home ranges of six Sagebrush Lizards are shown. The lizards were given identification numbers and were permanently marked by removal of two or more toes in combinations. Recaptures (black dots) were plotted in reference to numbered stakes (X) arranged in a grid at 20-yard intervals, and were located by pacing the distance to the two nearest stakes. Toes removed from the lizard shown are right fore 4, right hind 3, left hind 5, expressed as RF4-RH3-LH5. (Figure and legend quoted from Robert C. Stebbins, *A Field Guide to Reptiles and Amphibians* [Boston, Mass.: Houghton Mifflin, 1966], 20-21.)

Note: Numbers assigned to figures in the original texts are changed to be consistent with their use in this paper.

This figure is part of a set of instructions for doing a field study of reptiles. The instructions do not describe an experiment; they outline certain preparations for systematic observation and experimentation, and are in that sense ‘proto-scientific’.¹³ No explicit hypotheses are formulated or tested; instead, a set of elementary operations is performed which clears the way for observation and experimentation.

The diagram is organized as a map, with certain identified landmarks, a set of coordinates and a distribution of territories. The accompanying caption provides instructions for constructing the map: (1) marking lizards; (2) constituting a grid; and (3) placing a series of observations within the coordinates of the grid. The instructions can be summarized as a set of procedures for turning a ‘natural’ setting into a geometricized workplace.¹⁴ A landscape is transformed into the graphic grounds of careful observation and measurement, and the figures of the lizard territories are constituted on the ground of that transformation. The three themes, ‘marking’, ‘practically constituting graphic space’, and ‘rendering observations as points’ identify a programme of widespread use in science — one that will be examined in reference to other examples later in this essay. First, however, I will supply preliminary characterizations of each of the three themes in reference to the proto-experiment described in Figure 1.

Marking: Counting on the Fingers of a Lizard

The text in Figure 1 matter-of-factly describes a procedure for marking and coding lizards by amputating a unique combination of toes on each captured individual. A literary record of the individual’s mark is produced as a code for limb and amputated toe (for example, ‘RF4-RH3-LH5’, as a notation for ‘right front fourth’ digit, etc.). Each captured animal is thus given a unique ‘mathematical’ identity for any subsequent observations, through the construction of a ‘mark’ as a naturally visible code of the animal’s place in a numerical order.

The naturalistically visible lizard is no longer just a lizard, as it becomes the bearer of a numerical code. Marking preserves a class of lizards, equivalent in all respects except for the unique identity of each mark within the set of marks.

Constituting Graphic Space

The caption identifies each 'X' in the illustration as a 'numbered stake arranged in a grid at 20-yard intervals'. The arrangement of stakes produces the coordinates of a graph through a concrete construction on the ground surface, analogous to a surveyor's rendering of a landscape into grids or plots to set the stage for residential development. 'Mathematical' space comes to dwell within the 'natural' terrain. The two surfaces coincide at the visible points marked by the stakes.

The placement of stakes performs a double role. On the one hand, it is clear that the stakes mark off equivalent intervals in a two-dimensional grid, and that the placement attempts to approximate a geometric overlay on the uneven surfaces of the terrain. On the other hand, the selection of interval size appears to be 'phenomenally' and 'practically' oriented. Twenty-yard intervals are selected. The selection is not arbitrary, since it already includes reference to the sorts of size that lizards' territories might show. Three-inch intervals are not recommended, nor are 100-yard intervals. The interval is selected to be on a scale appropriate to the texture of territories it resolves. Too large an interval does not readily resolve the lizards' movements, while too small an interval creates a tedious and disruptive army of stakes. In other words, theoretical assumptions about lizard behaviour are already built non-discursively into the graphic device's scalar properties.

The ultimate reconciliation of the grid and the surface it marks off occurs on the surface of the map. The two-dimensional paper brings together the identified landscape and the mathematical grid. Graphic formats come to embody properties analogous to the Kantian categories of time, space and causality. The map transfers the categories from an ideal transcendental context to a concrete manipulatory region.¹⁵ No longer are they transcendental in an absolute way; they transcend the field of operations they prepare for, and yet they are themselves constructed in human activity. I suppose what this procedure amounts to is 'standing Kant on his hands'.

Although we are analyzing the chart on the page, its ordered properties do not originate there. A 'proto-map' is built into the natural landscape itself. The stakes driven into the surface of the ground mark off the outlines of a scale and the geometrical form of a graph.¹⁶

Normalizing Observations as Equivalent Dots

Individual specimens are graphically identified by their place on the grid. Each sighting of a lizard is typically governed by the constraints of place-on-the-grid. The temporal collection of sightings is spatialized and geometrized in the synthesis of animal territories. (The sequential order of sightings is not notated, presumably since it reflects the vicissitudes of observing and capturing specimens and not systematic patterns of the lizard movement.)

Note that each observation of a marked individual is rendered equivalent to all others through the use of the device of the 'dot'. The only material difference between one dot and another on the chart is its locale. Locales are reckoned in terms of the grid of stakes, and all other circumstantial features of observation 'drop out'.

The Docile Object: Merging Graphic Properties with the Visible Residues of a Specimen

The problem of visibility in science is more than a matter of providing illustrations for publication. Published and unpublished data displays, in the form of graphs, photographs, charts and diagrams, *constitute* the material form of scientific phenomena. By 'material' I mean sensible, analyzable, measurable, examinable, manipulatable and 'intelligible'. Although the procedures for making the object scientifically *knowable* implicate an independent object, they simultaneously achieve a graphic rendering of the object's materiality.

The question is not, 'How do objective properties correspond to graphic devices for isolating and ordering those properties?'; it is, 'How do graphic properties *merge* with and come to embody the "natural object"?' The latter question inquires about how science initially determines what is natural on the basis of what its graphic devices disclose.

From our brief examination of the 'proto-scientific' illustration we have introduced three themes: marking, constituting graphic space, and normalizing observations. A *docile object*¹⁷ is the product of those rendering procedures. It is an object that 'behaves' in accordance with a programme of normalization. This

does not mean that it fails to resist, or that its recalcitrance does not serve to adumbrate its objective news for science. It is to say that, when an object becomes observable, measurable and quantifiable, it has already become *civilized*; the disciplinary organization of civilization extends its subjection to the object in the very way it makes it knowable.¹⁸ The docile object provides the material template that variously supports or frustrates the operations performed upon it. Its properties become observable-reportable¹⁹ in reference to the practices for revealing them. If the object was not compliant to such a programme, its attributed properties would be incompletely or ‘unscientifically’ observable.

Constituting the Visible Anatomy of Axon Sprouting

The themes of marking, constituting graphic space and normalizing observations will now be explicated in more detail in reference to a more complex case: a project for anatomically demonstrating a regenerative process in the hippocampus. The report of the project was published in a neurosciences journal and was one of several similar studies by members of a small university research laboratory in California. I was able to observe this project *in situ*, and to tape-record several conversational interactions between laboratory scientists as they performed various tasks during the project.

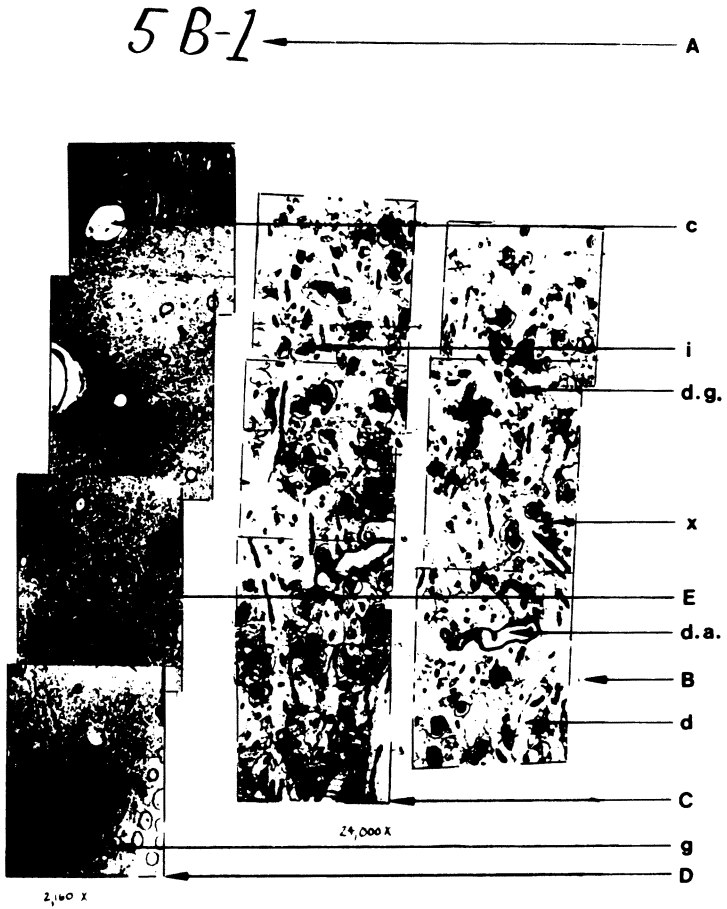
The focal point of the project was the construction and analysis of electron-micrographic ‘montages’ of the rat hippocampus (see Figure 2). The montages consisted of several electron micrographs which were placed together to show a continuous view of tissues, similar to the way an overlapping array of aerial photographs is used to display a more extensive terrain. Each montage consisted of a ‘map’ of two adjacent regions of axon terminals (the end ‘boutons’ of axons which form synapses with neuronal dendrites). The two fields of axons were said to arise from neurons in distal areas of the brain: one field arose from an area of the cortex, and the other from the hippocampus on the opposite side of the corpus callosum. The fields were said to be ‘layered’ in a direction roughly parallel to another layer of ‘granule cell’ bodies. The neurons in the granule cell layer sent tree-like branches of dendrites coursing across the two fields of axons, synapsing with terminals in both layers.

The montages were used as part of an experiment for assessing the anatomical changes occurring in the adjacent axon layers after the destruction of the area of the brain from which one of the axon layers originated. A lesion was performed on anaesthetized animals (Sprague-Dawley rats — a strain of rat bred for uniformity of brain dimension and behavioural docility), and the animals were revived and then killed at a variable number of days following the lesion. The brains were removed and preserved, and the hippocampus was dissected. Electron micrographs were taken at standardized locales in the dentate gyrus, and were carefully pasted together to produce the montages. The montages were then analyzed, and cross-sections of ‘intact’ (apparently ‘normal’) and ‘degenerating’ terminals were marked with colour-coded outlines drawn with felt-tipped pens. The edges of the montages were used as scales for constructing a grid of sectors, and counts of intact terminals were taken in each sector. These were then plotted on a graph (Figure 3), where one axis of the graph was a scale of distance in microns from the granule cell layer and the other axis displayed density of intact and degenerating terminals. The broken and solid lines indicate, respectively, ‘mean terminal counts’ of intact terminals at four days and at eleven days post-lesion. The graph can be read as evidence for a change in the distribution of intact terminals between four and eleven days after lesion.

Together with other evidences from the lab’s researches, these data were used to make a case for ‘axon sprouting’, a compensatory mechanism in the face of irreversible damage to nerve tissue. Axons from the undamaged field ‘sprouted’ new branches and formed new terminals partially to reoccupy synaptic sites vacated by the destroyed terminals in the other cell layer. Continued research on the topic over the past several years has substantiated these anatomical findings, and, further, has suggested a biochemical basis for the regenerative phenomenon.

The graph in Figure 3 is the literary end-point of a series of renderings which transformed cellular arrangements into graphic space. This transformation is nicely expressed in the figure, where the horizontal axis of the graph is extended to the left, across the page, to intersect with the schematic *camera lucida* drawing of a granule cell. Figure 4 further schematizes the naturalistic origins of the graph, tracing them back successively to a geometric slab of hippocampal tissue, a cross-section of the hippocampus, and the hippocampus as a whole (the banana-shaped item on the far left of the figure).

FIGURE 2
Electron Micrographic Montages



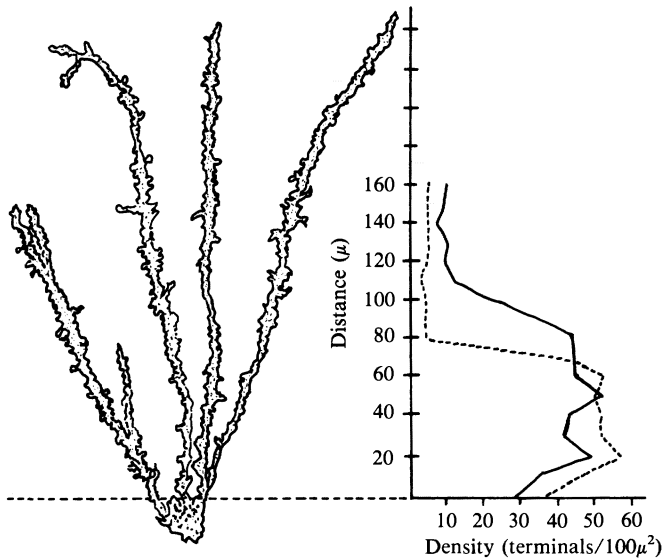
Key to Figure 2

- A = index identifying montage
 5 = number of 'days' post-lesion before specimen's sacrifice
 B = index for particular section of tissue used for montage
 1 = identification of particular animal used as specimen
- B = scale of 'micron equivalents' drawn along margin of column. Numbers on the scale represent vertical distance from the granule cell bodies.
- C = high-power electron-micrographic montage (24,000×)
 D = low-power electron-micrographic montage (2,160×)
 E = hand-drawn rectangle marking placement of 'high-power' montage in the field of 'low-power' montage (see closeup in Figure 5)
- d.a. = 'marked' degenerating myelinated axon. Dark outline and parallel slash marks within the borders of axon were drawn by hand to mark it.
 d.g. = 'marked' degenerating axon terminal. Black pen was used to trace outlines of degenerating terminals on a clear plastic overlay. Circle around the terminal marks it as a 'countable' instance.
 i = 'marked' intact axon terminal. Red pen was used to trace 'intact' terminals. Circle around the terminal marks it as a 'countable' instance.
 x = 'marked' degenerating axon, with an 'X' mark notating that terminal is a 'doubtful' instance. Often an X was used to mark a case where the terminal candidate was not visibly associated with a 'post-synaptic density' (a conspicuous feature of a synapse). In other cases an X noted that the analyst was uncertain about whether the instance was intact or degenerating.
- c = capillary (in cross-section)
 d = dendrite (presumably arising from granule cell layer)
 g = granule cell bodies (nucleii outlined with marking pen)

The low-power montage was used as a locational reference for the high-power montage. Analysis of axon terminal density and distribution was done on the high-powered montage by counting numbers of marked and 'countable' intact terminals for each 5-micron sector of the montage. A statistical display of the outcome of the analysis is shown in Figure 3.

Note: Photographs in this figure and Figure 5 are taken with permission from unpublished data displays used in an electron-microscope study of 'axon sprouting'.

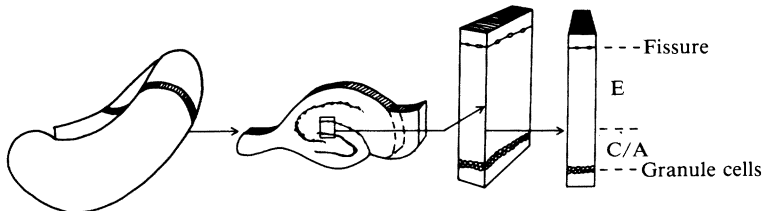
FIGURE 3



A camera lucida drawing of a Golgi [stain]-impregnated granule cell on a common vertical axis with a graph depicting density (terminals/100 μ^2) of the molecular layer as a function of distance (microns) from the top of the granule cell layer. The plots are mean terminal counts of the 4-day (dotted line) and 11-day (solid line) post-lesion groups.

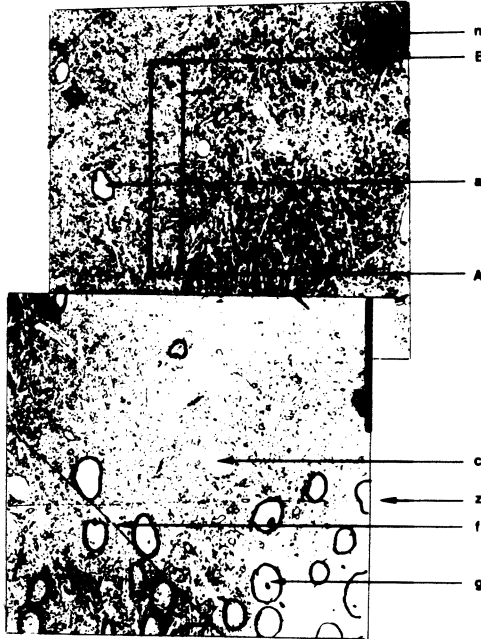
Note: Figures and legends for Figures 3 and 4 were taken with permission from a draft of a paper written in 1975 by members of the neurosciences laboratory discussed here. The specific names of the researchers and title of their publication is not mentioned in order to preserve anonymity.

FIGURE 4



A schematic illustration of the position and orientation of the region sampled by electron-microscopic montage. At left is the hippocampal formation ipsilateral to the entorhinal cortex lesion. A 125- μ coronal section from the dorsal portion of the formation is cut, and from that section is removed a block of tissue oriented perpendicular to the plane of the granule cells extending from below the granule cell layer to above the hippocampal fissure. Ultra-thin sections are cut from the medial edge of this block. The zones of afferent occupation in the molecular layer are indicated E = entorhinal, C = commissural, A = associational.

FIGURE 5
Enlargement of Low-power Montage from Figure 2, Showing Placement of High-power Montage in the Field above the Granule Cell Bodies



Key to Figure 5

- A = 'lower' edge of rectangle showing placement of high-power montage in the field of the low-power montage. The scale of micron equivalents begins at about 60μ above the granule cell bodies.
- B = 'upper' edge of rectangle, approximately 110μ above granule cell layer. Note, microns were computed in reference to the magnificational power of the photographs and a metric scale was constructed to mark 'micron equivalents' for each montage.
- a = astrocyte cell nucleus marked with blue line drawn around border. [Note: these were not discussed in the present paper.]
- m = two 'marked' microglia cell nuclei. [These also were not discussed here.]
- g = 'marked' granule cell nucleus in granule cell layer (nucleolus is dark spot in centre of nucleus)
- c = capillary cross-section
- f = artifactual line presumably due to the folding of the thin tissue section during preparatory procedures.
- z = line drawn to interpolate 'upper edge' of the granule cell layer for purposes of measuring distances from the cell layer. The line acts as the 'zero' point on the vertical scale of microns.

Given the naturalistic linkages between the graph and the hippocampal material, we can now examine in detail how the material was successively 'geometricized', 'chronologized' and 'mathematized' such that its scientific visibility and demonstrability was achieved. The three themes of 'marking', 'constituting graphic space' and 'normalizing observations' will now be reintroduced in the discussion of this particular instance.

Marking

Marking was achieved at numerous junctures in the course of the project, and in widely different ways. As mentioned above, colour-coded marks were hand-drawn upon the surfaces of the montages to distinguish 'intact' from 'degenerating' terminals. Among the several tasks achieved by such marks was that of indexing.

Indexing

Early in the project, while the animals were still alive, a varying number of ink slashes were drawn on the tails of each individual rat to index the animal's unique numerical identity in the corpus of specimens. The fragmentary remains of the animal were also indexed with marks and numerals to constitute a coherent 'biography'.²⁰

Marking was constituted not only through a relation between a practitioner's hand and a specimen. It was already built into the operation of the procedures which made 'tissue structure' visible in the first place.

Labelling

The term 'label' was used as a synonym for the various stains applied to tissues to make them visible for light and electron microscopy. Specimen materials were immersed in solutions of metallic compounds in order to distinguish protein structures by selectively covering them with dense precipitates. The structure of deposits composed a visible architecture of light or electron-absorbent material which enhanced the visibility of membranal structures. Cellular structure was thus dependent upon the devices of 'labelling' for its accountability.

Although writing in the familiar mode was not involved, the term 'label' was apt. The stain, like a name, *defined, pointed to* and *consolidated* the visibility of its object. Furthermore, 'labelling' was performed under a programmatic 'Cartesian' separation between the object-labelled and the artifice of labelling. The artifice of labelling was, in principle, distinguished from what the label revealed. Like language, however, 'labelling' was shadowed by a devil's playground full of possible mistakes, errors, oversights and fraudulent uses. Staining artefacts could obscure the object or create fictional resemblances; it could constitute ambiguities in the form of the object versus the form of the label. Daily lab activities were largely concerned with the practical maintenance of that 'Cartesian' division. Questions on the essential artificiality of *any* thing that becomes accountable within such a programme are entertained in the neurosciences, though only as a matter of 'philosophical' interest.

*Upgrading Visibility*²¹

As in the case of labelling, varieties of practices were used to enhance and select thematic constituents for appropriation within the continuing development of the project. These practices might be summarized as an externalized and instrumental labour of selective perception. For instance, marking terminals on the surface of the montages was not merely a matter of indexing. Each time a terminal was outlined, and thus coded, its visibility against the background of ultra-structural materials was highlighted and disambiguated. The number of marked terminals did not correspond to the number of 'actual' terminals in the field, nor could they. Instead, each time a terminal was marked, it was *counted* as 'good enough' to stand as a defensible case. Some possible cases were not marked because they were ignored. Others were marked as indistinct, within the plane of the photograph, on whether they were intact rather than degenerating or axon terminals rather than something else (see Figure 2). After they were marked, the traced instances stood out as a corpus of clear cases, easily distinguished and readily counted.

In other areas of the lab's work not directly affiliated to the particular project, an amplification and clarification of literary analyzability was instrumentally produced. Complicated electro-physiological equipment was used to transfer mechanically, within

pre-coded ranges of frequency, the electrochemical events of a region of brain cells to the graphic surface of a moving scroll of paper. Such electrophysiological monitors worked much like a seismograph on a different terrain to enhance and analyze faint and otherwise undetectable movements.

The *camera lucida* drawing in Figure 3 is a further instance of an upgraded specimen. The drawing is interesting for the way it straddles the vague line between drawing and photography — between the realm of ‘manual’ transfers, and the more respected realm of ‘instrumental’ transfers of imagery.²² The *camera lucida* projects a light microscopic field on to a sheet of paper. The projected conformations of a prepared slide of tissues can then be traced by hand on the surface of the paper. Unlike a photograph, the drawing can superimpose, in one continuous line, courses of dendrites and axons which snake in and out of the focal field of the microscope; a series of adjustments of focus can be collapsed into one schematic trace. *Outlines* can be clarified and continued across gaps and blurriness. ‘Inessential’ constituents can be omitted or glossed, as in the undifferentiated texture of dark shading in the interior of the granule cell in Figure 3. The drawing therefore retains its visible relation to the projected slide while offering the advantages of a schematic record which has been clarified in accordance with the analytic aims of the project.

Constituting Graphic Space

Practices for constituting graphic space can be described as pre-linguistic modes of order production. This does not mean that language and verbal conceptualization are not involved. Instead, it means that material media, in addition to the coded sounds or marks of verbal and written language, already define, to an indefinite degree, what becomes ‘knowable’ or ‘reportable’ in linguistic or conceptual terms. Intelligibility is built into the visible form of materials in the way they are brought under scrutiny.

In the case described here, all stages of the production of the ‘sense data’²³ for axon sprouting involved the location and use of empirical approximations of the perfected forms of geometry. These practical geometries were appropriated both from ‘endogenous’ conformations of the cellular material examined and ‘exogenous’ conformations of the instrumental fields and literary

formats used in rendering the materials examinable. The sequential stages of the project exhibited a kind of ‘bootstrapping operation’²⁴ which upgraded the visible form of ‘endogenous’ geometries to bring them into alignment with angular and dimensional properties of ‘exogenous’ graphic formats. There was thus a reflexive relationship between the regular features of the observing and measuring devices and the regularities observed in the tissue. The consequence of the operation was to identify ‘natural’ residues of the specimen *in and as* the instruments and scales used ‘scientifically’ to display and assess their properties. I will try to substantiate and clarify these assertions in the following discussion of ‘exposed geometries’, ‘upgrading geometricity’ and ‘utilizing formats to compose scales’.

Exposed Geometries

The dentate gyrus is characterized anatomically as a region of the brain’s hippocampus where the various neuronal constituents differentiate in a distinctly stratified fashion.²⁵ Granule cells, pyramidal cells and axons synapsing with the dendrites from those cells are sorted into distinct layers in cross-sectional representations of the dentate gyrus. In contrast, the cellular constituents of the cerebral cortex are less easily distinguished into homologous anatomical regions.

The distinctive organization of the dentate gyrus was appropriated as a ‘natural laboratory’ for experimentation. The layering and internal coherence of the anatomical structures provided a happy coincidence of anatomy and classification. Categorical groups of neurons were readily isolated in a visible and manipulatory space. The grammar of experimentation — of selection, control and comparison — was operated in the hippocampus with an ease that could not be approached elsewhere in the brain. The project discussed here, along with the bulk of the particular laboratory’s many other projects, utilized the hippocampus as a particular region for exploring generic brain structures and processes. The studies of axon sprouting, for instance, concerned a recovery process in the entire brain, with the hippocampus as a proximal ‘window’.

The exposed layering of the cells in the dentate gyrus also made possible its use as a naturally occurring graphic template. Figure 3 provides a genealogy of the scale for distance along the vertical axis

of the graph by tracing the origin of the scale to a line which intersects the cell body of the granule cell schematized in the *camera lucida* drawing (on the left-hand side of the figure). Figure 4, in turn, traces the linear conformation of the granule cell layer from a 'slab' of tissues extracted cross-sectionally from a section of the hippocampus. The tissue slices exposed the cell layer and excized it in such a way as to place the lower frame of the rectangular slice in a parallel alignment with a relatively straight segment of the curving granule cell layer (second from left drawing in Figure 4). The slab was cut so that its edges *located*²⁶ a parallel alignment of pre-delineated anatomical structures.

Upgrading Geometricity

A progressive series of operations ever more closely arranged the specimen materials into the form of a representational two-dimensional graph. The anatomical layout of the slab displayed the dendrites of the granule cells as vertical components and the axons synapsing with those dendrites as horizontal components. This, of course, relied upon the relatively parallel orientation of each dendrite and each axon with the other members of its class. It also used the roughly graphic anatomy of axons and dendrites, the fields of which are aligned at approximately 90° to each other. The horizontal and vertical axes of the graphic arrangement of the cellular constituents were, in turn, exposed through the orientation of the cross-sectional slices constituting the slab. Each linear slice instrumentally constituted *planes* and *lines* of orientation referenced, with a superior 'exactness', to the exposed-linearities of the anatomical divisions.

The uniformity and cross-sectional orientations of slabs and sections brought together the visible properties of tissue and the graphic properties of a page of text.²⁷ The thin sections were constructed as if they were pages of brain tissue to be read for their graphic imprint. This coincidence was, of course, no accident. Tissue choppers and microtomes were used, respectively, to slice thick and thin sections in preparation for microscopic viewing. Instrumentally designed planes of operation for the movement of the blade through the tissue assured the precise conformation, for all practical purposes, of a two-dimensional rectangular strip of tissue. Electron micrographs further accentuated the two-dimensionality and rectilinear form of the data. Under high-power

magnification a thin section appeared as a plane extending beyond the horizons of the field of the microscope. Photographs were aimed within that field carefully to frame selected features within a vertical column of prints identified with an up-down orientation to a reader.

The uniformity of the tissue grain was accentuated not only through the imposition of instrumental planes of operation and manually inscribed lines. The selection of sites for shooting the series of micrographs expropriated locales where the cellular layering was especially 'straight' and 'parallel'. The visible micro-anatomies showed considerable variance from the practical ideal of linearity, and occasional moments of alignment were selectively framed for use as templates of graphic formatting. (By graphic formatting I mean practices which compose a display by placing data within the parameters of a graph.)

Utilizing Formats to Compose Scales

The series of practices for upgrading natural formations show progressive degrees in the extent to which visible materials are 'mathematized'. Proto-mathematical properties of objects are selectively exposed and are carefully placed within lines and planes of orientation and operation which construct the material form of visible displays. Those lines and planes then provide linear edges for the location of scales, flat surfaces for the superimposition of grids, and discrete sites for use as points within the grids.

Montages were produced in reference to the cell layer. A regional view of tissue under low-power electron microscopic magnification was selected as an appropriate field for a series of higher-power photographs (see Figures 2 and 5).

The 'lower-most' of the photographs was aligned at a standardized point 'above' a line, drawn across the surface of the low-power field (Figure 5), representing the mean upper edge of the granule cell bodies. The drawn line constituted a graphic axis from which a perpendicular column of photographs (Figure 2) was reckoned. The perpendicular line simultaneously became a 'scale' whose standardized units, in microns, were calculated in reference to the power of magnification. Each photograph was shot in the series, moving 'upward from the cell layer', so that its lower border overlapped with the upper border of the photograph below it and its left and right borders aligned with the borders of the others.

Intracellular 'landmarks' were used as mnemonics for reckoning the placement of each photograph in reference to the others in the series, and for pasting together the photographs, after they were all developed, to reconstitute the continuous terrain. The resulting strip exhibited roughly aligned right and left edges which were then used as a scale for assessing positional relationships of axon terminals in the montages. The strip was designed to enclose the key area of overlap between the two adjacent axon regions 'above' the granule cell layer, and to allow the observation and measurement of the extent of overlap between the 'intact' axon terminals in one of the two regions and the 'degenerating' terminals in the other (see the graph in Figure 3 for a schematic account of the analytic results).

Once the scale was put in place for ordering the tissual plane in reference to measurable dimensions and locales, a measured distance from the 'starting point' (the line across the granule cell bodies) was used to standardize the locale of each montage extracted from each distinct specimen. This standardization was further assured by the selection of a domestic breed of rats whose brains were said to exhibit a high degree of dimensional conformity from one individual to another.

Within the linear frame of the montages, the visibly intact and degenerating axon terminals were categorically identified and counted as graphically significant *points* in the two-dimensional spatial grid of the photographs. Marking the terminals transformed them into usable points, equivalent (except for their spatial locale) to other such points identified with the same colour-coded mark. These points, although they facilitated the categorical transformation of terminals into 'numbers', were simultaneously inspectable as photographic images of singular terminals. One could still see the interior of the terminal outlined with the colour-coded mark; each instance was a pivotal entity — a meeting place of a graphic-mathematical point and the direct image of an empirical residue extracted from the remains of an animal.²⁸ Note that in Figure 3, the lines on the graph lose such concrete reference to the visible residues of the 'animal', and reside unambiguously in a statistical space.

Normalizing Observations

The marked 'points' on the surface of the montage and the broken and solid lines in Figure 3 are graphic devices for aggregating observational cases as categorically uniform objects. 'Intact' axon terminals, outlined in black, are aggregated within each sector of a grid of distances. (The vertical dimension of the montage becomes 'distance from the granule cell bodies', and the horizontal dimension becomes a swath of standardized width in which distributions of terminals are sampled.) Each marked point on the montage represents a single *observation*. The montage presents each observation as a spatial point within its grid of measured distances. Without contradicting or impugning such a reading, we can also see how each marked terminal is the product of a practical course of actions which prepared the specific terrain for visible assessment and measurement before including the specific case into the corpus of acceptable observations. The graphic surface of the montage confines and 'simplifies'²⁹ the singularity of each such observational procedure to a two-dimensional spatial position.

The graph in Figure 3 preserves the aggregate properties of the marked cases, while dropping any direct reference to the singularity of micrographed terminals. Unlike the montage, it no longer displays the image of each terminal within the crude outlines of the montage's graphic 'points'. Instead, it provides an average density of terminals in each sector of distance for two temporal classes of 'animals' (4-day and 11-day). The graph aggregates and homogenizes the collection of different marked points and specimen animals into a unitary spatial display.

The graphic display *normalizes* the properties of each animal and each counted terminal. The specimen 'animal' becomes both more than, and less than, a laboratory rat. It becomes *more than* a nervously staring creature living out its life in a wire cage, since the fine structures of its nervous system revealed through dissection of the animal, histological treatment of its tissues, and microscopic magnification are not at all apparent from the outset. The structures revealed by rendering the animal's remains are virtually abstracted while retaining their attachment to the concrete residues of the animal's body. It becomes *less than* the ordinary animal since the original animal is literally thrown away in favour of the residues retained for inspection.³⁰ In the end, the animal is 'sacrificed' along with a cohort of others for the sake of an

aggregate line on the graph. Its practical history drops off: the graphic line is indifferent to the fact that a particular animal may have struggled fiercely before going under anaesthesia, that a crisis occurred on whether the perfusing fluid would 'take' during the preservation of the brain during dissection, or that staining of thin sections of the animal's neural tissues created an unusual grainy texture that *almost* led to its being discarded from the corpus of analyzed specimens. The lines on the graph no longer represent rats in their ordinary, familiar mode; they represent measurements performed on methodically processed extracts of the animals' dissected brains.

The spatial coherence of the graph stands on behalf of a discipline of laboratory activities, and is tied intimately to the lab's structure of activities. The graphic aggregation of singular observations represents a claim about the standardization and efficacy of the rendering procedures applied to each animal. The solid and broken lines represent the lab's work as a production of essentially equivalent actions applied to each case, in each cohort, and by each separate lab technician involved in the production of the project. They further imply that such equivalency is explainable and accountable within the lab's programme; that members have resources for detecting instances of operational deviancy, and for keeping such deviancy in check so far as it penetrates the realm of the scientific data produced by members' activities. Such a programme includes matters of temporal scheduling, division of labour, monitoring and evaluation of technical activities.

The chart can be read as a disciplinary specific organizational scheme of activities — an idealized account of the lab's work. It bears both overt and hidden impressions of the labour constructive of it, and can be read by practitioners to evaluate whether the constructive practices were performed well, mistakes were made, or improvements should be devised. Furthermore, features of a bivariate curve, micrograph or diagram analytically reveal the organization of the work that produced them, since, for instance, temporal scales calendrically organize the scheduling of lab activities by defining beginning and end-points for each replication of an observation. A graphic display articulates the requirements of a scheme of action (the selection and imposition of objectives, means and constraints, and so on), while being no different from a specific representation of natural phenomena.

If, in the end, a line on the graph represents a cohort of animals,

it acts as a claim about the unremarkable character of the singular histories of each specimen, and of the practical actions and numerous assessments on the adequacy of the actions which accompanied and guided that history. The line stands on behalf of that history, reduces and objectifies it to a bivariate trajectory, and embeds it within an emptiness of graphic space. This emptiness is infused with moral significance inasmuch as it involves the tacit claim of scientific integrity, with motives assumed to be beyond reproach, and is offered with an unstated presumption that, if anything significant should have been said about the operational history of the graphic line, it will have been stated. Nothing intrinsic to the practices of reducing and objectifying cases to graphic lines guarantees or detracts from the foundations of that emptiness.³¹

Methodology as an Externalized Retina

The practices described above make up a 'social' programme of perception in science.³² It is not a psychological programme in the familiar sense, nor a social-psychological programme (if we understand social psychology to treat the interaction between society and mentalistic perception). Graphic formats, instrumental fields and preparatory techniques in histology penetrate both the field of what is visible and the means for perceiving it. It is as though they operate as elements of an externalized retina, activating the perceptible and schematically processing it. Analogous to the specialized retinal cells which are said to constitute our visual world by detecting lines, edges and coded ranges of colour, the externalized retina acts flexibly to manipulate graphic and instrumental lines, edges and codes in order to constitute the sensible, palpable, tangible and appreciable properties of data. Although a psychological subject is necessary to process what an instrument shows, the instrument does not merely *extend* the sensitivities of sensory perception. An instrument, and the accompanying project of 'domesticating'³³ or routinizing space and time in accordance with the instrument's use, prepares the way for perception by pre-coding, geometrizing and normalizing the properties of what comes to be perceived. An active reconstruction of the world is achieved.

Conclusion

The descriptions of scientific activity in this paper justify the conclusion that science is a constructive activity.³⁴ However, if we review *just how* the cases described here are constructive, we see that scientific data are artificial in only a certain sense. The data were neither wholly 'out there' in the animals' anatomy, nor wholly constructed out of thin air.

In the case of electron micrographs, features of the tissue were exposed and upgraded through a series of operations which enabled them to be perceived and analyzed. Laboratory practices were carefully produced to retain a continuity in analyzable form from one rendering to another. Such practices failed when, for instance, a high-powered photograph could not be located within the frame of a lower-power photograph, or when a blurry or grainy texture of a tissue section made it difficult reliably to mark the outlines of specific neuronal organelles.

The resultant data were therefore neither wholly constructed, nor simply a 'mirror of nature'³⁵ arising from an encounter between a rational mind and an inherently orderly nature. Instead, the representational adequacy of the data depended upon a tenuous coherence of actions established in the social environs of the laboratory.

● NOTES

Harold Garfinkel's teachings provided the fundamental doctrines and visionary directives for ethnomethodological studies of work which are misrepresented in this essay. John O'Neill, Ken Morrison and David Weinstein, each in a unique way, instituted the approach to literary details that I use. I would also like to thank Melvin Pollner, Gus Brannigan, Richard Hadden, Renee Anspach, Richard Hilbert, Steven Shapin and four anonymous reviewers from this journal for comments and criticism during the preparation and drafting of the paper. Bruno Latour, John Law, Elihu Gerson and Susan Leigh Star sent me their published and unpublished writings on related topics while I was working on this manuscript. The members of the neurosciences lab discussed in this essay patiently instructed me about their technical practices, put up with my strange and naive questions, and tolerated my surveillance of their laboratory activities.

1. A variety of metaphors make the point that laboratory workers do not directly relate to the 'natural objects' their accounts describe, but instead work with highly

processed materials. Harold Garfinkel, Michael Lynch and Eric Livingston, in 'The Work of a Discovering Science Construed with Materials from the Optically Discovered Pulsar', *Philosophy of the Social Sciences*, Vol. 11 (1981), 137, use the terms 'cultural object' and 'potter's object' to describe the character of the object scientists actually work upon. Karin Knorr-Cetina, in *The Manufacture of Knowledge: An Essay on the Constructivist and Contextual Nature of Science* (Oxford: Pergamon Press, 1981), describes laboratory work as a manufacturing process, and Bruno Latour and Steve Woolgar, in *Laboratory Life: The Social Construction of Scientific Facts* (London and Beverly Hills, Calif.: Sage, 1979), insist that 'literary inscriptions' provide the materials for scientific investigations.

2. Peter Toner and Katharine Carr, in *Cell Structure: An Introduction to Biological Electron Microscopy* (Edinburgh and London: E. S. Livingstone, 1968), 91, define a 'histological artefact' as 'any appearance or image in the specimen not present in that form in the living state but introduced by tissue processing or some other factor'. They go on to say that all light and electron-microscopic observations are observations of artefact, but because some systematic artefacts are reproducible and consistent, they are useful and meaningful in the context of cell biology.

3. A sampling of 'laboratory studies', as they have come to be called, are: Latour and Woolgar, *op. cit.* note 1; Knorr-Cetina, *op. cit.* note 1; Garfinkel et al., *op. cit.* note 1; Michael Lynch, *Art and Artifact in Laboratory Science: A Study of Shop Work and Shop Talk in a Research Laboratory* (unpublished PhD dissertation, University of California, Irvine, 1979; London: Routledge & Kegan Paul, in press); Michael Zenzen and Sal Restivo, 'The Mysterious Morphology of Immiscible Liquids: A Study of Scientific Practice', *Social Science Information*, Vol. 21 (1982), 447-73; Sharon Traweek, 'Culture and the Organization of Scientific Research in Japan and the United States', *Journal of Asian Affairs*, Vol. 5 (1980), 135-48; John Law and Rob Williams, 'Putting Facts Together: A Study of Scientific Persuasion', *Social Studies of Science*, Vol. 12 (1982), 535-58; Doug McKegney, *Inquiry into Inquiry: Local Action and Public Discourse in Wildlife Ecology* (unpublished Masters thesis, Simon Fraser University); Susan Leigh Star, 'Simplification in Scientific Work: An Example From Neurosciences Research', *Social Studies of Science*, Vol. 13 (1983), 205-28; Michael Mulkay and Nigel Gilbert, 'Accounting for Error: How Scientists Construct their Social World when they Account for Correct and Incorrect Belief', *Sociology*, Vol. 16 (1982), 165-83; Trevor Pinch, 'Towards an Analysis of Scientific Observation: The Externality and Evidential Significance of Observational Reports in Physics', *Social Studies of Science*, Vol. 15 (1985), 3-36; and a collection of studies in Harry Collins (ed.), 'Knowledge and Controversy: Studies in Modern Natural Science', Special Issue of *Social Studies of Science*, Vol. 11, No. 1 (February 1981), 3-158.

Studies of scientific texts which were particularly influential for the approach taken in this study are: Ken Morrison, 'Some Researchable Recurrences in Science and Social Science Inquiry', in Jay Mehan and Ann Rawl (eds), *New Directions in the Study of Social Order* (Chicago, Ill.: Arvington, in press); and John O'Neill, 'The Literary Production of Natural and Social Science Inquiry', *Canadian Journal of Sociology*, Vol. 6 (1981), 105-20.

4. Historical studies of the development of visual conventions in scientific research include: Samuel Edgerton, *The Renaissance Discovery of Linear Perspective* (New York: Harper and Row, 1976); Martin Rudwick, 'The Emergence of a Visual Language for Geological Science, 1760-1840', *History of Science*, Vol.

14 (1976), 149–95; William Ivins, *On the Rationalisation of Sight* (New York: Plenum Press, 1973); and Laura Tilling, ‘Early Experimental Graphs’, *British Journal for the History of Science*, Vol. 8 (1975), 193–213. For a discussion of the role of visualization in the rhetoric of early scientific writings, see Steven Shapin, ‘Pump and Circumstance: Robert Boyle’s Literary Technology’, *Social Studies of Science*, Vol. 14 (1984), 481–519. Also pertinent are Jack Goody’s investigations of literary phenomena such as lists and tables and their constitutive relationships to modes of reasoning and practice (*The Domestication of the Savage Mind* [Cambridge: Cambridge University Press, 1977]). Less specific, although no less inspiring for this study, are Michel Foucault’s discussions of perceptual reasoning in the human and medical sciences (for instance, *The Birth of the Clinic: An Archeology of Medical Perception*, trans. A. Sheridan [New York: Random House, 1973]).

5. Studies of laboratory conversation and their relation to scientific objects include Lynch, op. cit. note 3, Chapter 7; Latour and Woolgar, op. cit. note 1, Chapter 4; Garfinkel et al., op. cit. note 1; Michael Lynch, ‘Technical Work and Critical Inquiry: Investigations in a Scientific Laboratory’, *Social Studies of Science*, Vol. 12 (1982), 499–533; Steve Woolgar, ‘Documents and Researcher Interaction: Some Ways of Making Out What is Happening in Experimental Science’, paper presented at a conference on Communication in Scientific Research (Burnaby, BC: Simon Fraser University, September 1981); and Rob Williams and John Law, ‘Beyond the Bounds of Credibility’, *Fundamenta Scientiae*, Vol. 1 (1980), 295–315.

6. A theory of ‘literary inscriptions’ is presented in Latour and Woolgar, op. cit. note 1. See also Bruno Latour, ‘Visualization and Cognition’, paper presented at a conference on Visualization and Cognition (Paris: Ecole Supérieure des Mines, December 1983).

7. Studies which focus on the embodied production of experiments include: Friedrich Schrecker, ‘Doing a Chemical Experiment: The Practices of Chemistry Students in a Student Laboratory in Quantitative Analysis’ (unpublished paper, Department of Sociology, UCLA, 1980). Aspects of Schrecker’s study are summarized in Michael Lynch, Eric Livingston and Harold Garfinkel, ‘Temporal Order in Laboratory Work’, in K. Knorr-Cetina and M. Mulkay (eds), *Science Observed* (London and Beverly Hills, Calif.: Sage, 1983), 205–38. See also Ronald Amerine and Jack Bilmes, ‘Following Instructions’ (unpublished paper, Department of Anthropology, University of Hawaii, Honolulu, 1982).

8. ‘Rendering’ is a central theme in Harold Garfinkel’s recent researches. It describes the transformation of lived-activity into documentary phenomena. See note 17 below for further elaboration.

9. An analogy is made here to Merleau-Ponty’s description of the embodied ‘modalities’ of perception (*Phenomenology of Perception* [New York: Humanities Press, 1962]). The analogy relies upon personal communications with Melvin Pollner and Christopher Pack at UCLA, who suggested that phenomena such as typing paper, typewriter keyboards or, in this case, visual fields and displays in science could be viewed as modalities of perception in the way Merleau-Ponty describes.

10. Latour, op. cit. note 6, in his theory of literary inscription, argues that literary artefacts link the transient and situated world of the laboratory to the extensive and relatively permanent and extended world of the scientific literature. By

reducing the various activities of scientific research under the heading of literary inscription, the theory also provides for the application of the tools of literary criticism for the analysis of scientific work. Latour's theory borrows from historical arguments on the development of print technology and the growth of science: see Elisabeth Eisenstein, *The Printing Press as an Agent of Change* (Cambridge: Cambridge University Press, 1979). The present paper does not rely upon any claim about the necessity of print or any other specific kind of media for the accomplishment of scientific work, as it describes the rendering practices that use and rely upon various media.

11. Although the present study is not a semiotic analysis of illustrations in scientific texts, studies of illustrations in scientific texts by Bastide and Jacoby independently bear out some of the points made here: see Francoise Bastide, 'Iconographie des textes scientifiques: principes d'analyse', and Daniel Jacobi, 'Vulgarisation et illustration dans les sciences de la vie', papers presented to a conference on Visualization and Cognition (Paris: École Supérieure des Mines, December 1983).

12. This ethnography is reported in Lynch, op. cit. note 3, and Lynch, op. cit. note 5.

13. Rudwick (op. cit. note 4, 178) describes how visual materials from mining and surveying, 'which were not even "proto-geological" in their intentions', provided precedents for geologists' specialized diagrams. My use of the term 'proto-scientific' is slightly different. I am speaking of contemporary methods of preparing a field for scientific operations.

14. One of the identifying traits of 'constructed' form is the extent to which the simple limiting forms of geometry (the point, line, circle, square, sine wave and the like) are ever more closely approximated. Jacques Monod, in *Chance and Necessity*, trans. Austryn Wainhouse (New York: Alfred A. Knopf, 1971), argues that the unusual geometricity of the crystal and the bilateral symmetry of life forms were at one time assumed to be evidence of a deity's intelligence. Mathematical forms are, of course, assumed by most scientists to be intrinsic limiting elements of the structure of scientific objects, despite the otherwise 'messy' appearance of empirical instances. At the same time, the ever more exact approximation of these forms identifies the civilized landscape of the 'modern' world, visible in the utilitarian design of architecture and equipment.

15. George Herbert Mead has discussed the reference of manipulatory activity to scientific objects: see his *The Philosophy of the Present*, ed. A. E. Murphy (Chicago: The University of Chicago Press, 1980, first published 1932), 140-60.

16. Edmund Husserl, in *The Crisis of European Sciences and Transcendental Phenomenology*, trans. David Carr (Evanston, Ill.: Northwestern University Press, 1970), 23-59, argues that Galileo set the stage for modern consciousness by imaginatively displacing the geometric limit forms used for the mundane work of surveying into an eternal and inherently mathematical realm of nature; see also M. Heidegger, *What is a Thing?* trans. W. B. Barton and Vera Deutsch (Chicago: Henry Regnery Co., 1967). Although Husserl's grand thesis may lay too much responsibility on Galileo, there is some circumscribed historical support for the thesis that mathematical formalism has mundane practical origins. Rudwick, op. cit. note 4, 169, in a study of the historical development of geology, states that 'a fully structural approach to the interpretation of the complex phenomena of geology was most readily attained within a social context of practical mining and mineral

surveying'. Tilling, *op. cit.* note 4, 195, in a study of the historical origins of graphs, describes how early graph-like devices came into use as instrumental recording devices without, at first, being recognized for their analytic value *as graphs*. Although I am not making an historical argument in the present case, there seems to be an analogous, locally ordered, temporal development in the ordinary work of 'surveying' and rendering a specimen to prepare it for 'mathematization'.

17. The notion of the 'docile object' borrows themes from Foucault's discussion of 'docile bodies': see his *Discipline and Punish: The Birth of the Prison*, trans. Alan Sheridan (New York: Random House, 1979), 135-69; and from Garfinkel's idea of the 'docile record'. The latter idea is applied to documentary records in the form of writing, tape-recordings, photographs, charts, maps and so on. Garfinkel describes such records as 'renderings' of the work that produced them. They are significant more for what they hide about their practical genealogies than for what they reveal about them. The implication for ethnomethodological studies is to go beyond an analysis of residue documents to investigate the embodied real-time production of such 'docile records': see Garfinkel et al., *op. cit.* note 1, 136.

18. Foucault's writings (*op. cit.* note 17) disclose how certain modern forms of knowledge of the body became possible in the nineteenth century through the institution of programmes for regimenting the body's movements, subjecting it to detailed codes and constant surveillance, and evaluating it through the use of bureaucratic records. Goody, *op. cit.* note 4, more specifically relates the growth of modern forms of knowledge and social organization to the development and widespread use of literary facilities such as tables, written instructions and lists. Where Foucault identifies modern civilization with a new method of translating power into action, Goody locates it as an outgrowth of literary developments.

19. The hyphenated phrase, 'observable-reportable', is adopted from Garfinkel's usage: see his *Studies in Ethnomethodology* (Englewood Cliffs, NJ: Prentice-Hall, 1967):

Ethnomethodological studies analyse everyday activities as members' methods for making those same activities visibly-rational-and-reportable-for-all-practical-purposes, i.e., 'accountable', as organizations of commonplace everyday activities. ['Preface', vii]

20. At one time a lab assistant remarked casually to one of his colleagues about a particular animal, 'Old number 65 was a good animal all the way down the line'. I understand this to mean that the animal was docile when alive, and afterwards its corpse yielded 'good' results at each stage of its processing.

21. The theme of upgrading is introduced in Garfinkel et al., *op. cit.* note 1, 154. The theme was suggested by Eric Livingston, in his *An Ethnomethodological Investigation of the Foundations of Mathematics* (unpublished PhD thesis, Department of Sociology, UCLA, 1983; London: Routledge & Kegan Paul, in press).

22. I do not mean to claim that automated images and readings are intrinsically less suspect than their manual counterparts. However, they do tend to be treated that way under many, although not all, occasions of scientific research.

23. The mention of 'sense data' is playful. Clearly, there is no attempt here to resort to 'sense data' as an empirically solid ground of perception and knowledge. From my point of view, the 'sense data' in scientific investigation are docile objects — their features exhibit designs which are a consequence of human activity, while at the same time those features generate what counts as scientific knowledge.

24. For a related discussion of 'bootstrapping' in science, see Barry Barnes, 'Social Life as Bootstrapped Induction', *Sociology*, Vol. 17 (1983), 524-45.

25. The stratified structure of the dentate gyrus was first detailed at the turn of the century in the anatomical studies of Santiago Ramon Y Cajal, *The Structure of Ammons Horn*, trans. Lisbeth M. Kraft (Springfield, Ill.: C. C. Thomas, 1968). Rudwick's study of geology, op. cit. note 4, offers an interesting parallel. Rudwick points out how early geological drawings and maps utilized exposed cliff faces, mines or other outcroppings as observable bases for constructing formalizations of the underlying strata.

26. 'Located' does not necessarily mean 'located what already existed', but means something more like, 'produced alignment with'. To use a homely analogy, this sort of 'locating' is like 'locating a place on line' in a queue. The activity of 'locating' reflexively constitutes the place it finds. This example is from Harold Garfinkel's lectures on queues (Department of Sociology, UCLA, 1979-81).

27. Morrison, op. cit. note 3, and O'Neill, op. cit. note 3, develop an analysis which includes the concrete features of the literary page as constitutive elements of a text's sensible reading.

28. Different degrees of evidentiary value are assigned to renderings depending on how the literary representation 'packages' objective residues. A rendering which utilizes residues, extracts or other 'material' relics of the object is generally evaluated more highly than one which mediates the representation of the object with a human act of verbal description or drawing. This, of course, is not peculiar to scientific evidence. The reverence and controversy surrounding the Shroud of Turin revolves around the claim that the 'picture' is constituted through 'pigments' impressed into the fabric and exuded from Christ's wounded face. A sketch, though perhaps of evidentiary value, would not be taken as a 'relic'.

29. See Star, op. cit. note 3.

30. James L. Wilkins, University of Toronto, is fond of saying that statistical analysis in sociology 'throws out the baby and leaves the bath water for analysis'. My similar remarks here do not imply that the residues of an animal left for inspection have nothing to do with the original animal; instead, they have plenty to do with it within certain methodological restrictions.

31. This is to say that the adumbrated moral significances of the graph *can* be interpreted as products of Mertonian norms of science: see Robert Merton, 'Science and Technology in a Democratic Order', *Journal of Legal and Political Science*, Vol. 1 (1942), 115-26. However, the visible features of the graphic display do not by themselves *compel* such an interpretation. In the present case, finding 'normality' is ultimately dependent upon a good faith reading.

32. Mary Douglas (ed.), *Essays in the Sociology of Perception* (London: Routledge & Kegan Paul, 1982). Douglas's 'grid-group' scheme is, of course, not used in the present paper.

33. See Goody, op. cit. note 4.

34. For an exposition of a 'constructivist' programme in the sociology of science, see Knorr-Cetina, op. cit. note 1.

35. The phrase 'mirror of nature' is used in a critique of correspondence theories of knowledge: see Richard Rorty, *Philosophy and the Mirror of Nature* (Princeton, NJ: Princeton University Press, 1979).

Michael Lynch is Assistant Professor, Department of Sociology, Whitman College. His forthcoming book, *Art and Artifact in Laboratory Science* (Routledge and Kegan Paul) is due to appear early in 1985. *Author's address:* Department of Sociology, Whitman College, Walla Walla, Washington 99362, USA.