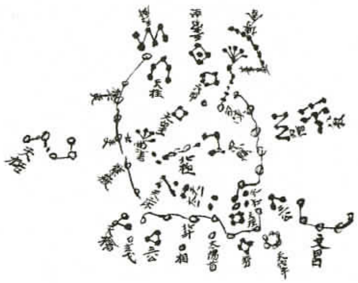
Interpreting Visualization :: Visualizing Interpretation

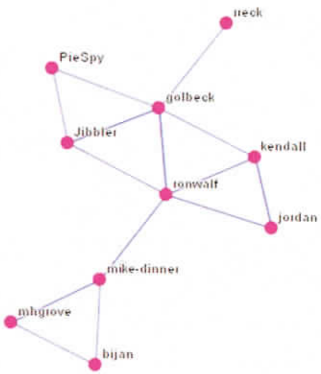
Almost all of the formats used in visualizations or information graphics have venerable histories. In this section we look critically at those intellectual lineages. The roots of tables and charts, calendars and timelines, maps and diagrammatic forms are as old as writing and record-keeping. The imprints of the disciplines of origin are still present in the schematic organization according to which these visual forms produce

meaning. Some are deeply humanistic in their orientation and use, others more tightly bound to managerial, administrative tasks, or to the empirical tenets of the natural and physical sciences. Making connections between the disciplinary roots and the current uses of visual forms lets us interpret the graphical relations encoded in these familiar images, teasing out from them some analytic principles about the way they work. We are still Babylonians, in our use of the calendar, our measure of days, hours, and minutes, just as we remain classical in our logic, medieval in our classification systems, and modern in our use of measurements expressed in rational form. Each of the many schematic conventions in daily use and the frequently unquestioned appearance in our documents and websites replicate ideologies in graphics.

A basic distinction can be made between visualizations that are *representations* of information already known and those that are *knowledge generators* capable of creating new information through their use. Representations are static in relation to what they show and reference—a bar chart presenting statistics about voting patterns is a good example. Knowledge generators have a dynamic, open-ended relation to what they can provoke; for instance, a train time-table can be used to calculate any number of alternative itineraries. The tension between static representations and dynamic generators will weave through our discussion.

We can also organize our study of the forms of visualization using several different parameters: graphical format (map, table, timeline, tree, bar chart, network diagram), intellectual purpose or function (mapping, navigating, record keeping, calculation), the type of content they express (qualitative, spatial, temporal, quantitative, interpretative), the way they structure meaning (by analogy, connection, comparison, using nodes/lines, vectors, columns, bi- and multivariate





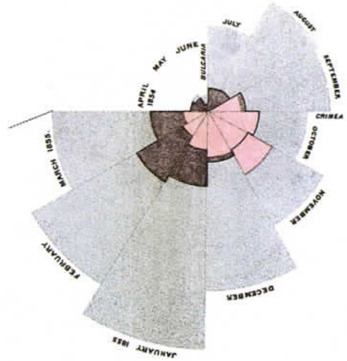
axes, point of view systems, etc.), or their disciplinary origins (bar diagrams from statistics, trees from genealogy, maps from exploration, and flow charts from management or electrical circuits). Many visualization programs give advice about which chart or graph to use based on the kinds of data and relations among variables being graphed.[76]

But however we classify the visualizations we use, they all require the same analytic approach to expose the workings of their graphical organization as meaning-producing. Diagrammatic images spatialize relations in a meaningful way. They make spatial relations meaningful. And they do so according to conventions that embody assumptions about how we translate observation, sensation, perception of phenomena into knowable forms. The interpretative acts that become encoded in graphical formats may disappear from final view in the process, but they are the persistent ghosts in the visual scheme, rhetorical elements of generative artifacts. The challenge is to develop a terminology for the rhetorical iconography of graphical forms that is grounded in the features of spatialized relations such as hierarchy, juxtaposition, and proximity. [See Window 6, information visualizations]

Information visualizations have their origins in record keeping and observation. Timelines, calendars, tables used for accounting purposes are among the oldest formats that come down to us in the conventions on which we draw for informa-

Dunhuang star chart (circa 700 AD).

A basic social networking diagram with nodes and edges.



tion visualization in the current moment.[77] Every calendar system has behind it the lurking shape of ancient observations.[78] Trees and maps are also ancient forms, with venerable pedigrees and hordes of evidence and exemplars.[79]

Visualization formats exist independent of particular media. Calendars don't have to be scratched into stone and bar charts don't need to be rendered by engravers with finely tooled burins—any more than scatter plots have to be generated computationally. The increase in availability of means of production and reproduction, and relative ease with which each medium can be used and its multiples put into circulation certainly have an impact on the popularity and quantity of visualizations at different moments. Thus we may cite many instances of diagrams—particularly medical, herbal, astrological, and alchemical—in the manuscripts produced in monastic libraries and Islamic courts in the millennium between the fall of Rome and the fifteenth century development of the printing press. But the development of copperplate engraving supported the flowering of a diagrammatic imagination that embodied late medieval enthusiasm for formal orderings and organizations in visual expressions that were profoundly humanistic in their outlook on knowledge and knowing.

The explosion of visual imagery integral to knowledge production and to exhaustive, extensive attempts at comprehensive presentations of knowledge is intimately bound to

Christopher Collins, Sheelagh Carpendale, and Gerald Penn, "DocuBurst" display of text analysis and data analysis.

Florence Nightingale, diagram of the causes of mortality in the army (1858).

the place of engraving in the publishing industries of the sixteenth and seventeenth centuries. Visuality and knowledge provided mutual guarantees in the late Renaissance as it met the early Enlightenment. Diagrams of all kinds migrated from spheres of intellectual activity as diverse as alchemy, kabbalistic practice, anatomy, astrology, astronomy, and medicine so that we can witness the mapping of one system after another into bodies, celestial spheres, and other combinatoric images of hybrid systems.[80] We have only to glance across the list of influential figures, some concerned with the occult, such as Robert Fludd, or to others committed to empirical methods, such as Johannes Kepler, Andreas Vesalius, Galileo, or Isaac Newton, to understand how quickly and completely visual forms became essential to intellectual inquiry in the sixteenth and seventeenth centuries, often without strict distinctions among what we would call "scientific" disciplines and other systems of belief. In the extensive publishing program of Athanasius Kircher, alone, we witness a dramatic demonstration of the embrace of visual means as an integral

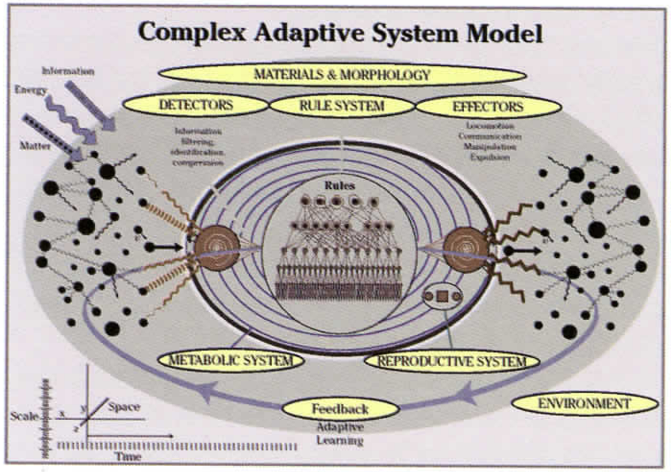
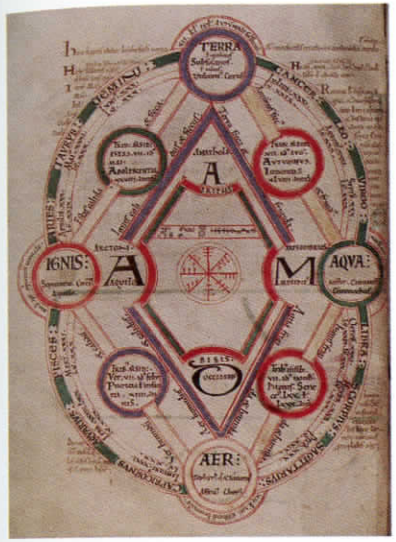


Diagram of a complex system.

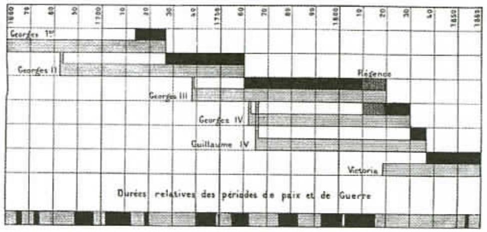


feature of knowledge production and presentation.[81] The diagrammatic imagination of the era is quite fantastic, and the use of figures or analogies as a way to present systematic and schematic information is both graphically and epistemologically stunning. Diagrammatic production surges in the eighteenth century, and the capacities of print production mustered in support were also the instrument through which visual reasoning could be performed in ways that served a rationalizing sensibility committed to the bureaucratic management of the emerging modern state. Whether these alignments were fortuitous or necessary, incidental or causal, hardly matters, since the archive offers a vivid testimonial to the power of statistical thinking and political arithmetic to create graphical conventions in diagrammatic forms.

Bar charts, flow diagrams, scatter plots, and other conventions are of more recent vintage. We find only a handful of anomalous precedents before they come into general use in the final decades of the eighteenth century. However, once they appear in the beautiful plates of Joseph Priestley and William Playfair in the late eighteenth century, they do not appear again in wide circulation for almost half a century.[82] Habits of thought and intellectual fashions are intertwined.

The use of diagrams is largely restricted to gridded ta-

Cosmological diagram on vellum from the Book of Byrthferth (circa 1090), St. John's College Library, Oxford, UK.



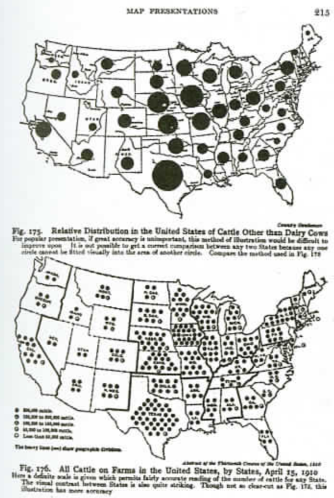
bles in the early decades of the nineteenth century. As I have noted, the diagrammatic character of tables is often overlooked. In the 1830s, when interest in statistics intensified, interest in graphical means of expression revived.[83] A wave of statistical charts and graphs made their appearance in scientific texts and, to a lesser but steadily increasing degree, in works of social or historical analysis. According to historian Michael Friendly, the use of diagrams rises and falls with a late nineteenth century "golden age" in Europe followed by one in the United States in the early twentieth century that drops off dramatically by about 1945. American interest revived steadily into the present, while the Europeans became focused on mathematical, rather than graphical, approaches to statistical analysis.

The fashion for visualization waxes and wanes, and the fortunes of graphs and charts to depict or generate abstract relations among elements (entities or quantities) spike and fall dramatically until the advent of computational systems. Now the ease with which the pie charts and standard timelines can be generated from any and every form of processed information as "data" makes these conventional forms as frequent as pop-up ads, animated banners, and other elements in the graphic landscape of the Web. Often these forms are used without clear understanding of their rhetorical force or the suitability of their underlying semantic structuring principles to the problem for which they supposedly present a solution or transparent analysis. As programs specific to the field of visualization become more sophisticated, so do the aesthetic qualities, as well as the sophistication of informa-

Etienne-Jules Marey, timeline of the reigns of the English monarchs (1885).

tion analysis and knowledge production. The challenge is to break the literalism of representational strategies and engage with innovations in interpretative and inferential modes that augment human cognition.

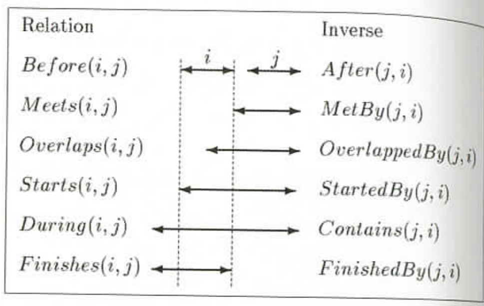
We will begin this study with a list of formats of visualizations, look to their antecedents and disciplinary origins for some insight into their formal organization as a knowledge scheme, reflect on the operation of their format features, and then engage with some of the contemporary uses and abuses of these visual conventions in current environments. This will begin to show how the relation between interpreting visualizations and creating schemes for visualizing interpretation can proceed.



Visualizations and diagrams depend on the same basic graphic principles as other visual sign systems: *the rationalization of a surface* (setting an area or space apart so that it can sustain signification), *the distinction of figure and ground* (as elements of a co-dependent relation of forces and tensions in a graphical field), and *the delimitation of the domain of visual elements so that they function as a relational system* (framing or putting them in relation to a shared reference). Without these basic principles, no graphical system can work.[84] The other graphical aspects gestured at above—the graphic variables, Gestalt principles, diagrammatic elements and their spatial organization—build on these principles.

Willard Cope Brinton, maps with pins and area symbols to show relative quantities; from *Graphic Methods for Presenting Facts* (1919).

schemes—strikes us as arbitrary and disorienting. The visual order of the calendar seems like the very structure of time itself, so naturalized has it become through graphic conventions. Like lines on a map demarcating one state or nation from another, the division of one day from another is powerfully structured through graphical conventions. These diagrammatic schemes are *performative*. They make the world by structuring our experience of it.



James Allen and George Ferguson, temporal logic diagram from "Actions and Events in Interval Temporal Logic."

James Allen and George Ferguson analyzed temporal relations using "interval logic," an abstract set of rules that describe relations that can also be expressed graphically.[89] Their goal was to identify the basic set of possibilities for the ways intervals in time could be related. Their list of primitives is based on assumptions about temporality that might not hold in fiction, imaginative works, or possible worlds scenarios, but apply well to linear, homogeneous, and continuous models of time. So, notions like "branches" or "parallels" are absent from their list of relations, which are descriptions of discrete intervals on a timeline. But the example serves very well to demonstrate that sets of relations that can be described logically or mathematically can also be expressed graphically. We have no difficulty understanding the meaning of "before," "after," or "meets" in the list compiled by Allen and Ferguson.

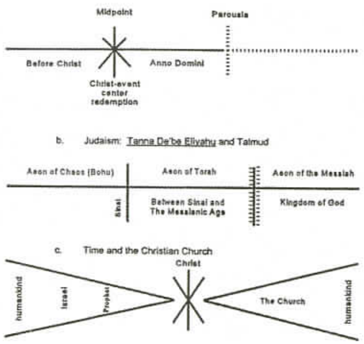
Some of these logics verge on philosophical investigations—as in the case of attention to the difficult "dividing instant" problem so crucial to computational operations (which side of a divide does a moment separating one task from an-

other belong to in an algorithmically initiated process). But these logical approaches do not provide an adequate conceptual framework for humanistic experience of temporal relations. Interpenetrated time, recollection and regret, or even the simple distinction between the time of telling and the time of the told in any narrative do not match the categories offered by the discrete categories of Allen and Ferguson's chart.

Temporal divisions have other ideological underpinnings. A timeline, with its single, linear, homogeneous directional flow, expresses a model of temporality consistent with empirical sciences.[90] But humanistic documents embody many alternative versions of temporality. Humanists deal with the representation of temporality *of* documents (when they were created), *in* documents (narrated, represented, depicted temporality), the construction of temporality *across* documents (the temporality of historical events), and also the shape of temporality that emerges *from* documentary evidence (the shape of an era, a season, a period, or epoch). They need a way to graph and chart temporality in an approach that suits the basic principles of interpretative knowledge.

Conceptions of temporality in humanities documents do not conform to those used in the social and empirical sciences. In empirical sciences, time is understood as continuous, uni-directional, and homogenous. Its metrics are standardized, its direction is irreversible, and it has no breaks, folds, holes, wrinkles, or reworkings. But in the humanities time is frequently understood *and represented* as discontinuous, multi-directional, and variable. Temporal dimensions of humanities artifacts are often expressed in relational terms: before such and such happened, or after a significant event. Retrospection and anticipation factor heavily in humanistic works, and the models of temporality that arise from historical and literary documents include multiple viewpoints. Anticipation, foreshadowing, flashbacks, and other asynchronous segments are a regular part of narratives, and they create alternative branchings, prospective and retrospective approaches to the understanding of events that cannot be shown on empirical timelines.[91]

Human experience of temporality is always relational, thus the marking of epochs in accord with expectations of a messiah's return or in recognition of this as a still-future event mark major distinctions in the Christian and Jewish world views.[92] All of historical time takes its measure in relation to such markers and milestones, and the shape of temporality is an expression of belief, not a chart of standard metrics. The experience of time is highly subjective, as is that of space, and thus the sense of a long moment, a swift day, a fast movie, a slow book requires elasticity in the ways we measure, record, and express temporality. The human record is full of gaps and breaks, ruptures and missing documents, so that any historical reconstruction necessarily provides only partial evidence. Humanistic temporality is broken, discontinuous, partial, fragmented in its fundamental conception and model. How to find the right graphical language to communicate this knowledge in ways that are sufficiently consistent to achieve consensus while being flexible enough to inscribe the inflections that characterize subjective experience?

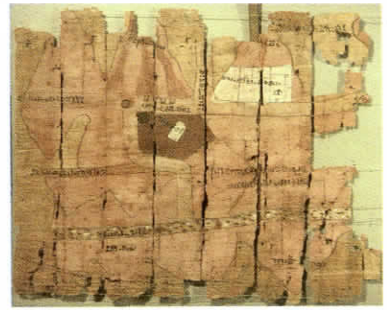


Herbert Bronstein, diagramming time in relation to cultural events; from *Time, Order, Chaos: The study of Time,* James Fraser ed. (Madison, CT: International Universities Press, 1998).

Space-making

Digital mapping often begins with geo-rectification, a task that reconciles spatial data and maps of all kinds with a

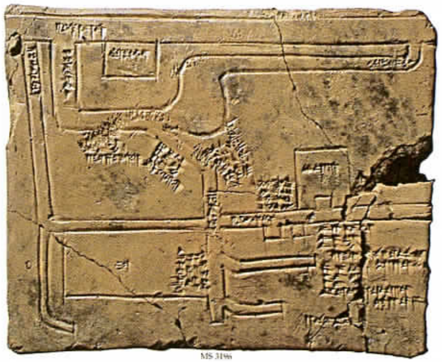
given standard, such as Google maps or government survey instruments. But the greater intellectual challenge is to create spatial representations without referencing a pre-existing ground. What is the figure of space that emerges from data, observation, experience, human record, when no a priori coordinates are used to structure that representation in advance? Much can be gleaned from early maps, or indigenous presentations of spatial knowledge, that do not follow rationalized conventions of projection.



Early maps served two main purposes: navigation and way-finding, or the identification of ownership and administration of property. Capturing the image of a large landmass within the compass of perception is not part of experiential activity, but requires translation into another system through a complicated series of abstractions, measurements, surveying, compilation, interpolation of quantitative information, representation schemes, and projections. We can see the stars and their relations directly. We cannot "see" the land's shape, its contours, or outlines. The need to navigate contours of the earth and manage its division into property gave rise to mapping techniques in Egypt and Sumeria. An Egyptian map drawn on papyrus dating to 1300 BCE is one of the oldest extant navigational charts, making it younger by more than a millennium than the charts of the heavens tracking movements of the stars. Cadastral maps are early examples of abstraction. They are used to keep track of ownership and property lines and are a feature of the same Near Eastern cultures of Ur and Uruk that produced writing. Wayfinding along a path or across a terrain relies on narrative. A description of a sequence of geographical events based on observation can be transformed into a draw-

Turin papyrus mining map (1160 BCE).

ing of features and landmarks. But abstracting this into a topographic view requires understanding the rationalization of surface and its ordered schemes. Navigation requires both wayfinding narratives and charts based on abstraction. Land management relies more heavily on the representation of geography on a flat surface. City maps were made in Babylonian times, as were plans of architectural spaces.[93] In the opinion of historians of cartography and anthropologists, these represent a significant level of cultural organization.[94]



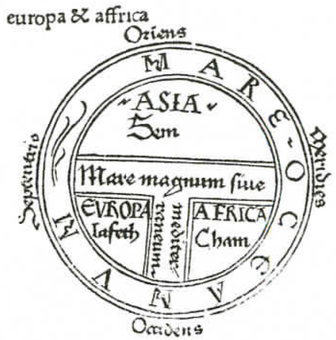
A beautiful cadastral map from 1500 BCE shows a plan of fields in ancient Nippur.[95] Elegantly sketched in clay and inscribed with boundary lines and owners' names, the map is a testimony to the capacity of Babylonian cartographers to perform an act of conceptual abstraction from observation rooted in the experience of the world to a planar representation of it. Six hundred years earlier, someone inscribed a plan for a wall surrounding a large structure, like a temple, onto a tablet on the lap of a stone statue of a prince of Lagash.[96] The drawing may have been used as the plan for construction, or merely to conjure an imagined building, but either way it demonstrates the ability to project a multidimensional form from a flat drawing. These two modes of abstraction—from three-dimensional space to a surface and from a flat plane to an image of projected space—are intellectual activities of a high order that engage their diagrammatic images in a complex social network of administration and planning. They are works that sustain elaborate transactions, both cognitively and culturally. In this case, they derive their structural order

Babylonian clay property map MS 3196, Niru, Babylonia, 22 lines and captions in cuneiform script (1684–1647 BCE).

from existing or projected forms, rather than being abstract diagrams that function without a referent.

The task of mapmaking requires a spatial imagination abstracted from direct observation or experience. In *Making Space,* John Rennie Short describes six distinct "spatial discourses: the construction of the grid; emergence of cosmography; the mappings of the world; the navigation of the oceans; the surveying of the land; and the annexing of colonial territories."[97] To this could be added the earlier acts of narration, description, the records of observation, and journeys. A comprehensive grid system was invented by Ptolemy, the second century Greek-Egyptian working in Alexandria. Complete with longitude and latitude, Ptolemy's system was preserved from antiquity in the work of Arabic scholars, then translated into Latin in the fifteenth century when it came into widespread use.[98] In the medieval period, however, Western cosmography synthesized astronomy, astrology, geography, in a view that put the earth and heavens into a coherent system of spheres and hierarchies. In an era before Ptolemy's system was widely adopted, medieval maps of the known

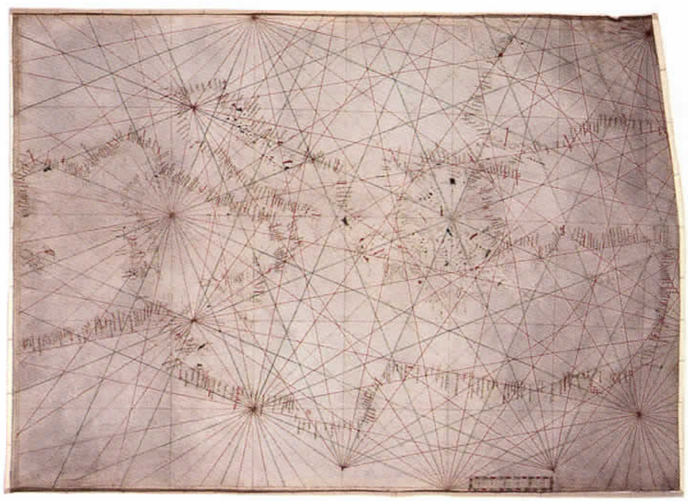
World map from Claudius Ptolemy's *Geography,* engraved and hand-colored by Johannes Schnitzer (1482).



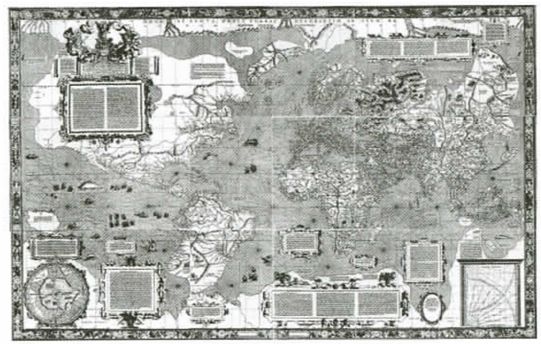
Isidore of Seville's *mapamundi* from his *Etymologies,* written in 623, reprinted by Günther Zainer (Augsburg 1472).

world took the T-O scheme, the circle of the world (Africa, Asia, Europe) with Jerusalem at the center.[99] The allegorical significance of the form, matching the T of the waters in the shape of a cross with the O of the earth as the bounded globe, aligned with medieval Christianity. While scale and orientation were different from later rational projections or conceptions, the T-O maps were representational, constructed on a visual analogy to the geography familiar to the era. They were symbolic, and fulfilled an expectation that the earth conform to a Christian plan of divine design.

T-O maps were not particularly useful for navigation since they displayed almost no information about the seas, currents, coastlines, or compass points. The invention of the nautical compass and exigencies of the Crusades spawned a new charting system in the thirteenth century known as the "portolano" in which intersection points (later developed



Portolan chart showing navigation routes across the Mediterranean, probably from Genoa (circa 1320-1350).



Gerhard Mercator, world map, *Nova et Aucta Orbis Terrae Descriptio ad Usum Navigantium Emendate Accommodata* (1569).

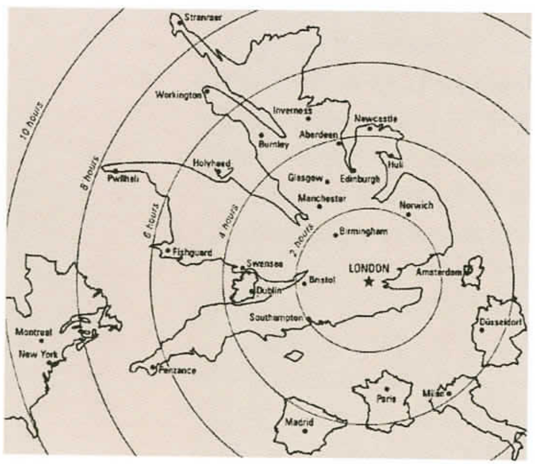
into compass roses) served to orient ships and assist them in charting their course.[100] The imposition of schemes meant to serve particular purposes transformed maps from descriptive to instrumental artifacts, but the basic approach to mapping global geography remained rooted in Ptolemaic schemes until Gerhard Kremer (known as Mercator) made suggestions for an alternative approach in the sixteenth century.[101] Mercator's rhumb-lines or lines of "constant course" depended on using a consistent linear scale projecting the globe onto a cylinder. The description of the observed world was put into dialogue with graphic systems imposed as abstractions that were not derived from the features of the landscape but imposed upon it through human activity. Advantageous for navigation—Mercator's scheme can be readily translated into directional information—it makes for exaggerations of the size of landmasses at the poles. These distortions are the result of the conceptual abstractions according to which the graphic scheme is conceived. They are convenient conceits, and the rhetorical force of analogy persists. The basic contours of continents and coastlines provide enough familiarity to obscure the abstractions of distorting schemes. Continual corrections and innovative variations of global projection systems continue to this day. Each construction, old or new, is a graphical expression of conventions grounded in historical and cultural exigencies.

Once systematic mathematical means for creating systems of navigation were put into play, "the world was en-

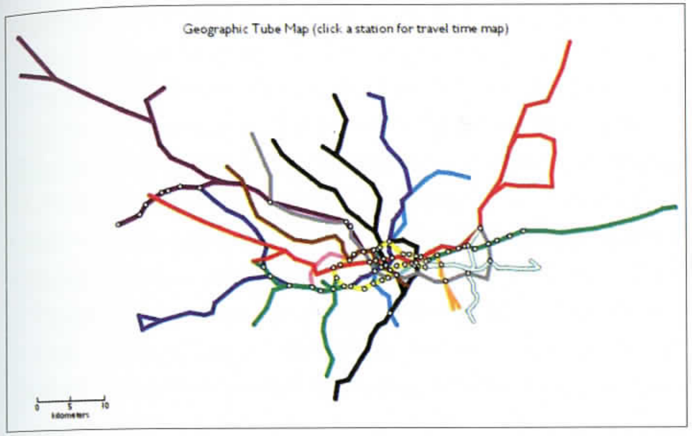
Peter Dicken and Peter Lloyd, "The Unevenness of Time-Space Convergence," *Modern Western Society* (NY: Harper and Row, 1981).

meshed in a grid, laced with compass lines and seen through the lens of the theodolite, back-staff, and cross-staff."[102] The interplay of abstract schemas and concrete reality blurs our understanding, making maps seem "real" though they are elaborate constructions created with allegiance to the conventions of representation as well as expressing a conception of space.[103] Maps depend on a process of "constructing analogies between two-dimensional and three-dimensional space" that "are part of a culture's world view or ontology."[104] After all, "the world itself *has no surface*" experienced by "its manifold inhabitants, journeying along their respective ways of life."[105] Maps, like other graphic conventions, construct normative notions about time, space, and experience that become so familiar we take them for accurate representations rather than constructions. The constructed experience of space cannot be presented in standard cartography any more than the variable concepts of temporality can be charted on a standard timeline.

Spatiality, or the concept that space, like time, is always relational, always produced as a factor of experiential or sub-



jective effect, is in striking contrast to the empirical concept of space. Mapping depends on projections, of course, but these might take other factors into account as part of the metrics of their design. Francis Galton, for instance, mapped space as a function of subjective observations.[106] Galton's problem, formulated in the mid-nineteenth century,



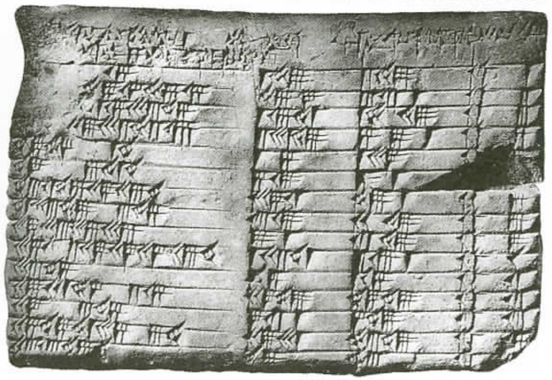
takes into account that most statistical phenomena are observer-dependent and situated, and cannot be separated from the dependencies that bear upon the creation of data. Galton, in other words, recognized that in many circumstances, data were capta. The statistical description of phenomena depend upon the observer's circumstances. A more recent demonstration of these principles is a map designed in 1981 by the team Dicken and Lloyd to show England's geography distorted by travel time.[107] In a related example, designer Tom Carden created a dynamic interface that redraws the London Underground map as a function of time of travel from any selected station to any other station.[108] Another striking example is an early twentieth century map of the United States in which horsepower capacity determines the area of each state though the boundaries and outlines are still recognizable.

Many mathematical forms are diagrammatic in character, and it could be argued that without spatial techniques, mathematical thinking would not have advanced. The sequential ordering of early counting systems occurs in pre-history, where notched bones and other objects provide

Tom Carden, Tube map application that reorganizes the map by time of travel from a particular station.

Pythagorean triplets (length x measure = area), Plimpton 322 clay tablet (circa 1800 BCE), Columbia University, Plimpton Collection.

material evidence of these early experiments. Order, sequence, grouping, size, scale, and placement are signifying features in graphical numbering systems. The Indus Valley civilization of the third millennium BCE (which also gave rise to an indigenous script, which later disappeared) developed place-holding systems, ratio, and other means of controlling proportion, size, and quantity that are spatial as well as quantitative. The sixth century BCE Greek mathematician Pythagoras purportedly travelled to Egypt to absorb the lessons of astronomy, geometry, and other advanced systems that were the combined legacy of ancient learning. Evidence for early Egyptian mathematical activity is sparse, but from Babylonian sources we can trace the development of multiplication and division, as well as simpler computation. These activities are almost impossible to perform without spatial organization in which the numbers hold value through position. Spatial organization in which position confers value underpin many basic mathematical activities from simple calculation to more complex topological concepts. The diagrammatic aspect of basic arithmetic operations tends to disappear in habitual use. We see the numbers as a column in addition, but overlook the implied grid that keeps them bound into meaningful relations. Such organization is an instance of figure/ground relations at play. The spaces that serve to keep columns separated and figures aligned are not passive or inert. They are active elements supporting crucial tasks of differentiation. The same observation can be made of the features of writing and other notation systems.



Administration and record-keeping

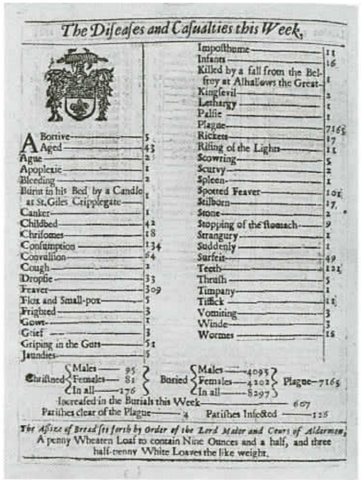
Proto-writing systems that served counting and accounting purposes take shape in the ancient Near East in Sumerian proto-cuneiform around the seventh millennium BCE. By the fourth millennium, the use of well-ordered grid space on clay tablets to separate signs of different types, content, or function demonstrates highly organized graphical principles of organization.[109] Notation and writing systems proper are outside the realm of my discussion here, since their primary purpose is linguistic, rather than graphic.[110]

But as with mathematical forms, the graphical structures that support proto-writing participate in an essential stage of the development of graphical principles.[111] This graphic organization becomes increasingly sophisticated as literacy arises in the ancient Near East. Denise Schmandt-Besserat's study of the relation of pictorial imagery and proto-writing demonstrates the extent to which a ground line essential to the ordering of written notation comes to serve a useful purpose in narrative pictorial art.[112] Whether visibly present, as in the case of many Bablyonian tablets and texts, or implied, the ground line is a functional point of reference against which the basic graphic properties of sequence, direction, orientation, size, and scale can register their significance. If the original *trace* complies with logician George Spencer Brown's fundamental *distinction* (as the basis of his *Laws of Form*) and Derridian *différance* (as the originary process of the possibility of signification), then the ground line is the first cognitive *frame*, a *referential boundary*, for putting elements of a

Kish Tablet, from Uruk (3300-3100 BCE) British Museum.

graphical system into relation with each other through a common element. Diagrammatic forms of all kinds are constructed on these bases.

The creation of various tabular formats for lists, accounting purposes, and other administrative tasks to which I have been referring in the discussion of mathematics and writing might be the first fully diagrammatic human activity: one in which the spatial distribution of elements creates a structure in support of meaning production, but in which that spatial ordering has no analogical reference or prior existence. The grid format makes its earliest (at least to all current archaeological evidence) appearance in the cuneiform tablets of the late fourth and early third millennia BCE.[113] These were preceded by a series of stages of slowly developing transformations of graphic space in which the signs of quantity and those of specific entities (grain, sheep, etc.) are distinguished from each other by where they are placed on a clay tablet. Groupings, separated by lines, and impressed with respect to alignment and proximity, are all strategies whereby spatial and graphical properties are engaged in a systematic set of relations that help produce meaning. The same signs, in a different order or arrangement, would have different values. The grid is a regular feature of clay and stone tablets by the fourth millennium BCE. The Kish limestone tablet, dated to approximately 3300–3100 BCE, is divided into five distinct zones with vertical and horizontal grid lines.[114] The


The Diseases and Casualties this Week,

Abortive	5	Impostheme	11
Aged	43	Infants	16
Ague	2	Killed by a fall from the Belfrey at Alhallows the Great	1
Apoplexie	1	Kingsevil	2
Bleeding	2	Lethargy	1
Burnt in his Bed by a Candle at St. Giles Cripplegate	1	Palsie	1
Canker	1	Plague	7165
Childbed	42	Rickets	17
Chrisomes	18	Rising of the Lights	11
Consumption	134	Scowring	5
Convulsion	64	Scurvy	2
Cough	2	Spleen	1
Dropsie	33	Spotted Feaver	101
Feaver	309	Stilborn	17
Flox and Small-pox	5	Stone	2
Frighted	3	Stopping of the stomach	9
Gowt	1	Strangury	1
Grief	3	Suddenly	1
Griping in the Guts	51	Surfeit	49
Jaundies	5	Teeth	121
		Thrush	5
		Timpany	1
		Tissick	11
		Vomiting	3
		Winde	3
		Wormes	15

Christned: Males 95, Females 81, In all 176. Buried: Males 4095, Females 4202, In all 8297. Plague 7165

Increased in the Burials this Week 607

Parishes clear of the Plague 4 Parishes Infected 126

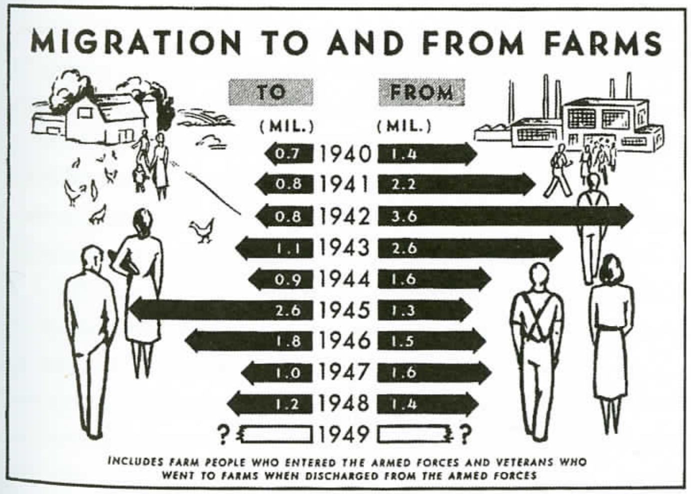
The Assize of Bread set forth by Order of the Lord Maior and Court of Aldermen, A penny Wheaten Loaf to contain Nine Ounces and a half, and three half-penny White Loaves the like weight.

Bill of mortality during the Great Plague, Museum of London (Sept. 1665).

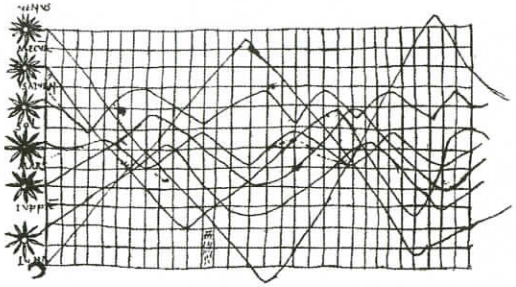
horizontal lines are doubled, a gesture that is self-conscious enough to indicate that the lines themselves are not mere conveniences, but play an active part in regulating the signs on the tablet to different roles.

Some visualization formats, such as tables, are so generalizable and re-purposable that their structure almost disappears from view. We take their operations for granted. This graphical organization and its spatial properties carry the trace of the purpose for which a graphic was created. I am not suggesting that this "original" root is some sort of key to semantic value—as if every tree diagram could be reduced to a genealogical meaning. But tree diagrams do share some conceptual commonalities that are structured into the way they use spatial and graphic features that bear the imprint of organic imagery of bloodlines, continuities, derivation, and so on.

Thus the static arrangement of information in a tabular form suggests that it has been modeled according to a strict distinction of content types and that these columns and divisions are neither mutable nor combinatoric. When we con-



Bar chart showing migration to and from farms, U.S. Bureau of Agricultural Economics Outlook Chart (1950); from Calvin Schmid, *Statistical Graphics* (1983).



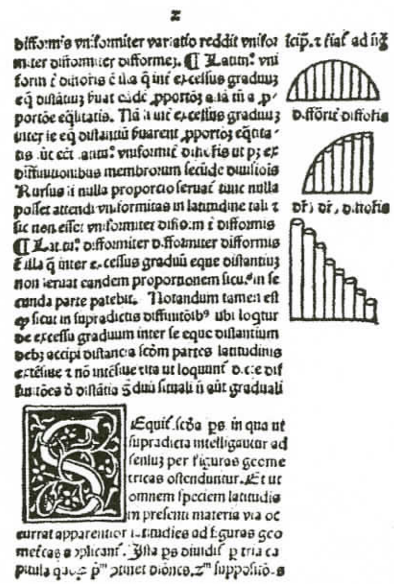
sider the format of an actuarial table or a train timetable, we see that the combinatoric activity it supports necessarily depends on the fixed structure, but that the results generated are a factor of the number of possibilities put into play. The act of reading across and down, through the coordinate grid, to find information is a generative act. A train timetable may present a finite number of options for departure times or arrivals, but making each combination of stations and times generates a result anew. In addition, the information generated engages other non-statistical factors—in particular, the interpretative frame into which these calculated outcomes are put by their human generators. This is not trivial, but essential, to the performative capabilities of tables. They provoke multiple scenarios through their use because the graphic form permits combinatoric variation. Axes are the fundamental spatial elements in graphs, and the allocation of metrics onto the lines that chart variables against each other so that either cross points of intersection or areas between lines (implied or explicit) become charged with value. Sequence and order are constituted spatially as well, and while volvelles and other knowledge generators with movable parts rely on alignment, charts and graphs rely on cross-referencing variables from points on axes into the graphical space. The basic column and row intersections make graphs extremely efficient, but unlike tables, which hold information, graphs and charts make relations among aspects visible according to a set of graphical parameters. Thus selective factors give a powerful rhetorical force to the visualization, and decisions about rela-

Earliest known chart of planetary movements from a translation of Macrobius's commentary on Cicero's *Somnium Scipionis* (tenth century).

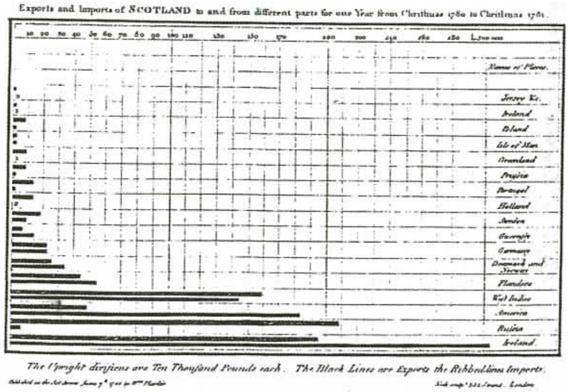
tive scale of the (decidedly spatial) metrics on each axis are crucial to the way these relations among elements take shape (literally and intellectually).

Statistical graphs and other modes of data display are intermediate forms between the static format of trees and charts and the dynamic design of knowledge generators, whose designs are capable of giving rise to multiple interpretations or analyses. In the eighteenth century, the science of statistical analysis came into its own with unprecedented force.[115] A few harbingers appeared in the late seventeenth, with the study by John Graunt on the bills of mortality, and the introduction of the term "Political Arithmetic" in a publication by William Petty in the 1670s.[116] The emergence of modern states and the bureaucratic administration for their management drives this development accompanied by the rapid increase of uses of the "Terms of *Number*, *Weight*, and *Measure*."[117] The purpose of this new approach was to abstract quantitative information from human conditions. All bar charts, line graphs, and scatterplots bear the imprint of that administrative agenda through the assumptions their metrics naturalize in images. Demographics with complex human factors become starkly simplified and reduced graphic statements that conceal as much as they reveal.

Before the seventeenth century, the number of statistical graphs—that is, visual expressions of variables charted against each other as abstract quantities—was extremely small. A rare, and wonderfully innovative image in a



Nicolas Oresme's bar charts, from *Tractatus de latitudinus formarum* (1505).



William Playfair, bar chart illustrating the exports and imports of Scotland (1780-81).

tenth century manuscript shows the movements of the planets (*De cursu per zodiacum*).[118] The image is an anomaly, and like the mid-fourteenth century plottings of variables and functions by Nicolas Oresme, remains without imitators for more than three hundred years.[119] The idea of graphical plotting either did not occur, or required too much of an abstraction to conceptualize. For unknown reasons, from 1350 until the late 1600s, no instances of plotting statistical information in graphic form seem to have been put into practice. Tables and charts abound, and so do many variations on tree structures, but no graphs of variables plotted as abstract data.

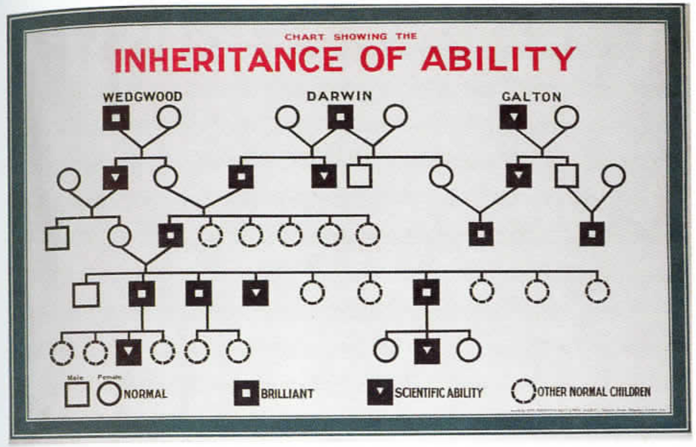
René Descartes's seventeenth century work in analytical geometry established the mathematical basis for statistical graphs, for which "the principle of coordinates and the idea of functionality" were "sufficient."[120] His creation of a rational grid (grids had been extant, as we have seen, from ancient times) allowed lines and points to serve as key markers on a surface plane. Either could be used as a method of creating a systematic set of graphic relations (either cross-points or intervals or both could carry value). These mathematical means combined with intensifying interest in empirical measurements, but they were only slowly brought together into graphic form. Instruments adequate for gathering "data" in repeatable metrics came into play, as one of the defining elements of modern scientific methods. Thus the eighteenth century astronomer William Herschel charted barometric pressures and temperatures at

different elevations, but the intellectual means for putting such information into statistical graphs only appeared in fits and starts.[121] Tabular presentation of statistical information remained a mainstay even after the spectacular work of Playfair in the 1780s demonstrated the benefits of "presenting to the eye a figure, the proportions of which correspond with the amount of the sums intended to be expressed."[122]

Playfair's brilliance resides in his intellectual accomplishment as well as the elegance of execution.[123] The roots of political arithmetic are in the analysis and management of nation states. The link between statistical tables and bureaucratic administration is historical as well as cultural, and Playfair's innovative presentation of statistical information in a manner that made patterns of imports, exports, commodities, and time frames legible established graphical conventions later banalized by common use. We can easily overlook the leap necessary to abstract data and then give form to its complexities. The bivariate graph, with its inexhaustible capacity to spatialize parameters and put them into relation with each other, is an intellectual product of an era in which rationality could be put at the service of theoretical and practical knowledge. Though our perception of its theoretical sophistication has become dulled through constant use, it allows any two conceptual entities to be put into relation with each other to generate a new result through graphical form.

Primitive graph paper appeared in the 1680s, but commercially prepared gridded sheets were not in production until almost two centuries later.[124] The late eighteenth century work of Playfair and his contemporary, Joseph Priestley, notwithstanding, the use of bar charts and line graphs did not proliferate immediately. The visualization depended on "the dual process of plotting experimental and observational data and of analyzing the resulting graph."[125] Decisions about how statistical parameters are translated into graphics are crucial.[126] The scale of one axis in relation to the other, the use of broken or continuous metrics, decisions about how to sequence and order statistical information, and the rhetorical force of choices about graphic attributes (color, tone, weight of lines) had to develop as a set of conventions; they were not self-evident elements. Each represents a variable that becomes part of the statistical material in visual form. Tonal value, height of bars, or decisions about whether to use bars or curves become part of the value legible in these graphs. In many instnances, eighteenth century elegance degenerated into late nineteenth and early twentieth century crude and clumsy methods.

The intellectual assumptions expressed in bar graphs and pie charts combine empirical and managerial approaches. The basic questions of how parameterization is set up, how samples are taken, and whether curves are presented in smoothed or rough format become instruments of meaning production. Francis Galton's studies of inherited characteristics are classic images in this field, with their well-shaped diagrammatic forms supporting rather too well his eugenic arguments.[127] Their method and format meet a comfortable match, with outliers removed, effaced, eliminated, and the argument made into a hygienic and consumable form. They emphasize the overall curve and obliterate the specifics. The very act of "chunking" dates, quantities, in the abstraction of observation into data, underlies graphical chart making. The width of bars, the height of grids, the proportions of areas created as a result, are the means by which statistics become abstracted from circumstance so that the human conditions may be administered without troubling detail. Here we see the social sciences gain legitimacy through appropriation of supposedly empirical methods, and the presentation of infor-



Francis Galton, English Eugenics Education Society poster with tree diagram of inherited ability (1926), Museum of London 84.1/122.

mation in abstracted, deracinated disconnection serves its particular ends with legitimating means.

Florence Nightingale's cockscomb formats were invented to catch attention, to grab the eye, and bring home the real circumstances of hospital conditions for the wounded in the American Civil War.[128] They are presentational, rather than analytic. The area represented in the arcs is not proportional to the quantities they are supposed to represent. But they worked. By contrast, the scatter plot of statistical information that allowed the course of a cholera epidemic to be traced to a single pumping station for water in a quarter of London in 1885 was an analytical instrument.[129] It situated its "data" in a graphical form that had some connection to the information being managed, and the use of points in the plotting scheme was a closer match to the circumstances from which they were derived. Many questions can be raised about what, exactly, these points represent in the lifecycle of the disease and its victims, but the scatterplot approach works well in the presentation of discrete bits of information that can be graphed to reveal a pattern. The conviction that normative curves could be generated from all human statistics, and that the tribulations of individuals could be subsumed into such neutral and objective seeming diagrams, had as its mission "the calculus of reasonableness for a world of imperfect knowledge."[130] The "knowledge" produced in such diagrammatic displays, filled as they are with the bureaucratic character of managerial sensibility, is already meant for instrumentalization.

Flow charts appeared in the early twentieth century, apparently for the first time in a presentation done by efficiency expert Frank Gilbreth.[131] His 1921 paper to the American Society of Mechanical Engineers, titled "Process Charts—First Steps in Finding the Best Way," is considered the first demonstration of a flow chart. The continued use of flow charts in management and organizational analysis supports the claim that they are well-suited to bureaucratic purposes. Human behaviors and complex situations are reduced to a formalized language of types of information (start points, end points, actions, change moments, input and output, conditionals and decision points). The current codes of activity diagrams and process diagrams is a dramatic example of the ideological imprint of origin on a still-functioning system. The human factors are repressed in these schemes, and the complicated network of interactions is devoid of emotional affect or impact. They are extremely useful for showing work flow, or reducing processes to discrete chunks of activity. They make it easy to impose the will of an administered culture on the complexities of human behaviors.

Area-based visualizations can be created directly from computational methods. Tree-maps, for instance, are based on percentage values. These are presented as solid areas within a whole, their hierarchy expressed through proximity and subdivision of a rectangle. Because these can be generated

easily from mathematical processing, they are specific to the environment of digital media. Creating such a diagram by hand requires too many calculations to be feasible. A scatterplot, by contrast, lends itself to hand techniques, since each data point has to be put into place and determining where each point goes is evident on the x-y axes. Scale issues tilt the balance in favor of computational methods, with their automated calculation capacity. Nonetheless, tree-maps depend on several orders of processing—into statistical data, into percentages, and then into a graphic representation—that are readily carried out computationally. A similar point could be made about other visualization formats that take quantitative information into a graphic mode of display that doesn't have any connection to the logical format of the original phenomenon. Tree-maps have no real analogy in the physical world, their spatial divisions are not like those used in cutting cake, dividing a field, allocating space, but are generated automatically through analysis of percentage expressed as a graphic hierarchy dividing a given area in proportion to a quantifiable variable.

Arbor scientiae (Tree of Wisdom), Ramon Llull (Barcelona: Pere Posa, 1505).

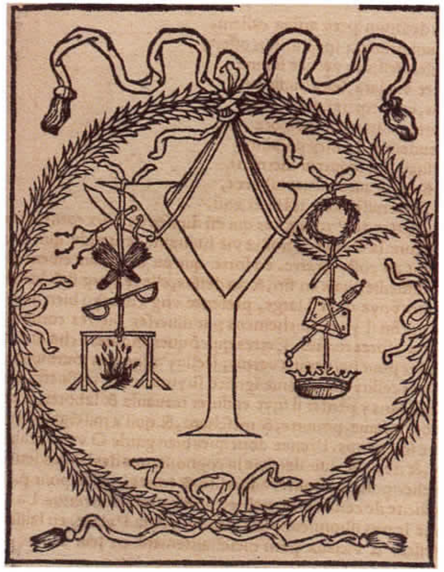
Trees of knowledge

Trees of knowledge are graphical forms whose structure is static and fixed, but whose spatial relations carry meaning.[132] Their depiction of hierarchy, derivation, consanguity, proximity, and distance, as well as scale, all participate in the production of meaning. Many databases have a tree structure, as do many forms of structured data and files.

In tree diagrams, the nodes and the

Geoffroy Tory, Pythagorean Y, *Champfleury* (1525).

branches embody value, their spatial organization structures meaning. A genealogical tree presents an easy example of a venerable form repurposed in digital formats. The generational distinction of father or mother from grandparent, aunts and uncles from children, and first from second and third cousins is structured into the presentation, as are assumptions about bloodlines. The spatial organization of family members tells us about birth order, consanguity, generational breadth and span, as well as patterns of marriage, fertility, and mortality rates. Charts, graphs, and other structures, like trees, are static rather than combinatoric, and use contrast, comparison, sequence, ordering, rates of change, distribution across the plane, bivariate and multi-variate axes, and time axes to show temporal activity or causality. These spatial features are available to knowledge generators and process diagrams as well, though the combinatoric and generative features of these modes are not really part of trees and other static structures.[133]

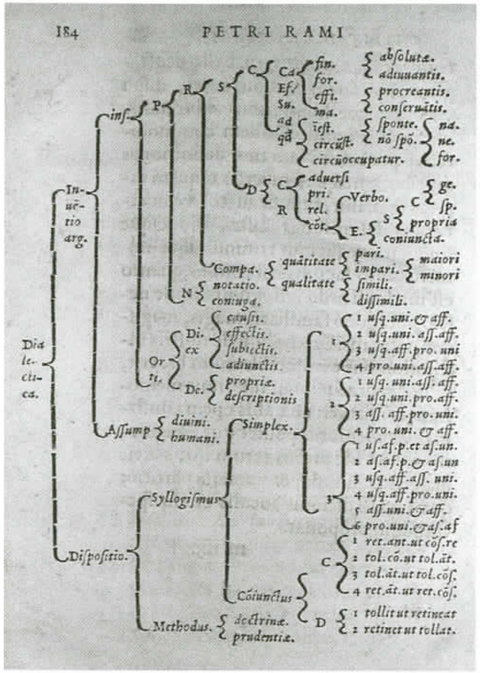


The image of the tree as an allegorical symbol has, like many motifs of human culture, a history that reaches into antiquity. Images of a tree of life anointed by the gods, as an image of fertility, or as a link between the divine and the earthly realms are found throughout the Mesopotamian region.[134] Both the tree of life and the tree of knowledge play decidedly crucial roles in Old Testament imagery and are pervasive symbols in Judeo-Christian culture. Among the Greeks, Pythagorean tradition

included a tree with two life paths, one easy, one difficult, the first a fat branch filled with earthly pleasures and temptations that dropped its climbers into the jaws of hell and the other a slim and thorny branch, leading to an angelic sphere. Pythagorean imagery was readily absorbed into Christian iconography, its diagrammatic and allegorical features overlaid with reductive moral lessons. Little of this imagery would belong in the discussion of diagrams if it were not for the fact that a schematic abstraction of this structure is used for so many intellectual tasks. Trees of knowledge, whether they imitate natural forms in texture and design or merely adopt its nodes and branchings, are graphical structures that produce meaning through spatial arrangement, not only through a persistent allegorical association.

Purchotius, Porphyrian tree from *Institutiones Philosophicae I* (1730).

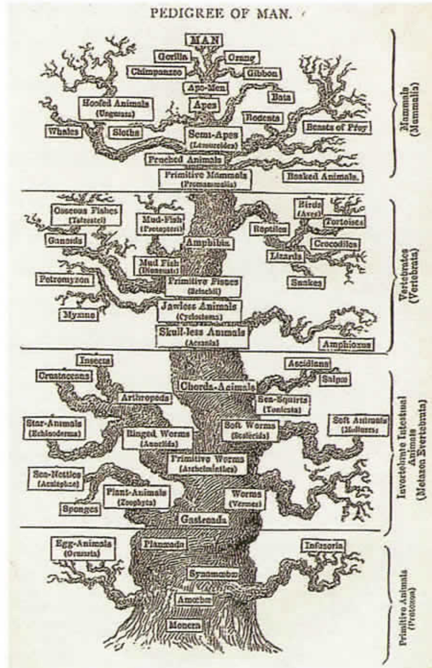
Tree diagrams contain the imprint of their allegorical origins by implying relations of hierarchy, categories, consanguity, derivation, and degrees of proximity. Thickness of limbs carries meaning, though of course many tree diagrams are abstracted into a scheme of lines and branches. As a method of constructing thought, tree diagrams "were widely used by medieval clerics and then by early modern scholars as they sought to explain through them the meaning of the world."[135] When the tree structure is adapted for genealogical purposes, we mark the shift from metaphor to diagram.[136] Once pressed into service of for-



mal logic, or conceptual schemes, the tree structure functions in a fully diagrammatic way.

The Porphyrian tree is among the most widespread of these diagrams.[137] The tree is a graphical expression of Aristotle's logical categories, shown as a series of dichotomies along a central branch. The model is simple, powerful, and hierarchal, embodying the neo-Platonic character of Porphyry's influences, Plotinus and Longinus.[138] Porphyrian trees are single, unitary structures whose shape expresses a cosmological hierarchy from highest to lowest being (humankind). The branched pairs at every level of its structure permit a "class" of being and an instance of it to exist in parallel. Questions of universals and their relation to particulars (a priori structure or classification from observation) that divide Platonic and Aristotelian positions are not resolved in Porphyry's organization, but the tree structure could support the projection of logical organizations and classifications of all kinds. The graphical form of the Porphyrian tree is always the same—a trunk serves as the central column of terms, and the branches arranged in perfect bilateral symmetry express the extremes of the central term. The hierarchy moves from crown to roots, with the most abstract and general concept at the top. Thus "Substance," which is the overarching concept in Aristotelian categories, is followed by Body, Animate Body, Animal, and Man.

Petrus Ramus, classification structure from *Dialectique* (1555).



The hierarchy structures a clear value system into the diagrammatic form.

The force of this tree as a descriptive presentation of the Aristotelian categories was so strong that it continued to be the basis of classification systems of all kinds well into the Enlightenment.[139] The binaristic process of division it embodies, founded on a simple act of differentiation (e.g. animate/inanimate) made it adaptable for any systematic ordering based on divisions. These appear in one medieval treatise after another concerned with organizing knowledge in a variety of disciplines. Petrus Ramus, the highly influential sixteenth century French humanist and pedagogue, used the system as the foundation of his method, which in turn gave rise to a whole host of classification schemes in the philosophical and natural sciences.[140] Ramus made a crucial change in visual orientation. He turned the tree on its side so that the classification systems and divisions could run across the page. The single classificatory order could be complemented by a textual order. The alignment of terms follows a columnar organization so that the elaboration of sub-categories forms a clear visual grouping. In essence, this puts both axes (top to bottom, left to right) into play as meaningful. This change calls attention to orientation as a diagrammatic property.

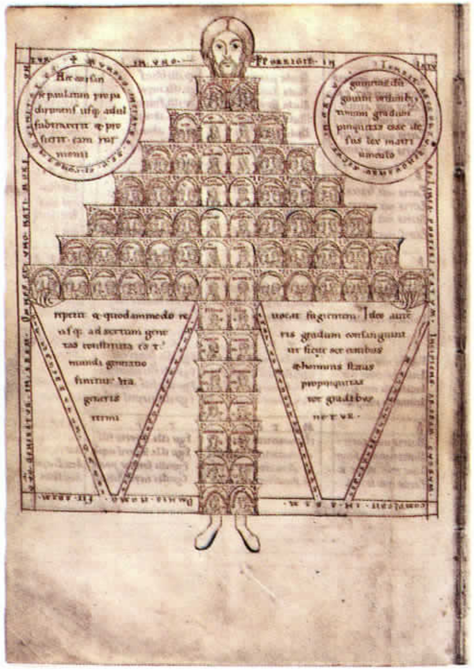
The influence of Ramus's system shows in the "Diagram-

Ernst Haeckel, *Evolution of Man* (1879).

matic System of Human Knowledge," presented by Denis Diderot at the opening of the *Grande Encyclopedie*. His chart elaborates "a genealogical tree of all the sciences and the arts, marked the origin of each branch of our knowledge, the links they have between them, and the connection to the common stem."[141]

The inflexibility and over-determined relations structured into this format became apparent, however, and between 1750 and 1752, a corrective set in. D'Alembert suggested a cartographic, rather than hierarchical tree format, as a representation of the encyclopedic system.[142] The intellectual implications of a map metaphor replacing a tree image in tables of contents have yet to be played out.

Tree forms can express relationships, not just present a classificatory order. In 1891 Ernst Haeckel's tree of life, a

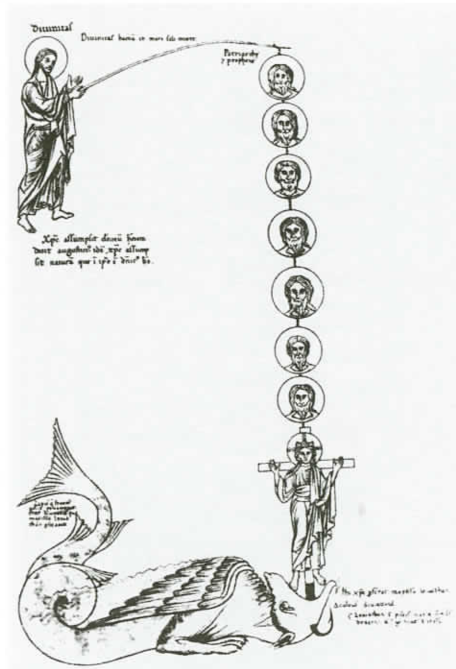


Isidore of Seville, medieval genealogical chart (circa 1160-1165), Bayerische Staatsbibliothek, Munich, clm. 13031.

centerpiece to his *General Morphology Based on the Descent Theory,* combined a descriptive classification scheme with a powerful model of derivation.[143] A popularizer and supporter of the work of Charles Darwin, Haeckel drew a fully leafed tree, complete with twists and turns worthy of his talents as an illustrator. With single-celled organisms at its base and men at its crown, the tree imposes a very different order from Porphyry's tree. Far from the world of metaphysics, Haeckel structured his tree to make the evolution of humans from cells into a single continuous process, holistic,

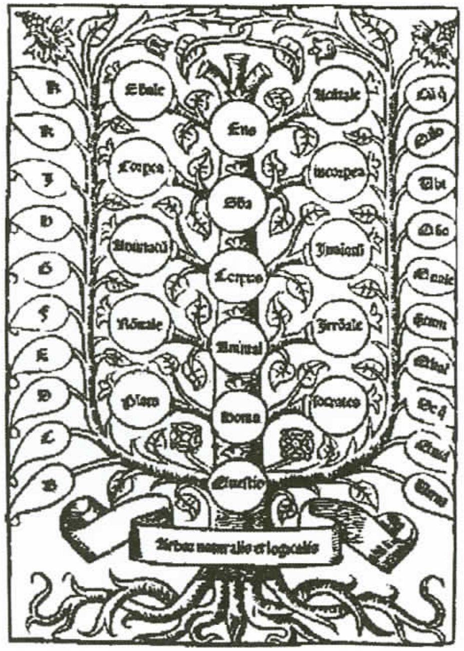
organic, and unbroken by leaps or checks in the progress toward humankind. Here the disposition of limbs is strategic, and the placement of *gorillas* and *orangutans* on either side of humankind, but on a branch that stems from a point in the trunk they do not share with their human brethren, is significant. In fact, the juncture points on Haeckel's trunk are the clues to his scheme of the animal kingdom. His is not a simple binary structure. The many branches at each level are bracketed into classifications he marks on the right edge. The passage from protozoans to crustaceans, from amphibians to mammals, appears as smooth as the growth of a single organism.

Haeckel's image is highly rhetorical. The expression of continuity tends to conceal the nodes or decision points that organize its structure. Graphical expediency plays a role as well, so that mollusks are level with echinoderms though their branch peels off at a higher level from the main trunk of the tree. The substitution of the naturalistic tree for the schematic disks and lines of Porphryian structures imposes its force. Though both are classification systems, Haeckel's suggests continuous derivation while the Porphyrian suggests discrete levels that remain separated by the graphic structure in a manner that reinforces their conceptual separations.



Herrad of Hohenburg, Tree of Jesse from *Hortus Deliciarum* (early twelfth century).

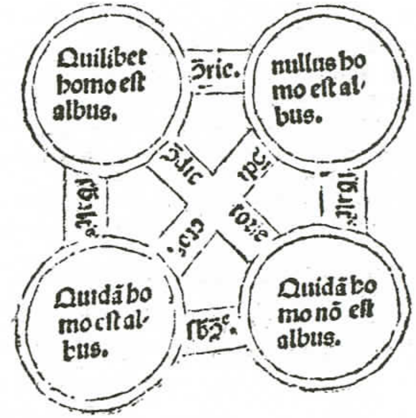
Biblical texts traced a lineage of begetting, and ancestral connections would bring Old and New Testament into alignment with the iconography of the Tree of Jesse. Genealogical trees are of late medieval vintage, not appearing until about 1200.[144] Little in the way of genealogical diagrams exists in antiquity or the early medieval period. Though brought into use around 1300 for justification of royal lineage, "the figure of the genealogical tree as we know it became fully established" only toward the end of the fifteenth century.[145] In medieval scholastic culture, family relations were shown by disks connected with lines, but Arab calligraphers spelled out the names of individuals in bands that connected branches of families, stressing the identity of the link, rather than the autonomy of entities.[146] By the early Renaissance, the lineage of sovereigns, and even of nations, as well as the "organs in the apparatus of the monarchical state" were



Ramon Llull, tree structure from mss. of *Arbor naturalis et logicalis, Ars Generalis Ultima* (1305).

often rendered in arboreal images.[147] Here the ideological message is quite clear in the effect of naturalizing an administrative organization by presenting it as an organic form. The designs produced by Albrecht Durer for a printed image of the triumphal arch of Emperor Maximilian (a project that spanned two years from 1517–18 and was three meters high and made of about 200 woodblocks) might be the single grandest expression of such relations.[148] Genealogical charts reify generational distinctions, making family histories into a

series of marked levels, one descended from another, and with members entering the family through marriage often presented without roots or connections. The more complicated structures of kinship, often necessary for determining royal succession or inheritance, or for the many other matters of anthropological importance, are not able to be fully accommodated in a branching structure of nodes and lines, especially when generations overlap or bloodlines are concealed. Tree-based classification systems assumed common ancestors and direct lineages. DNA mappings often tell a different story, one that contradicts the organic metaphors with their linear narratives of evolution. When these structures are adopted for organizational charts with reporting lines, or data structures in which "inheritance" is a feature, the full force of the ideological effect is in play.



Examples of trees and schemes could be proliferated endlessly, and each, in its structured arrangement, offers the opportunity for examination. If the branches of the Porphyrian structure suggest that the paired branches of its limbs have equal stature, and if trees of consanguity imply an indisputable relation of continuity (and legitimacy), and the adoption of these formats into the structure of classification systems implies that relations of elements in such a system are built on concepts of parent-child inheritance of characteristics of a class, and spheres suggest discrete zones of containment, then what they have in common is that they are fixed, schematic expressions of information in which spatial relations have value.

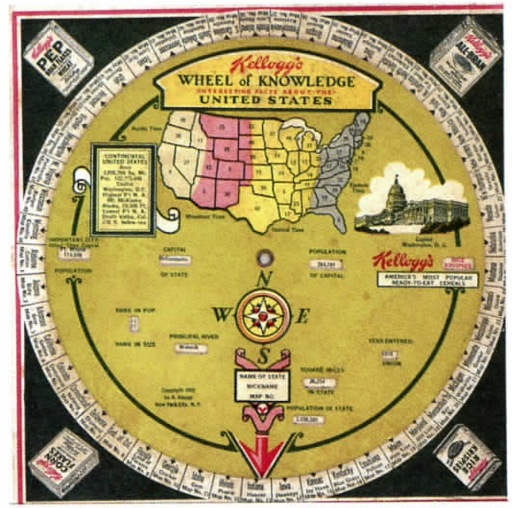
Network diagrams and topic maps have many features in common with trees, but they are not hierarchical.[149] They

John Major, logic diagram (fifteenth century).

have nodes and lines, or points and edges, whose relationship is usually directed. Trees of knowledge almost always express directed graphs whose order cannot be reversed. Just as a biological child cannot become the parent of its parent, so a child in a data structure cannot assume hierarchical dominance over the parent node. In network diagrams the structures are created through tripartite relationships. An entity-relationship-entity model allows the line that connects two elements to have an attribute or character assigned to it. Weight and value, color coding or inflection through other graphic features that distinguish one kind of relation from another, can be readily generated from well-structured data sets. These have the branching structure of trees, but in the case of topic maps, might have variability in their configuration. If any node can become the top node, by selection, and the graph reconfigured around that node, then the hierarchical fixity of the tree structure is transformed. Because directed graphs carry information attributes (e.g., *x knows y*) that are not necessarily determined by a sequence of lived events (e.g., *z is the father of a*), their polarities may be reversed and their order manipulated. The spatial distribution of network diagrams, topic maps, and other graphical expressions of processed text or intellectual content is often determined by the exigencies of screen real estate, rather than by a semantic value inherent in the visualization. This introduces incidental artifacts of visual information. A point in a graph may be far from another because of a parameter in the program that governs display,

Ramon Llull, volvelle from ms. for the *Ars Combinatoria, Ars Generalis Ultima* (1305).

rather than on account of the weight accorded to the information in the data set. The argument of the graphic may even be counter to the argument of the information, creating an interpretative warp or skew, so that what we see and read is actually a reification of misinformation.



Kellogg's Company Wheel of Knowledge (1932).

Knowledge generators

Knowledge generators are graphical forms that support combinatoric calculation.[150] Their spatial organization may be static or mobile, but their spatial features allow their components to be combined in a multiplicity of ways. They make use of position, sequence, order, and comparison across aligned fields as fundamental spatial properties. Train timetables and Ramon Llull's volvelles are knowledge generators. So, I would suggest, is a list of numbers to be added up, or a problem in long division. The outcome is determined by a set of operations, but the result is a product, generated through the combination of spatial organization and a set of rules for its use. Many instruments for the calculation of times of day, position on the globe, navigation, are knowledge generators. They are taking a fixed set of values and allowing them to be recombined for different uses and purposes. The spatial organization supports the combinations or calculations that produce the result. The values do not change, and no new information goes into the system in the process of computation, though results are arrived at through the mechanical, dynamic operation of their elements.

At the outset of their classic, *Logical Reasoning with Diagrams*, Jon Barwise and Gerard Allwein state, "A striking feature of diagrammatic reasoning is its dynamic character."[151] Their goal was to study the "logical aspects of reasoning that use non-linguistic forms of representation."[152] Diagrams, clearly, are not surrogates for linguistic statements, nor are they mere representations of formal knowledge already gained. They are generative systems composed of unambiguous elements that can be used to model and articulate proofs.[153]

In a landmark 1987 essay, "Why a Diagram Is (Sometimes) Worth Ten Thousand Words," Herbert Simon and Jill Larkin argue that a diagram is fundamentally computational, and that the graphical distribution of elements in spatial relation to each other supported "perceptual inferences" that could not be properly structured in linear expressions, whether these were linguistic or mathematical.[154] They state at the outset that "a data structure in which information is indexed by two-dimensional location is what we call a diagrammatic representation."[155] They argue that the spatial features of diagrams are directly related to a concept of location, and that location performs certain functions. Locations exercise constraints and express values through relations, whether a machine or human being is processing the instructions. Larkin and Simon were examining computational load and efficiency, so they looked at data representations from the point of view of a three part process: search, recognition, and inference.[156] Their point was that visual organization plays a major role in diagrammatic structures in ways that are unique and specific to these graphical expressions. In particular, they bring certain efficiency into their epistemological

operations because the information needed to process information is located "at or near a locality" so that it can be "assessed and processed simultaneously."

By contrast to trees, knowledge generators are combinatoric. In some instances, the generative capacity is effected by moving parts. In others, the diagrammatic form produces multiple outcomes through the reading of variables against each other even though no part literally moves. The combinatoric art of the already noted thirteenth century Catalan philosopher Ramon Llull was based on the use of rotating wheels. In 1275, Llull designed his first major treatise, *Ars Generalis Ultima*, published in 1305 as *Ars Magna*.[157] His system consisted of lists of the attributes of God, and all the possible connections between them, virtues of the divine creator, and other exhaustive, formalized systems for contemplating and meditating upon theological points. Martin Gardner summarizes Llull's method succinctly: "In every branch of knowledge, he believed, there are a small number of simple basic principles or categories that must be assumed without question. By exhausting all possible combinations of these categories we are able to explore all the knowledge that can be understood by our finite minds."[158] Thus tables of combinations and concentric volvelles produced all possible permutations through multiple rotations. Llull used the term *camera*, meaning room, to indicate the divisions of space on his wheels, suggesting they were containers of value, not just conveniences or labels. If we are to study the attributes of god, we can rotate a volvelle to find that his patience is eternal, his glory just, and his wisdom truth. Fixed entities on stable structure allow for realignment as an effect of their graphical structure. Not all his diagrams were so affirmative, and the states of the soul allowed for forgetting, abnormal hatred, and other negative combinations.[159] The combinations of virtues and sins gave advice, offering appropriate responses or conditions for anger or patience. The set of combinatoric wheels governing relations between things put abstractions and qualities into play: beginning, end, affirmation, negation, doubt, similarity, contrariety. All were distributed in accord with a system of triangular pointers and pivoting disks which had value in each and every of the many extensive possible combinations. Llull's is a generative system, not a representation.

Gottfried Leibniz, *characteristica universalis* frontispiece to *Dissertatio de Arte Combinatoria* (1666).

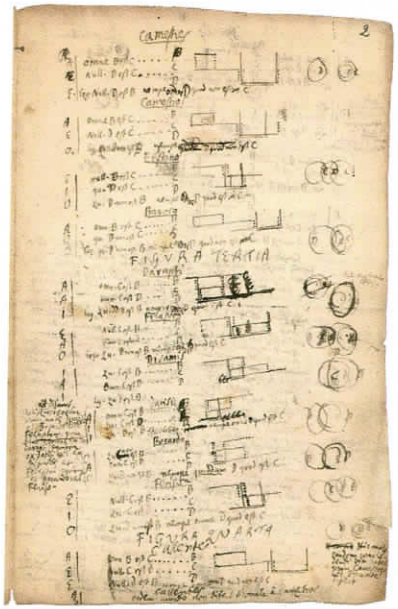
Like astrolabes, nocturnals, and other devices for calculating time, position, or direction in celestial observation and navigation, Llull's circular elements pivoted around a central point to produce their multiple combinations. Arabic philosophers used a device called a *zairja* that used the 28 letters of the Arabic alphabet to calculate new ideas along similar lines. Other combinatoric uses of rotating devices appear in astronomical studies, allowing the positions of stars to be forecast. The late medieval imagination engaged in elaborate diagrammatic invention in the design of charts, instruments, and devices that could be used to chart the heavens.[160]

Though Ramon Llull is regarded by some as a predecessor to modern computing, his mechanical calculators are rigid in graphical form.[161] Their fixed formats only support limited permutation, and though their formal structure can be adopted for many different values, the method remains mechanistic and limited in the generative activity of its outcome. Volvelles were adaptable. The 1564 edition of another late medieval work, Petrus Apianus's *Cosmographicus Liber*

(updated by Gemma Frisius), makes use of volvelles to more naturalistic ends, for calculation of the movements of planets, calendars, and the like.[162] An extremely popular work from its initial publication in 1524 through the end of the sixteenth century, Apianus's text served as a reference work on astronomical, navigational, geographic, and other matters. The simple device of revolving circles as a generative instrument was readily disconnected from philosophical and mystical realms. The simple principles of rotation and alignment, spacing and metrics along a circumference, are powerful spatial elements that sustain combinatoric activity. The design of volvelles, rotating wheels, can be put to many purposes.

Leibniz's *Dissertatio de arte combinatoria*, published in 1666, absorbs the lessons of Llull into a dialogue with Descartes's idea of an alphabet of reason grounded in *mathesis*.[163] Descartes's coordinate system had made a crucial step by allowing geometrical forms to be represented algebraically and graphed. The focus of Leibniz's search—for a universal calculus that would demonstrate the way the four basic elements gave rise to all other objects in the world—shows how much the late medieval cosmologies still held sway. The diagram drawn by Leibniz for the 1666 publication seems a world away from the approaches to logical syllogisms that fill his notebook pages.[164] When put next to his "stepped reckoner," a mechanical device that exhibits its modernity through the rational workings of its design, the diagrams for his *arte combinatoria* seem like peculiar anachronistic vestiges of a kabbalistic sensibility.[165] The "reckoner," like other mechanical devices mentioned above, used for specific purposes (celestial, navigational, or time-keeping) was a knowledge generator in built form. The relation of this device to the combinatoric format of diagrams is obvious, and the extension of the principles of a system of elements put into combinatoric play is what makes them effective for calculations. Leibniz's combinatoric sensibility led him into the study of binary arithmetic, and his discovery of the *I Ching*, with its hexagrams of solid and broken lines, confirmed the power of the system as both a universally symbolic and cosmologically generative one.[166] The *I Ching* is a powerful combinatoric system. Leibniz was attracted to its simplicity (the lines work as a set of binary combinations of broken and unbroken, stable and changing elements in all sixty-four possible combinations of two trigrams) and its claims to be complete.

The squares of opposition prevalent in medieval logic were first described by Aristotle in *De Interpretatione*.[167] The earliest graphical instance seems to come in a second century manuscript of Boethius.[168] The arrangement of four terms in relations as contradictory and contrary allows combinatoric contemplation and discussion. They can be used to express

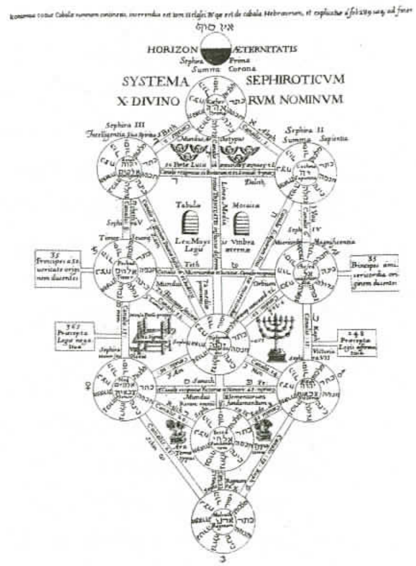


Gottfried Leibniz, manuscript analyzing syllogisms (late seventeenth century).

any set of terms to be put into productive tension. Their simplicity supports a highly generative set of relations, since each of the terms is connected with the others and the mind contemplates these alternative arrangements as an intellectual exercise. In short, they provide a performance of probable interpretations. The square with its four nodes and crossings can be extended with additional nodes and connecting lines, but the dynamic tensions generated by the combinatoric structure are present even in the simplest ver-

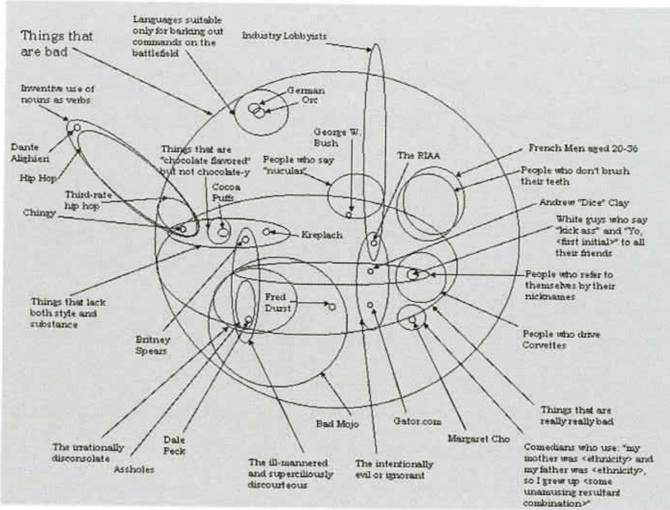
sions. In hyperbolic examples, the lines of relation, each labeled and carefully interlaced, can track an entire field of dynamic interplay.

Another object of contemplation, the Sephirotic Tree, is an outgrowth of twelfth and thirteenth century Kabbalah, a set of Jewish mystical practices.[169] The Sephirotic Tree is a chart of emanations, made concrete in cosmic creation. The central axis is deemed neutral, the outer ranks designated as conduits of active and passive energy. The mystical practice of contemplation was meant to bring the soul into holistic relation with God through engagement with the movement of spiritual energy through the sephirot. Allegorical images from the late medieval period abound in Renaissance emblem books, and the symbolism of the Tarot, astrological signs, and many occult practices. But the Sephirotic Tree is distinct among these other images by virtue of being diagrammatic—the shape of its organization and the intellectual structure it represents are the same. Its generative potential is spiritual knowledge, rather than rational or intellectual insight. As such, it is representative of diagrams used in esoteric and mystical practice, such as magic squares and other configurations. Its workings are combinatoric, the mind must move through its structure to engage.

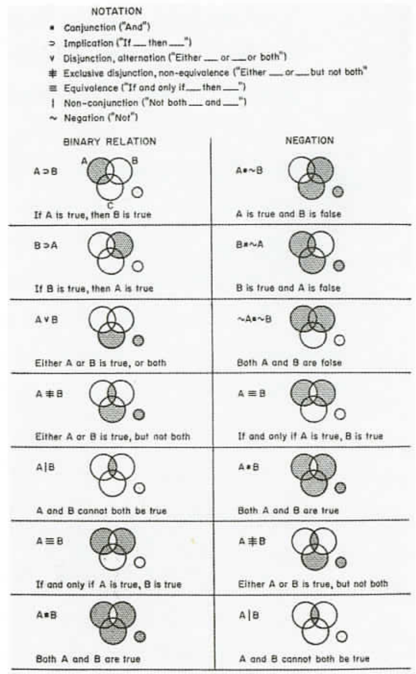


Athanasius Kircher, Sephirotic Tree, *Oedipus Aegyptiacus* (1652-1654).

Graphic tables were used to solve computational problems from the time of Hipparchus, and graphical systems for calculating logarithms had been made into working instruments in the seventeenth century. Descartes developed his analytical geometry as a "means for the general graphic representation of laws and formulas by aid of two axes at right angles."[170] These are generative graphic techniques. Another such instance is the contribution made by the eighteenth century mathematician Leonhard Euler who created a method of using circles in intersecting and enclosing relations to demonstrate syllogistic principles, sets, and their relationships. These are similar to the diagrams of John Venn, familiar from set theory, created in the late nineteenth century, though the two systems differ in their particulars.[171] Each is a graphical means of resolving syllogistic questions, and determining an outcome about sets and relations through graphical means. Euler worked on graph theory, calculus, and topological problems that had graphical counterparts. The diagrammatic methods and formal logic in Venn diagrams are not isomorphic to their arguments—any "set" can be represented by a circle so that its intersection with another set can be graphed. But the information itself need not have anything to do with circular forms or formats.



Venn diagram utilized to display behaviors.

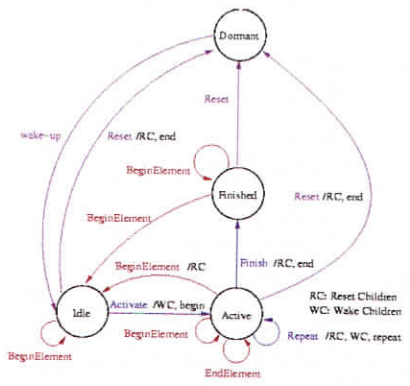


By contrast, other graphical systems for the analysis of propositional calculus or solving problems in formal logic generate specifically visual solutions to mathematical problems.[172] For instance, in the late nineteenth century graphical systems for solving calculus problems were developed that became standard in training engineers. The use of specific methods of making curves, plotting intersections, graphing functions, and arriving at a result with graphical methods stayed in use until the advent of digital computers. The complexities of ballistics problems led to development of graphic calculating scales in the early nineteenth century.[173] *Abacs*, or graphic methods of computing, were in common use for designing roads and bridges.[174] Nomography, the system of using graphical calculating devices, makes use of specialized systems of coordinates to create instruments that can compute a mathematical function.[175] The point? Diagrammatic methods of generating knowledge have been integral to mathematics in many varied and subtle ways—the tabular underpinnings of arithmetical operations—as well as more evident ones—set theory, calculus, topology, network theory, vectors, and other fields in which solutions to complex problems may be arrived at through graphical means.

John Venn, diagram used to show behaviors, *Symbolic Logic* (1894).

The discussion of knowledge generators and logical graphs would be incomplete without mention of Charles

Sanders Peirce and his existential graphs.[176] Venn's work in symbolic logic, first published in 1881, introduced his diagrams. But as Peirce observed, these lacked "iconicity" and were limited in what they could do. Interest in topological relations—spatialized mathematics that is the foundation of network theory—is generally traced to Leonhard Euler's 1736 solution to the Königsberg bridge problem (a problem in routing), but Leibniz had expressed the need for a graphical system of mathematics to address complex geometrical problems more than half a century earlier.[177] The term topology first appears in the 1840s when mathematicians Moebius and Reimann, among others, become interested in connectivity of surfaces as spatial-graphical and mathematical problems.[178] Soon after, Enrico Betti broke away from standard Euclidean understandings of space and introduced the concept of n-dimensional spaces that could only be described mathematically. Set theory and topology are close correlates, and Venn's simple but powerful diagrams used a flat plane that had no metrical features, taking advantage of the simple facts of intersection, area, inclusion, and exclusion.

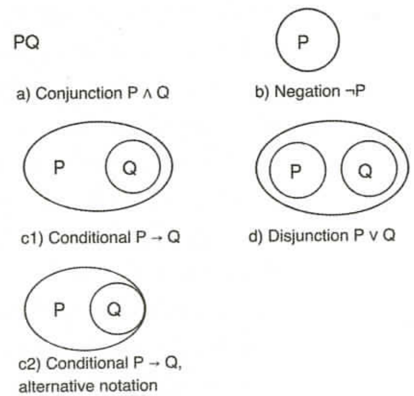


Charles Gordon, state transition diagram.

These graphical principles also provided the basis of Peirce's systems. Intent on developing his existential graphs, Peirce envisioned an entire system of graphical reasoning.[179] Peirce's graphical system was a method of logical expression, but also, a means of making logical proofs. He had three systems—alpha, beta, and gamma—each of which had its own rules and constraints. Peirce developed his graphical systems

from a conviction that the linear notation using informal logic was inadequate to the semiotic theories he was formulating in the 1870s and 1880s. The philosophical motivation for the graphical system Peirce invented sprang in part from inspiration by George Boole's *calculus ratiocinator* and its potential to support multiple interpretations. Though largely ignored by his contemporaries, Boole's 1854 *Laws of Thought* put forth a symbolic method from which modern computational procedures are drawn. Like Boole, Peirce considered "logical language as a re-interpretable calculus."[180] Peirce was convinced that reasoning itself was diagrammatic. He distinguished diagrams from figures, saying they were "closer to a unit of a system equipped with representational input and its own transformational rules." Diagrammatic reasoning, he insisted, must be carried out through such a visual, spatial system. The existential graphs were the result of this conviction, the means and site of diagrammatic reasoning. Symbols in a diagram could "be manipulated to obtain other relations."[181] Peirce's project remained unfinished, but aimed at graphing a complete system of relations among existing entities. The graphical vocabulary of his "diagrammatic syntax" consisted of simple but powerful elements, such as inclusion and exclusion, that could be combined according to sophisticated logical rules. The diagrams *performed* the act of reasoning, they did not *represent* it after the fact but were the means of making the logical processes work.

The semantic web makes use of node and line structures that make connections without hierarchy. Webs, like lattice and matrix



Charles Sanders Peirce, existential graphs.

formats, are inherently non-hierarchical, with proximity and connectivity relations serving a more powerful rhetorical purpose. Like any two-dimensional surface, a screen can support the illusion of depth using a third axis, particularly useful for graphing events or time-based media like film, video, and audio. Each additional dimension adds complexity. Node-link diagrams support pathfinding, connections, through adjacency and associational trails. In diagrams that need to support multiple paths, even overlapping paths, such as those that display transportation systems (where some lines or roads pass over or under each other rather than intersecting), multiple layered matrices are better suited to the schematic organization of the information than flat diagrams.[182]

Dynamic systems

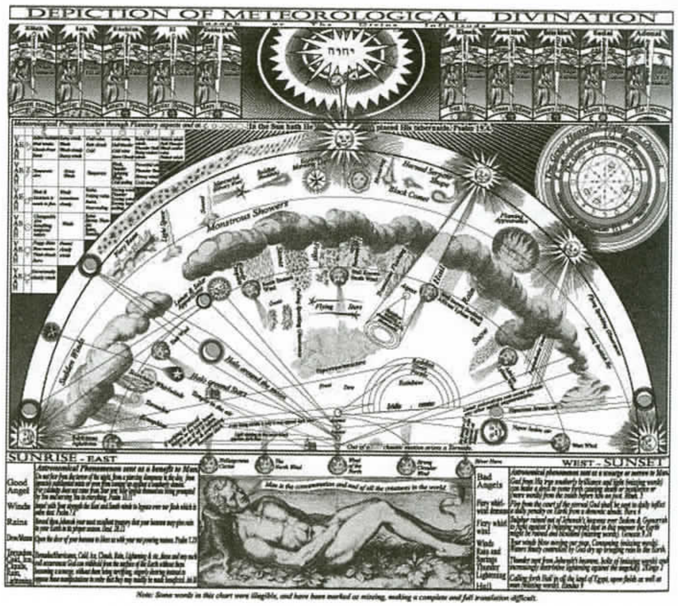
The combinatoric generators we have been describing can be used to reorganize relations among elements, but they do not change either the elements or the structure that contains them in that process. Diagrams of dynamic events or processes are also generative, but they often display processes rather than products.[183] They use dynamic elements, such as vectors, or directed graph lines, direction, flow, movement, and rates of change as components whose spatial order creates a graphical field. A diagrammatic event is a means of provoking and sustaining processes that are in flux, unfinished, open-ended, complex, or probabilistic. Diagrams of dynamic processes are different from knowledge generators. They are not meant to produce an outcome that can be repeated, or guaranteed by the careful observation of rules (as in calculating scale changes with a ruler or adding a sum of numbers). Instead these diagrams make use of graphical or-

ganizations, operations, and relations to analyze or model events or processes. Diagrams of complex systems model many possibilities and probabilities. Values change as the diagrammatic activity progresses, and multiple variables may be active at different scales and rates of change so that the outcome for such a dynamic system is necessarily probabilistic.

New challenges arise in using graphical means to show dynamic processes and events, including complex adaptive systems. Because an event is a state change, a presentation of dynamic circumstances, conditions in which various force, vectors, flows, pressures, or other changeable phenomena are being charted, it does not necessarily lend itself to graphical format. Nonetheless, visualizations of fluid dynamic systems—such as the weather, tides, and atmosphere—have a much longer history on which we can draw. Once again, we can trace literary references into antiquity. Among the Greeks, Thales and others described weather phenomena but creating graphic techniques for meteorological analysis was slower. Aristotelians charted the four elements—earth, air, fire, water—in a diagram that was meant to be generative, productive, capable of the infinite variety of combinations that produced the natural world.[184] This system was frequently refined to show the zones of frigid, torrid, and temperate air, and to indicate the power of the winds to blow from each direction and formed, as we have seen, the basis of Leibniz's view in the 1660s. The effort to align weather changes with planetary movements also gave rise to an industry of observations and calculations. The astronomer Tycho Brahe was convinced that weather forecasting could be done based on astronomical observation.[185] The efforts of the sixteenth century astronomer were copied in later years by figures like John Goad, who recorded thirty years of observations in his 1686 publication, *Astrometeorologica*, tracing the "Discourses of the Bodies Celestial, their nature and influences, discovered from the variety of the Alterations of the Air [...]."[186]

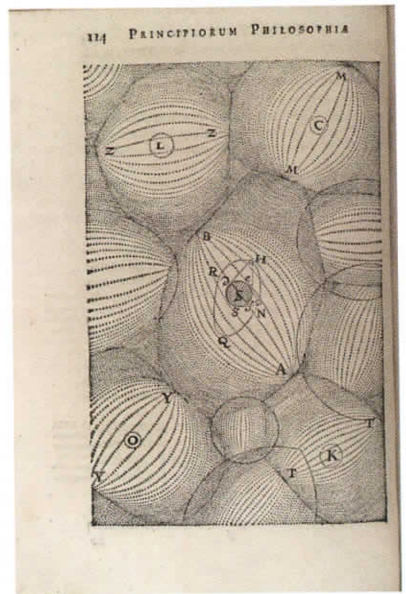
The aforementioned Fludd produced a remarkable image of Meteorology (1626) that combines occult and astronomical imagery. His system allegorizes natural phenomena and allows for the Twelve Winds to be interspersed with images of the Four Archangels.[187] Though mechanistic, his vision of interlocking wheels and spheres hints at dynamic representations of processes and forces.[188] His weather scene is theatrical, and combinatoric, a stage on which diagrammatic play can be enacted by calling the selective elements into play. What it lacks in scientific accuracy it makes up for in imagination.

Diagrams of wind and currents became a feature of navigational maps (Leonardo had done detailed studies of waves and currents, vortices, and other formations in moving water), and seemed to belong to the world of things, observ-



Robert Fludd, *Philosophia sacra et vere christiana seu meteorologica cosmica* (Frankfurt: T. de Bry, 1626).

able, and tractable. But the motions of air, vapor, clouds, and the actions of the atmosphere were more difficult to describe in graphical form. René Descartes's 1637 *Discourse on Method* contains several diagrams that chart processes of atmospheric transformation.[189] These are fascinating, since they are visual attempts to show activities that are almost unseen. Descartes still imagines the world to be composed of the primal elements—earth, air, fire, and water—but his scientific imagination addresses the particulars of molecular structure and operation. Molecules of water, he suggests, are shaped with wiggly tales, small and slippery, so that they can move in between the hard-edged and larger molecules of wood, earth, or stone. These materials are composed of molecules whose edges catch and lock together, but are large enough that water can sometimes still find its way into the crevices left in the interlocking structures. His analyses of rising water vapor, cloud formation, and changes in temperature, early attempts to show complex processes, are unique in their connection of atmospheric activity and landmass. He recognizes that what he is observing and describing is a system, not isolated entities. The lines of pressure and change align directionally, become compressed, and make

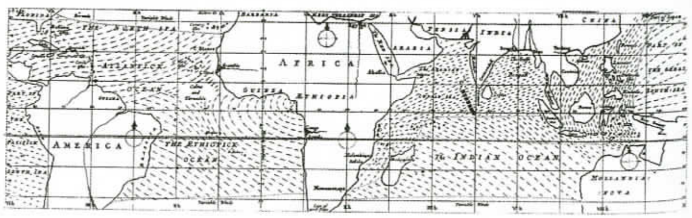


René Descartes, images of meteorological phenomena from *Discourse on Method: Dioptrics, Meterology, and Geometry* (1637).

use of other innovative visual means. Static images, they optimized their graphic capacity to show the thermal and pressure systems in relations of land and air.

Descartes also created a remarkable diagram of energy vortices in the plenum, showing the substance that fills the voids of the universe. The image has a magical dimension to it, presenting the imagined force fields exerted by planets in a pulsing field of activity.[190]

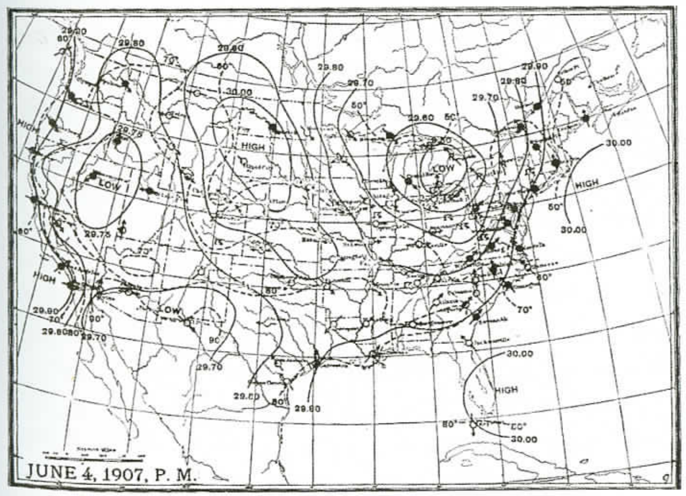
Meteorological observation took a leap with the development of instruments for gauging wind velocity, temperature, and barometric pressure, thus creating a statistical foundation for the science.[191] The thermoscope, invented by Galileo in the last years of the sixteenth century, was soon succeeded by thermometers and barometers capable of regular and reliable readings. Statistical metrics were becoming standardized in this period. Abstracting intangible, sometimes invisible, phenomena into a graphical language and diagrammatic form depended on the intersection of adequate instrumentation and measure, sufficient record keeping to supply data, mapping techniques on which the information could be projected, and then a graphical language for diagramming ephemeral phenomena—or, at least, making a study of the forces and variables of a highly complex system. While meteorological observation forms one excellent case study, the attempt to depict magnetism and other unseen forces was another area in which dynamic processes sought



Edmond Halley, map of the winds (1686).

graphical expression as a foundation for understanding.

Basic instruments for taking temperature and barometric pressure readings, recording wind direction and, to a limited extent, velocity, as well as precipitation gauges, were chiefly seventeenth century inventions. Edmond Halley is credited with creating the first meteorological chart when he mapped the winds on the surface of the globe in 1686.[192] His arrows of wind direction are not systematic, but they do indicate unstable, changeable conditions. The combination of direction and force is intuitive, but systematic creation of what are known as surface analysis maps only emerged after development of coordinated telecommunications systems. Records of meteorological data started to be mapped in the early nineteenth century, though tides and currents had been charted several centuries earlier. The creation of isobars (lines connecting areas of similar barometric pressure) is attributed to the French meteorologist Edme Hippolyte Marie-Davy in the 1860s, though a map with isobars appears in the 1834 treatise on meteorology written by William Prout.[193]



June 4, 1907 thunderstorm mapped using standard conventions with isobars (early twentieth century) from Sverre Peterssen, *Introduction to Meteorology* (1941).

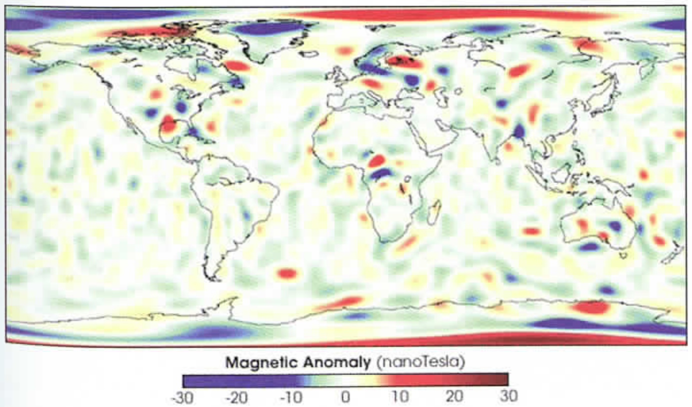
One of a storm in New England in the late nineteenth century shows the graphical system for wind direction and force, isobars, temperatures, and pressure in place. Snapshots of particular moments, they imply process and change rather than actually showing it.

Interest in the microlevel of analysis of meteorological events, long expressed in passages of poetic prose description, found graphical expression in several detailed studies produced in the 1860s. H.W. Dove's *The Law of Storms*, published in 1862, is filled with detailed and technical discussion of measurements of barometric pressure, temperature, wind velocity, and direction as well as storm tracks and wind shifts, even as its title aligns it with the systematic approach to thinking characteristic of other approaches to knowledge and its representation at which we have already glanced.[194] Rear Admiral Fitz Roy's 1863 *The Weather Book* contained carefully mapped meteorological data for several days running that showed the wind directions, velocities, precipitation, temperature, and barometric pressures during a major storm in October 1859.[195] Two years later, Francis Galton's *Meteorographica, or methods of mapping the weather*, created a system of conventions for showing meteorological conditions in Europe for the entire month of December 1861.[196] Methods of showing fronts, precipitation, using isobars, and mapping other data were quickly adopted. The military interest in weather forecasting intensified the pace at which conventions were pressed into use. More sophisticated methods of measuring, including balloons and other devices, combined with simultaneous coordination of information across distances, gave rise to the modern weather map by the late nineteenth century.

Much more could be detailed in the history of graphical representation of fluid dynamics, as increasing sophistication of instruments combined with improved methods of

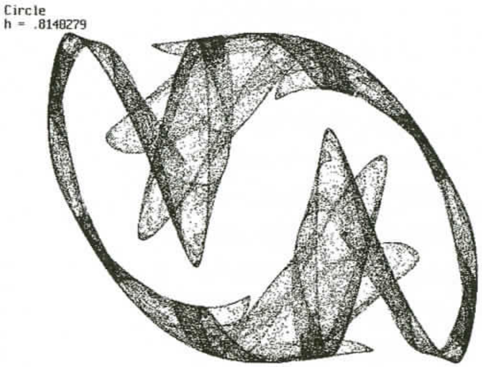
calculation so that rapidly changing conditions, graphed temperature, pressure, and wind conditions became part of forecasting and analysis.[197] But challenges arose from studying thermodynamic properties of the atmosphere whose complexity was just glimpsed by nineteenth century scientists. Non-linear systems posed mathematical challenges. For purposes of thinking about the visualization of interpretation, approaches to the thermodynamics of the atmosphere offer an example of ways an enormous number and type of variables can be put into a model for analysis to generate outcomes that cannot be predicted mechanistically. These systems are extremely sensitive to start conditions, and exhibit emergent behaviors. By the early twentieth century, meteorologists were not only recording observable phenomena (wind, temperature, etc.) but also modeling dynamic systems.[198] The combination of motion graphics, simulation, and computational capability necessary for visualization of complex mathematical models has only been possible with digital computers.

Graphical means in two dimensions, or even the third and fourth dimensions created as spatial-temporal illusions,



Magnetic activity visualized, NASA.

are often inadequate to address the mathematical complexities involved. But conceptually, we can imagine diagrams of systems with variable organization, changes of scale, and almost inexhaustible complexity in micro to macro modeling. The foundations of chaos and complexity theory arose from the observations of Edward Lorenz, a meteorologist and mathematician, while watching the dynamics of cloud formation.[199] If we are to model interpretation with all of the many variables, statistical and probabilistic distributions it involves, these are the sources to which we will have to turn, even for a speculative vision.



Euler circle, chaos diagram.

Lorenz's engagement with chaos theory resulted in the production of standard diagrams to show the ways tipping points and other events transform the dynamics of systems. Related to chaos theory in its dynamic unfolding, complexity theory uses non-predictive modelling to study probabilistic outcomes of variables in relation to each other within a system as it changes over time. Chaos models show transformation, they are built on interactive variables in a co-dependent, adaptive system, rather than mechanistic models. Dynamic systems, in which adaptation and emergence occur, cannot be graphed in advance. A model has to run its course in order for the outcome to become apparent, and in the process, graphical forms and expressions allow the emerging patterns to become legible. Knowledge is generated, and expressed graphically, but the graphical system is not the means of data input in either chaos or complex systems.

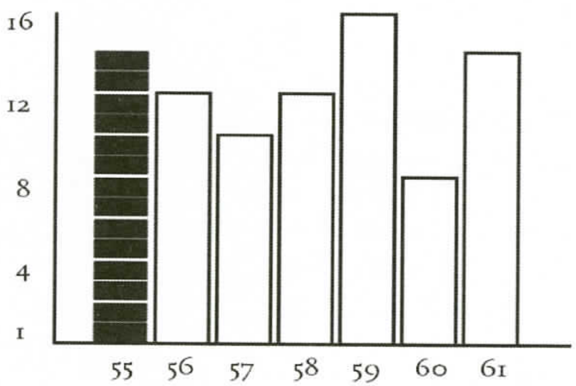
Visualizing uncertainty and interpretative cartography

T. Zuk, S. Carpendale, and W.E. Glanzman, "Visualizing Temporal Uncertainty in 3d Virtual Reconstructions," *Proceedings of the 6th International Symposium on Virtual Reality* (2005): 99-106.

Most, if not all, of the visualizations adopted by humanists, such as GIS mapping, graphs, and charts, were developed in other disciplines. These graphical tools are a kind of intellectual Trojan horse, a vehicle through which assumptions about what constitutes information swarm with potent force. These assumptions are cloaked in a rhetoric taken wholesale from the techniques of the empirical sciences that conceals their epistemological biases under a guise of familiarity. So naturalized are the maps and bar charts generated from spread sheets that they pass as unquestioned representations of "what is." This is the hallmark of realist models of knowledge and needs to be subjected to a radical critique to return the humanistic tenets of constructedness and interpretation to the fore. Realist approaches depend above all upon an idea that phenomena are *observer-independent* and can be characterized as *data*. Data pass themselves off as mere descriptions of a priori conditions. Rendering *observation* (the act of creating a statistical, empirical, or subjective account or image) as if it were *the same as the phenomena observed* collapses the critical distance between the phenomenal world and its interpretation, undoing the concept of interpretation on which humanistic knowledge production is based. We know this.

But we seem ready and eager to suspend critical judgment in a rush to visualization. At the very least, humanists beginning to play at the intersection of statistics and graphics ought to take a detour through the substantial discussions of the sociology of knowledge and its critical discussion of realist models of data gathering.[200] At best, we need to take on the challenge of developing graphical expressions rooted in and appropriate to interpretative activity.

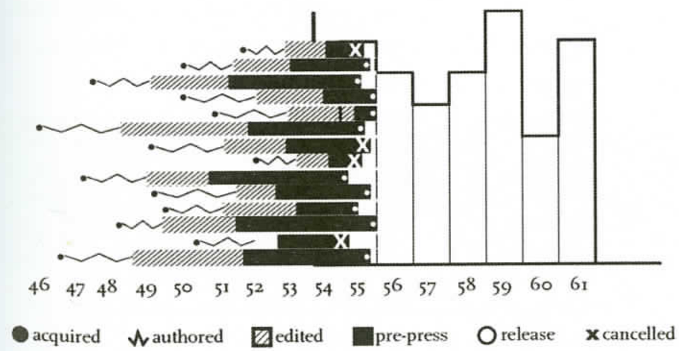
Because realist approaches to visualization assume transparency and equivalence, as if the phenomenal world were self-evident and the apprehension of it a mere mechanical task, they are fundamentally at odds with approaches to humanities scholarship premised on constructivist principles. I would argue that even for realist models, those that presume an observer-independent reality available to description, the methods of presenting ambiguity and uncertainty in more nuanced terms would be useful. Some significant progress is being made in visualizing uncertainty in data models for GIS, decision-making, archaeological research, and other domains.[201] But an important distinction needs to be clear from the outset: the task of representing ambiguity



Standard bar chart based on discrete data entities.

and uncertainty has to be distinguished from a second task —that of using ambiguity and uncertainty as the basis on which a representation is constructed. This is the difference between putting many kinds of points on a map to show degrees of certainty by shades of color, degrees of crispness, transparency, etc., and creating a map whose basic coordinate grid is constructed *as an effect* of these ambiguities. In the first instance, we have a standard map with a nuanced symbol set. In the second, we create a non-standard map that expresses the constructedness of space. Both rely on rethinking our approach to visualization and the assumptions that underpin it.

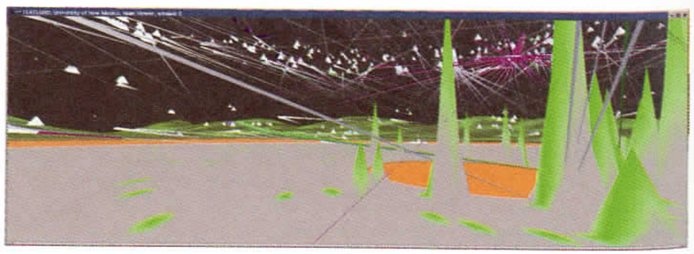
If I set up a bar chart or graph, my first act is to draw a set of one or more axes and divide them into units. The conventional forms of the graphical display of information, "data," make use of a formal, unambiguous system of standard metrics. Charts use simple (if often misleading) geometric forms that lend themselves to legible comparison of values, proportions, or the exhibition of state changes across time. Lines, bars, columns, and pie charts are the common and familiar forms. They render *quantitative* relations with a transparency that seems natural, so that, for instance, if we look at the



Alternative to standard bar chart showing greater complexity.

changes in population across a series of years for a particular location, we can simply accept that from one year to the next rises or drops occurred in the numbers of persons alive in X city in X country at X time. A pie chart showing percentage of resource allocation from national budgets seems completely transparent, self-evident even. A bar chart could compare daylight hours at different latitudes, or the average size of men and women in different countries, or the number of hospital beds in different institutions in a single geographical location and not raise a skeptical eyebrow. But the rendering of statistical information into graphical form gives it a simplicity and legibility that hides every aspect of the original interpretative framework on which the statistical data were constructed. The graphical force conceals what the statistician knows very well—that no "data" pre-exist their parameterization. *Data are capta*, taken not given, constructed as an interpretation of the phenomenal world, not inherent in it.

To expose the constructedness of data as capta a number of systematic changes have to be applied to the creation of graphical displays. That is the foundation and purpose of a *humanistic approach* to the qualitative display of graphical information. That last formulation should be read carefully, *humanistic approach* means that the premises are rooted in the recognition of the *interpretative* nature of knowledge, that the *display* itself is conceived to *embody qualitative ex-*



Steve Smith, immersive data visualization.

pressions, and that the *information* is understood as *graphically constituted*. Each of these factors contains an explicit critique of assumptions in the conventional "visual display of quantitative information" that is the common currency.

The basic categories of supposedly quantitative information, the fundamental parameters of chart production, are already interpreted expressions. But they do not present themselves as categories of interpretation, riven with ambiguity and uncertainty, because of the *representational* force of the visualization as a "picture" of "data." For instance, the assumption that gender is a binary category, stable across all cultural and national communities, is an assertion, an argument. Gendered identity defined in binary terms is not a self-evident fact, no matter how often Olympic committees come up against the need for a single rigid genital criterion on which to determine difference. By recognizing the always interpreted character of data we have shifted from data to capta, acknowledging the constructedness of the categories according to the uses and expectations for which they are put. Nations, genders, populations, and time spans are not self-evident, stable entities that exist a priori. They are each subject to qualifications and reservations that bear directly on and arise from the reality of lived experience. The presentation of the comparison in the original formulation grotesquely distorts the complexity, but also the basic ambiguity, of the phenomenon under investigation (nations, genders, populations). If the challenges we are facing were merely to accommodate higher levels of complexity into a data representation model, that would require one set of considerations and modifications. But the more profound challenge we face is to accept the ambiguity of knowledge, the fundamentally interpreted condition on which data is constructed, in other words, the realization of my refrain *that all data is capta*.

Humanistic methods

The humanistic aspect of this approach should be obvious: that knowledge created with the acknowledgment of the constructed nature of its premises is not commensurate with principles of certainty guiding empirical or realist methods. Humanistic methods are counter to the idea of reliably repeatable experiments or standard metrics that assume observer-independent phenomena. By definition, a humanistic approach is centered in the experiential, subjective conditions of interpretation. Phenomena and their observers are co-dependent, not necessarily in equal measure. A viewer gazing on a sublime landscape or recording migrations at a large scale may be more affected by the phenomena than the phenomena are by the observation. Theoretical physicist Werner Heisenberg never suggested that the relation of intervening observer and effect on phenomena was symmetrical, merely that it was codependent, when he introduced the concept of uncertainty in the early twentieth century.

Creating bar charts with ambiguity and degrees of uncertainty or other variables in them might cause champions of legibility and transparency some unease, but the shift away from standard metrics to metrics that express interpretation is an essential move for humanists and/or constructivists across disciplines. To emphasize the expressive quality of interpretation, I am going to characterize all information as *constructed*: as expressing the marks of its inflection in some formal way. The shift to expressive metrics and graphics is essential in changing from the *expression of constructed, interpretative information* to the *constructed expression of perceived phenomena*, but constructedness and inflection are not

the only features of interpretative approaches. Capta is not an expression of idiosyncracy, emotion, or individual quirks, but a systematic expression of information understood as constructed, as phenomena perceived according to principles of observer-dependent interpretation. To do this, we need to conceive of every metric "as a factor of X," where X is a point of view, agenda, assumption, presumption, or simply a convention. By qualifying any metric as a factor of some condition, the character of the "information" shifts from self-evident "fact" to constructed interpretation motivated by a human agenda.[202]

The standard elements of graphic display for statistical information are simple and limited: scale divisions, coordinate lines, scale figures, circles, rectangles, curves, bars (or columns or percentages of pie charts or other forms) and labels (numbers and terms), signs of movement, flow, or state change (arrows, vectors, paths). The ordering and arrangement of elements within a chart create another level of information, relational information. Relational information is graphically produced; the ordering of elements by size, by color, by alphabetical order, by texture, shape, or other feature happens in graphical space. The resulting arrangement has a semantic value produced by features of proximity, grouping, orientation, apparent movement, and other graphical effects.

Now take these basic elements of graphical display and rethink them according to humanistic principles:

In conventional statistical graphics, the scale divisions are equal units. In humanistic, interpretative graphics, they are not.

In statistical graphics the coordinate lines are always continuous and straight. In humanistic, interpretative graphics, they might have breaks, repetitions, and curves or dips. Interpretation is stochastic and probabilistic, not mechanistic, and its uncertainties require the same mathematical and computational models as other complex systems.

The scale figures and labels in statistical graphics need to be clear and legible in all cases, and all the more so in humanistic, interpretative graphics since they will need to do quite a bit of work.

Perhaps the most striking feature distinguishing humanistic, interpretative, and constructivist graphical expressions from realist statistical graphics is that the curves, bars, columns, percentage values would not always be represented as discrete bounded entities, but as conditional expressions of interpretative parameters—a kind of visual fuzzy logic or graphical complexity. Thus their edges might be permeable, lines dotted and broken, dots and points might vary in size and scale or degree of ambiguity of placement. These graphical strategies express interpreted knowledge, situated and partial, rather than complete. They can be employed as systematically as other charting elements, though part of my intention is to disturb the grounds of certainty on which conventions of statistical legibility are based. Point of view systems introduced into graphs and charts will make evident a perspectival position with respect to their information, an inner standing point in the graphical rendering of space. This is true of all cartographic projections. Every map contains within its coordinate system for graphical expression a set of assumptions about the place from which the map is drawn. Information spaces drawn from a point of view, rather than as if they were observer-independent, reinsert the subjective standpoint of their creation into the graphical expression. Finally, any point or mark used as a specific node in a humanistic graph is assumed to have many dimensions to it, each of which complicates its identity by suggesting the embeddedness of its existence in a system of co-dependent relations. Information entities, or units, are thus understood as fictional abstractions

serving a purpose. But their potential to be read again in relation to any number of other equally significant relations can be made evident. This approach destroys the ground on which standard metrics are used to abstract quantitative information from human circumstances. Humanistic premises replace notions of statistical concepts of self-identity with entangled co-dependence and contingencies.

All of this may sound unduly complicated to someone merely wanting to count the number of pupils enrolled in a group, calculate the number of pencils needed, or to show budgetary expenditures on a per capita basis in the classroom, for example. But this example—an instance of administrative and bureaucratic management—shows that such crudely conceived numeric statistics are useful only in the most reductive circumstances. They tell us nothing about whether the pencils can be used, whether the pupils are prepared or disposed to do their work, whether the budgets will have any effect on learning outcomes, or any of the other factors that come into play in assessments based on metrics extracted from lived experience. They do not account for the ecological, social, cultural, ideological, expertiential aspects of the larger system of which they are a part. But each metric—number of x or y—is actually a number as a factor of a particular intellectual assumption or decision: pupils as a factor of seats in a room, birthdates, population, illness; pencils as a factor of resource allocation, and so on. All metrics are metrics about something for some purpose.

The challenge is to design graphical expressions suited to the display of interpreted phenomena: information *about subjective user-dependent metrics, constructed displays of information*, and *inflected methods of graphical expression*. Interpretative construction registers point of view, position, the place from which and agenda according to which parameterization occurs. Constructedness does not align with the first term in a subjective/objective opposition. It is not individual inflection of mere idiosyncracy. Constructedness stresses co-dependent relations of observer and phenomena (in contrast to presumptions of objectivity, of observer-independent phenomena).

The display of information about affect often uses standard metrics. For example, a chart that shows mood changes or degrees of attraction or any other information related to subjectivity can be created with standard metrics and visual conventions.

The next task is more complicated. Constructed information (which is, in essence, all information, though for practical purposes, I insist on these approaches only in domains where the humanistic component of the interpretative act needs to be structured into the visualization), that is information whose constitution exhibits its situated, system-dependent character, deviates from the standard norms by using graphic variables such as intensity of tone, size, color, or other feature to embody its qualities. Constructed information can use graphical means to show its inflected character, demonstrating its deviation from standard norms in the way the display looks, or, in dynamic displays, *the way it acts*. One might imagine skittish points on an unstable grid to display the degrees of anxiety around a particular event or task, for instance, or points that glow hot or cold depending on the other elements that approach them. That would be *a constructivist display of information*.

Creating a display that uses *constructivist methods* of graphical expression extends this last example to the design of the basic visual structure. A constructivist grid used to show anxiety might have a widely varying set of spacings to show that the information on display is constituted as a variable of some other aspect of experience (number of family

members present at an event, for instance). Recognizing that such methods are anathema to the empirically minded makes even more clear that they are essential for the generation of graphical displays of interpretative and interpreted information. The point is to create visualizations that expose, rather than conceal, these principles of knowledge in the domains where the authority of information makes (still persistent and often pernicious) claims to "truth" through the "transparency" of the visualization.

Visualizing interpretation

In proposing a new model for humanities' work, I am suggesting that the subjective display of humanistic phenomena can be applied across the domains with which we are concerned at four basic levels of interpretation or knowledge production:

1) Modeling phenomenological experience in the making of humanities (*data* as *capta*, primary modeling, the representation of temporal and spatial experience);

2) Modeling relations among humanities documents, i.e., discourse fields (a different metric might be needed to understand dates on diplomatic documents from the spring of 1944 or 1950);

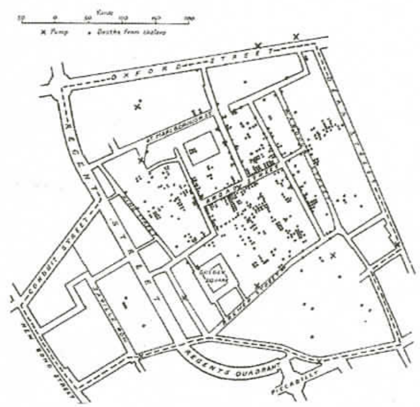
3) Modeling the representations of temporality and spatiality that are found in humanities documents (narrative is the most obvious);

4) Modeling the interpretation of any of the above (depicting or graphing the performative quality of interpretation).[203]

The humanistic concept of knowledge depends upon the interplay between a situated and circumstantial viewer and the objects or experiences under examination and interpretation. That is the basic definition of humanistic knowledge, and its graphical display must be specific to this definition in its very foundational principles. The challenge is enormous, but essential, if the humanistic worldview, grounded in the recognition of the interpretative nature of knowledge, is to be part of the graphical expressions that come into play in the digital environment. If we do not engage with this challenge, we give the game away in advance, ceding the territory of interpretation to the ruling authority of certainty established on the false claims of observer-independent objectivity in the "visual display of quantitative information."[204]

I will conclude with one more concrete example of the shift from observer-independent realism to co-dependent constructivism. Snow's justly famous chart of deaths from cholera allowed city officials to track the source of the epidemic to a single water pump. The distribution of dots on the street map makes evident the role of the pump by the way they cluster. A useful map, crucial to analysis, its clarity and succinctness served an important purpose. It was sufficient to that purpose, adequate, but we could revisit that map and use it to express other factors. Who are those dots? Each individual has a profile, age, size, health, economic potential, family and social role. In short, each dot represents a life, and no life is identical. Many demographic features could be layered into this map to create a more complex statistical view of the epidemic. That is neither subjective data nor a subjective display. But what if we take the rate of deaths, their frequency, and chart that on a temporal axis inflected by increasing panic. Then give a graphical expression to the shape of the terrain, that urban streetscape, as it is redrawn to express the emotional landscape. Then imagine drawing this same streetscape from the point of view of a mother of six young children, a

recent widow, a small child, or an elderly man whose son has just died. These latter are all instances of the graphical expression of humanistic interpretation. They are as different from the visual display of quantitative information as a close reading of a poem is from the chart of an eyetracker following movements across a printed page. They are fundamentally different in character and in their basic assumptions about the role of graphical expression as an aspect of knowledge production. We have a very long way to go in creating graphical expressions that serve humanistic interpretation, but I hope I have suggested some of the premises on which this work might begin.



Snow original followed by point of view system built into the representation.