Lines, Shapes, and Meaning

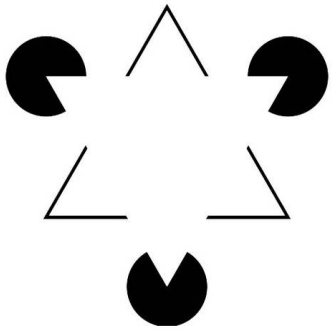
Barbara TVERSKY[1]
Columbia Teachers College and Stanford University

Abstract. Lines are mysterious. They are drawn by the hand, they are seen by the eye, they appear in the world. Lines are what the hands draw, what the eyes see, and what the page represents. Lines form forms. Simple regular visual/spatial forms like dots, lines, and containers, have meanings that are readily apparent in context. They are used in the service of clear communication, to self and others, notably in diagrams and gesture. They are used to organize, indeed to diagram, the world. Other, messy sketchy lines are used for exploration and discovery.

Keywords. diagrams, sketches, visual communication, cognitive artifacts, abstraction, creativity, design

Introduction

We see lines everywhere. We see them even where they aren't there at all, courtesy of Kanizsa:



The eye generates them by connecting the dots, creating the continuous contours that allow us to discern objects in the camouflage of shadows and occlusion. The natural world provides them, the plane of the earth as it meets the sky and the perpendiculars of the things that grow from it. The hand draws them on paper and in the air to represent other things, concrete and abstract. The designer constructs them, connecting buildings and towns along streets, books and dishes on shelves. We travel on them as we go from place to place. Are all these lines, real or virtual, in the world or in the mind, connected?

[1] E-mail: btversky@stanford.edu

Creating Meaning: Orderly Lines

Lines on paper. Let's begin with the abstract, with lines that represent, lines that flow from the pen held by the hand. The simplest line is just a dot, a point, hardly there at all. Next, a line, a point extended in one dimension. After that, lines with bends and turns, zig-zags and swirls, arrows and writing. Lines that catch their tails, that close, form shapes, simple forms like circles and squares and more complex forms like contours of animals or trees. Lines create meaning by creating recognizable forms like ducks and rabbits, wives and mothers-in-law. They also create meaning by forming shadows, words, sketches, and diagrams.

Diagrams are constructed from lines. Typically, diagrams are meant to simplify a more complex state of affairs to inform or influence or instruct. A frequent kind of diagram is based in forms that bear physical resemblance to what they are intended to represent. Maps are a prototype for this kind of diagram, but also other diagrams, for example, those designed to show the crucial parts of the heart or an engine, to show how the heart pumps or an engine works, to show how to assemble a heart or an engine. Yet, such depictions in diagrams are not typically designed to be realistic renderings but rather diagrammatic renderings; that is, they may omit or exaggerate or reorganize physical appearance and structure, and they may add information, verbal, symbolic, and visual in the service of informing or instructing. Part of what makes them diagrams and not simple depictions is the addition of simple forms, notably, dots, lines, and arrows that organize, label, integrate, explain, extend, and otherwise add to the depictive information about appearances of parts and wholes. Other frequent kinds of diagrams, notably charts and graphs, don't generally bear physical similarities to what they are meant to represent, relying primarily on simple visual forms and spatial relations, and of course language and symbols, to show data and relationships.

Commonly, these simple visual forms, dots, lines, and blobs, and spatial relations, center, up/down, left/right, carry meanings that are readily understood in context. The meanings seem to derive from their geometric and gestalt properties (e. g., Tversky, 2011 a, b). Consider networks, arguably the simplest diagram, in its most rudimentary form, two dots and a line. Networks are constructed from dots and lines; the dots are nodes, the lines, edges. Abstractly, the dots are idea or entities, the lines, the relations between them. Variations of networks are used to represent myriad concepts: the network of roads on the ground, or airline routes in the air, of computers on the net, of concepts in a semantic net. Varieties of networks can represent the phylogenetic tree, a family tree, a corporate organization, a set of social connections, the transmission of ideas over time, data points along a dimension. What is shared is that the nodes represent entities and the lines represent the links among them. Why are dots understood as concepts, places, people, computers, roles, functions and more and lines understood as relations among them? River boat navigators who do not read and have not seen maps when asked to sketch a map of their travels draw settlements on the river as dots and the river routes that connect them as lines, pearls on a string (Woodward and Lewis, 1998), just as typical sketch maps (e.g., Tversky and Lee, 1998; 1999). Notably, the links form straight lines, despite the geographic irregularities of the river and the dots are the same size despite variations in size and extent. That information, the exact forms of the river and the communities, is not relevant for showing the route. What matters is the ordering and connection of the locations. For these ends, the communities are conceived of as points of zero dimensionality, the river as a line of a

single dimension. Language (at least English) makes a similar distinction (Talmy, 1983): the journey began *at* the Capitol and *continued* to the White House; any two locations could be substituted for those venerable ones.

Journeys can be one-way, relationships can be asymmetric. For that, asymmetric lines are needed, and arrows serve that need nicely. Arrows are asymmetric lines, and have a basis in the experienced world: arrows shot from a bow fly in the direction indicated; arrows form in the mud in the direction of erosion. Arrows change the meaning of lines. When asked to describe a diagram of a mechanical system without arrows, people give structural descriptions; they list the parts and their spatial relations. When asked to describe a diagram of the same systems with arrows, people provide functional descriptions; they give a step-by-step description of behavior, process, causality of the system (Heiser and Tversky, 2006).

Often a broader perspective is needed, two dimensions, not a single one. Not *at* or *to,* but *in*. Not simple dots, but containers. The cells of tables or the bars in graphs or circles on graphs or maps contain and represent many entities, those that hold the properties defined by the cells: the cars manufactured in India in 1998, the number of spectators at soccer games in Brazil in 2004. The variations that characterize each of the cars and each of the spectators is irrelevant; all that matters is their numbers; similarly, their exact locations and the exact time of the year are irrelevant. They are represented as featureless numbers by simple containers, cells, bars, and circles. This third distinction, container, is also made in language, signified by the preposition *in* (Talmy, 1983).

Why these regular, almost perfect forms; why not blobs of uncertain shape? After all, we don't know the exact shapes, so why is a perfect idealized shape used to represent a shape that might actually be known? Just as "red" represents a range of shades of red including magenta whereas "magenta" is a more specific shade of red, a purplish red (e. g., Rosch, 1978) and "noon" represents a range of times from about 11:50 to 12:15 whereas 12:02 is a specific minute—but not a specific second within that minute—circles and rectangles and squares represent a range of shapes. Just as *red* and *noon* are prototypic linguistic categories that contain and represent a set of values, dots, circles, and lines are prototypic spatial categories that contain and represent a set of values. Just as on average, the myriad shades of red contained in the category would average to the prototypic red, the myriad shapes that are contained in the visual categories points, lines, and containers would average to the prototypic values.

Again like linguistic categories, these spatial categories allow inferences, and the convergences of those inferences are evidence for their meanings, converging with their geometric and gestalt properties. People interpret bars in graphs as discrete comparisons, lines as trends; similarly, they produce bars to represent discrete comparisons and lines to represent trends (Zacks and Tversky, 1999). People invent boxes to represent categorical relations and lines of various thicknesses to represent continuous ones; their inferences follow the same patterns (Tversky, Corter, Yu, Mason, and Nickerson, 2012). Graphs of people, place, and time that connect the people with lines encourage inferences about movement of people in time whereas tables of the same information encourage a broader range and number of inferences (Kessell and Tversky, 2011).

Diagrams, maps, charts, and graphs select relevant information and omit irrelevant information. They may exaggerate, even distort, the relevant information for emphasis, for readability. Overall, their goal is clear and unambiguous communication. These simple spatial forms, and others like them, are their units of meaning, like morphemes,

of a visual/spatial vocabulary for communication. They can be combined systematically, like rules of syntax, to form genres of diagrams, sketch maps, circuit diagrams, architectural plans.

Finding Meaning: Messy Lines

Sketches are a very different case of lines on paper. They use lines, the lines may form shapes, but they are typically uncertain, tentative, unclear. They represent ideas, but amorphous ideas, ideas that are not yet fully formed. Their very lack of certainty creates ambiguity, allowing many interpretations, not a single clear one. Perhaps for that reason, messy lines in sketches encourage exploration and discovery, they promote new ideas. Messy sketches are used productively by artists, designers, and architects, especially experienced ones, to explore a domain with impunity, and to generate new ideas (Goldschmidt, 1994; Kantrowitz, in preparation; Schon, 1983; Suwa and Tversky, 1996; Suwa and Tversky, 2001; Suwa and Tversky, 2003; Suwa, Tversky, Gero, and Purcell, 2001; Tversky and Chou, 2010, Tversky and Suwa, 2008). Experienced architects, artists, and designers use their sketches in deliberate ways to get new ideas, a process we have called *Constructive Perception* (Suwa and Tversky, 2003; Tversky and Suwa, 2008). One common strategy adopted by experienced architects and designers is to deliberately reconfigure their sketches, to reorganize the parts and wholes. The reconfigured perceptual array suggests new objects, encourages new interpretations, even ah-ha experiences. Reconfiguration is one of several strategies that promote constructive perception in the service of new ideas. Interspersing other tasks that expose thinkers to other perceptual and conceptual ideas help (Tversky and Chou, 2010). Prompted hints help, especially top-down hints, thinking of other domains (Tversky and Chou, in progress). Talent helps, two talents actually, a perceptual talent, measured by the ability to see elemental complex figures embedded in more complex ones (Gottschaldt, 1926) and a cognitive talent, the ability to make remote associations among ideas (Mednick and Mednick, 1967) (Suwa and Tversky, 2003). These talents capture the two aspects of constructive perception, perceptual reconfiguration and conceptual interpretations.

Now the caveats. Of course, messy lines aren't always ambiguous, and ambiguity isn't always productive. Similarly, orderly lines do not always convey a clear message.

Lines in the World, Lines in the Brain, Lines on the Page

Lines are what the hand draws and what the eye sees, a magical convergence. The world on the retina is pixels, dots, representing light of varying brightness and hue. The brain connects the dots, forming lines and shapes that constitute the uncountable number of things we recognize. Designers sketch lines, first messy tentative ones that allow interpretation and reinterpretation, evolving into orderly forceful lines that can convey myriad ideas with clarity.

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