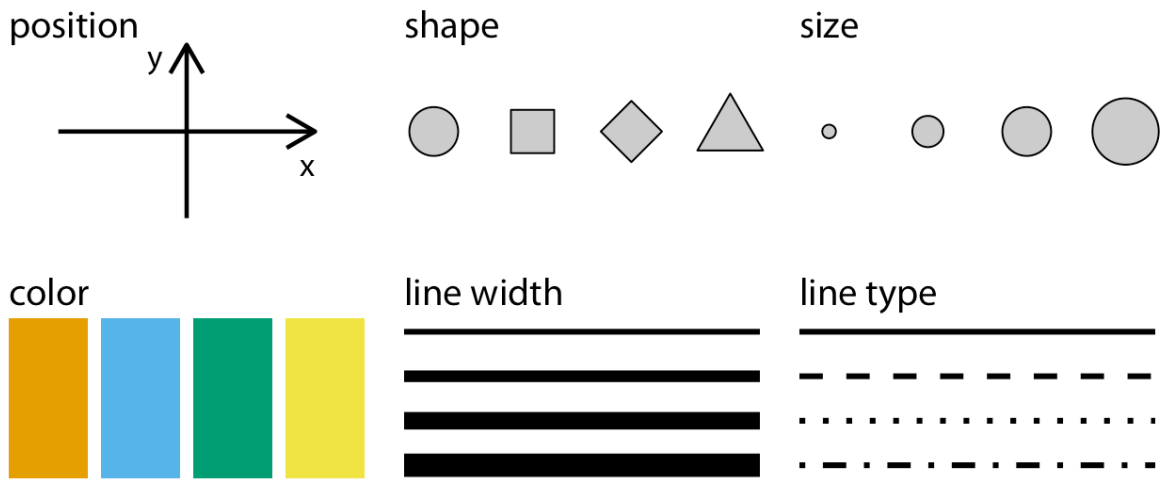
SESSION 4

Visualizing Categorical Data

Whenever we visualize data, we take data values and convert them in a systematic and logical way into the visual elements that make up the final graphic. Even though there are many different types of data visualizations, and on first glance a scatterplot, a pie chart, and a heatmap don't seem to have much in common, all these visualizations can be described with a common language that captures how data values are turned into blobs of ink on paper or colored pixels on a screen. The key insight is the following: all data visualizations map data values into quantifiable features of the resulting graphic. We refer to these features as *aesthetics.*

Aesthetics and Types of Data

Aesthetics describe every aspect of a given graphical element. A few examples are provided in Figure. A critical component of every graphical element is of course its *position*, which describes where the element is located. In standard 2D graphics, we describe positions by an *x* and *y* value, but other coordinate systems and one- or three-dimensional visualizations are possible. Next, all graphical elements have a *shape*, a *size*, and a *color*. Even if we are preparing a black-and-white drawing, graphical elements need to have a color to be visible: for example, black if the background is white or white if the background is black. Finally, to the extent we are using lines to visualize data, these lines may have different widths or dash–dot patterns. Beyond the examples shown in Figure, there are many other aesthetics we may encounter in a data visualization. For example, if we want to display text, we may have to specify font family, font face, and font size, and if graphical objects overlap, we may have to specify whether they are partially transparent.



Commonly used aesthetics in data visualization: position, shape, size, color, line width, line type. Some of these aesthetics can represent both continuous and discrete data (position, size, line width, color), while others can usually only represent discrete data (shape, line type).

All aesthetics fall into one of two groups: those that can represent continuous data and those that cannot. Continuous data values are values for which arbitrarily fine intermediates exist. For example, time duration is a continuous value. Between any two durations, say 50 seconds and 51 seconds, there are arbitrarily many intermediates, such as 50.5 seconds, 50.51 seconds, 50.50001 seconds, and so on. By contrast, number of persons in a room is a discrete value. A room can hold 5 persons or 6, but not 5.5. For the examples in Figure, position, size, color, and line width can represent continuous data, but shape and line type can usually only represent discrete data. Next we'll consider the types of data we may want to represent in our visualization.

You may think of data as numbers, but numerical values are only two out of several types of data we may encounter. In addition to continuous and discrete numerical values, data can come in the form of discrete categories, in the form of dates or times, and as text (Table). When data is numerical we also call it *quantitative* and when it is categorical we call it *qualitative*. Variables holding qualitative data are *factors*, and the different categories are called *levels*. The levels of a factor are most commonly without order (as in the example of *dog, cat, fish* in Table), but factors can also be ordered, when there is an intrinsic order among the levels of the factor (as in the example of *good, fair, poor* in Table).

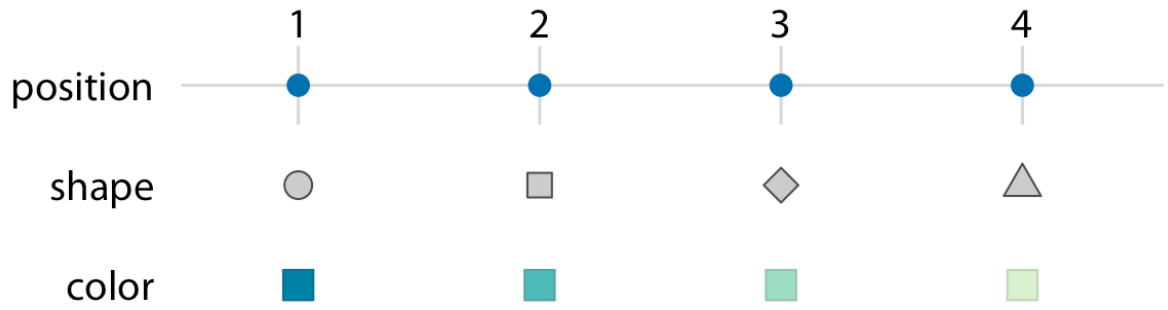
Table.Types of variables encountered in typical data visualization scenarios.

Type of variable	Examples	Appropriate scale	Description
Quantitative/ numerical continuous	1.3, 5.7, 83, 1.5 × 10–2	Continuous	Arbitrary numerical values. These can be integers, rational numbers, or real numbers.
Quantitative/ numerical discrete	1, 2, 3, 4	Discrete	Numbers in discrete units. These are most commonly but not necessarily integers. For example, the numbers 0.5, 1.0, 1.5 could also be treated as discrete if intermediate values cannot exist in the given dataset.
Qualitative/ categorical unordered	dog, cat, fish	Discrete	Categories without order. These are discrete and unique categories that have no inherent order. These variables are also called *factors*.
Qualitative/ categorical ordered	good, fair, poor	Discrete	Categories with order. These are discrete and unique categories with an order. For example, “fair” always lies between “good” and “poor.” These variables are also called *ordered factors*.
Date or time	Jan. 5 2018, 8:03am	Continuous or discrete	Specific days and/or times. Also generic dates, such as July 4 or Dec. 25 (without year).

Text	The quick brown fox jumps over the lazy dog.	None, or discrete	Free-form text. Can be treated as categorical if needed.

Scales Map Data Values onto Aesthetics

To map data values onto aesthetics, we need to specify which data values correspond to which specific aesthetics values. For example, if our graphic has an *x* axis, then we need to specify which data values fall onto particular positions along this axis. Similarly, we may need to specify which data values are represented by particular shapes or colors. This mapping between data values and aesthetics values is created via *scales*. A scale defines a unique mapping between data and aesthetics. Importantly, a scale must be one-to-one, such that for each specific data value there is exactly one aesthetics value and vice versa. If a scale isn't one-to-one, then the data visualization becomes ambiguous.



Scales link data values to aesthetics. Here, the numbers 1 through 4 have been mapped onto a position scale, a shape scale, and a color scale. For each scale, each number corresponds to a unique position, shape, or color, and vice versa.