2. Describing Numbers

> *Hear about the statistician who drowned crossing a river? It was three feet deep on average.*
>
> Anonymous

Levels of Measurement

Nominal scales are labels with no order, such as a ZIP code, a housing type code (1 = single family, 2 = townhouse, 3 = apartment), a land use category. Nominal categories cannot be rank-ordered. Only the **mode**, the most frequent value, summarizes them. The mean of a set of ZIP codes has no meaning.

Ordinal scales are ordered, but the gaps between adjacent categories are not equal: a design review outcome (pass, pass with conditions, fail), a level of satisfaction from 1 to 3, a hazard mitigation plan's probability rating from 1 to 4. The **median**, the middle value once the cases are sorted, and the **mode** are meaningful. The mean is not: it treats the step from 1 to 2 as equal in size to the step from 4 to 5, and the scale does not guarantee that.

Example 2.1. The American Public Health Association's 1945 Appraisal Method scored housing quality for urban renewal by assigning penalty points to each of 29 deficiency items, for example:

- 45 for lacking a toilet
- 30 for lacking dual egress
- 20 for obstructed daylight
- 3 for lacking central heating

Then, sum them to a dwelling total with a maximum of 600. The order of penalty points is reasonable: lacking a toilet is worse than obstructed daylight. The sum is not (Hodge 1963).

Interval scales have equal distances and an arbitrary zero. Temperature is the standard case: means are meaningful, ratios are not (80 degrees is not twice as hot as 40).

Ratio scales have equal distances and a true zero, such as commuting minutes, parcel area in square feet, dollars, acres. Every summary is available.

Table 2.1: Level of measurement examples.

Level	Planning example	Meaningful summaries
Nominal	ZIP code, land use class	mode
Ordinal	design review outcome	mode, median, percentiles
Interval	temperature in Fahrenheit	mode, median, mean, standard deviation
Ratio	acres, minutes, dollars	all of the above, plus ratios

Population and Sample

A **population** is the entire group of people or things about which we want information. For example, all people lived in Seattle during 2026. However, it is more practical to gain information about the whole population by only examining a part. **Sample** is a smaller subset of a larger set of data to draw inferences about the large set, such as 1,000 selected people lived in Seattle during 2026.

We always are interested in some quantities of population, such as the average age. We call such quantity a **parameter**. The quantities we calculate from this sample are called **statistics**.

The process of collecting samples from population is **sampling** and the process of estimate parameter based on samples is **inference**.

It is important to first identify whether your data is "population" or "sample". If it is the population, no inference is needed. Just descriptive analysis. If it is the sample, we need to consider how to collect the sample and the associated sampling errors and uncertainty.

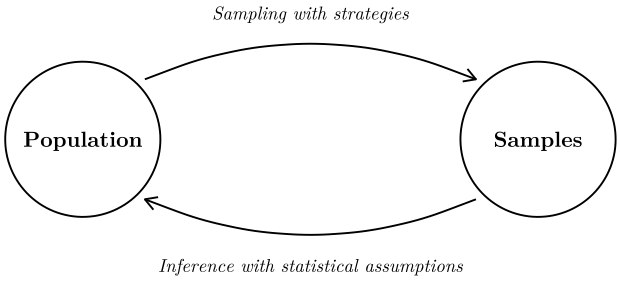


Figure 2.1: Sampling moves from the population to a sample; inference moves back with some statistical assumptions. Notice that this framework is under Frequentist view of statistics. Bayesian view of statistics is different, which will be introduced in later chapters.

Example 2.2. Estimate the average age of people lived in Seattle during 2026.

- Population: all people living in Seattle during 2026
- Sample: 1,000 selected people who lived in Seattle during 2026
- Parameter: the true average age of people who lived in Seattle during 2026 (UNKNOWN unless we survey everybody)
- Statistic: the average age of 1,000 selected people who lived in Seattle during 2026

Frequency Table

A **frequency table** is a listing of possible values for a variable, together with the number of observations for each value. A **proportion** of observations that fall in a certain category is the count of observations in that category divided by the total number of observations. (NOTE: percent = 100 × proportion)

Table 2.2: A frequency distribution of a categorical variable.

Mode of travel to work	Frequency	Proportion	Percent
Drove alone	147	0.411	41.1%
Carpooled	29	0.081	8.1%
Public transit	86	0.240	24.0%

Mode of travel to work	Frequency	Proportion	Percent
Walked	43	0.120	12.0%
Bicycle	15	0.042	4.2%
Taxi, motorcycle, or other	8	0.022	2.2%
Worked at home	30	0.084	8.4%
Total	**358**	**1.000**	**100.0%**

Measures of Center

The **sample mean**, written $\bar{y}$ and read "y-bar", is the total divided by the count. Average is a more general and everyday representation for the similar meaning.

$$\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$$

Percentiles is score below which a specific percentage of the distribution falls. For example, the 75th percentile is a score that divides the distribution so that 75% of the cases are below it.

Median is 50th percentile. When n is even, median is the average of the middle two values. **Mode** is the value that appears most frequently. On a symmetric distribution mean, median, and mode nearly coincide.

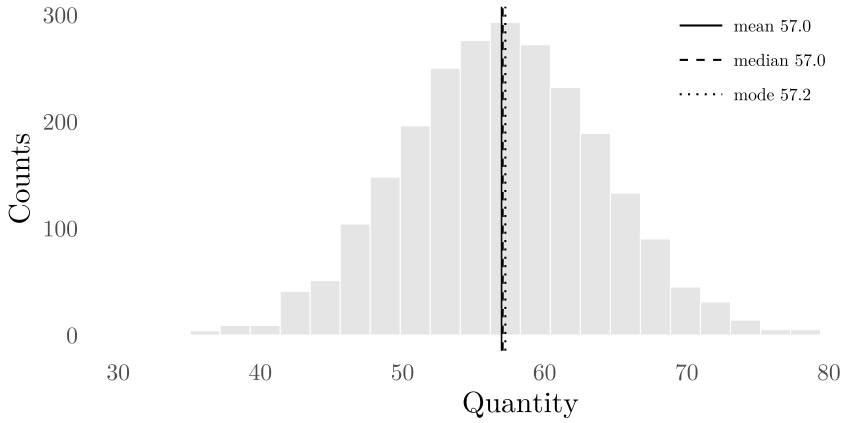


Figure 2.2: A symmetric distribution. And this is a histogram.

Example 2.3. Medians do not add: the averaging the medians of the parts does not give the median of the whole; the median is not an additive quantity. The arithmetic mean of census tract median household incomes is not the city's median household income, and weighting each tract by its population does not repair it.

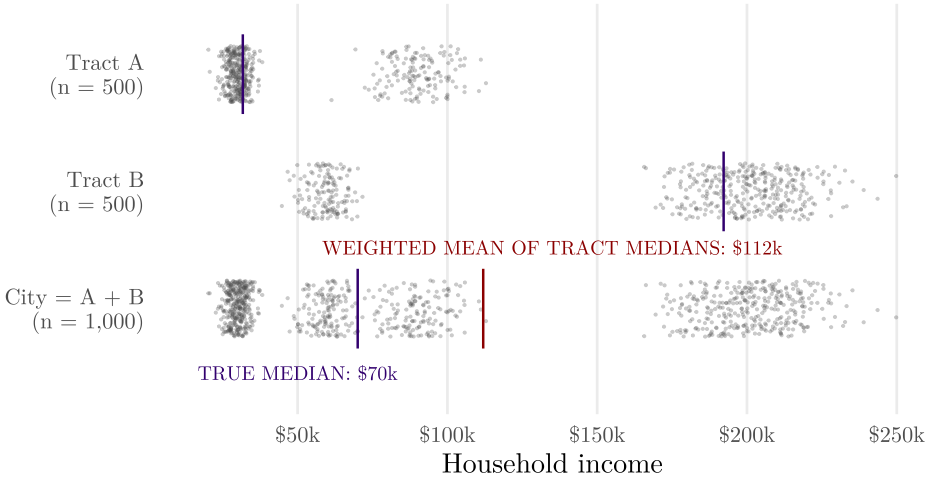


Figure 2.3: Two tracts and the city. Each tract's median summarizes its own households, but the population-weighted mean of the two medians is $112k while the true city median is $70k.

Measures of Spread

Minimum is the smallest value while **maximum** is the largest value. We use the difference between max and min to represent the **range** of data: Range = Maximum - Minimum.

After arranging the data from smallest to largest, the **first quartile (Q1)** is the 25th percentile of data, the **second quartile (Q2)** is the 50th percentile of data (which is the median), the **third quartile (Q3)** is the 75th percentile of data. The **interquartile range** (IQR) is the 75th percentile minus the 25th.

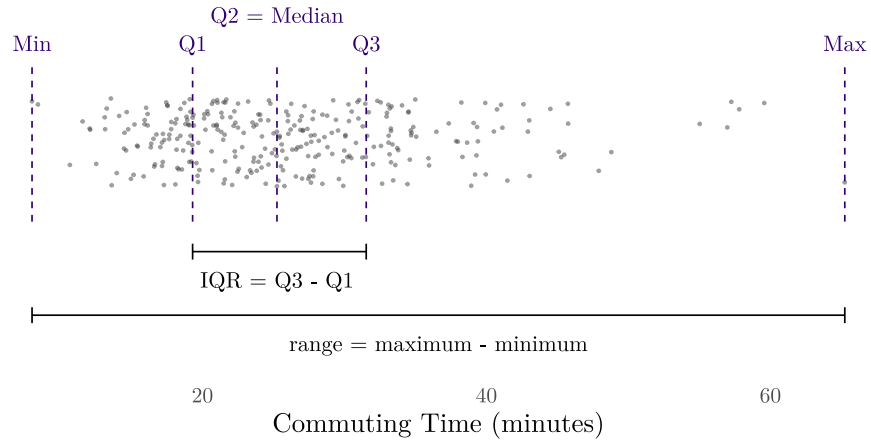


Figure 2.4: Three hundred simulated commuting times with their quartiles.

If we have every unit of a population, the **population standard deviation** (σ) measures how far a typical unit sits from the population mean μ: subtract μ from each value, square the deviations, average them over the N units, and take the square root. Without the square root, the result is the **population variance** (σ^2).

$$\sigma \;=\; \sqrt{\frac{1}{N}\sum_{i=1}^{N}(y_i-\mu)^2}$$

Usually we only have a sample and we want to estimate the SD or variance from it. The **sample standard deviation** (s) estimates σ from the sample. Without the square root, the result is the **sample variance** (s^2), the estimate of σ^2.

$$s \;=\; \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(y_i-\bar{y})^2}$$

The divisor is $n-1$ rather than n because the deviations are measured from the sample's own mean, which sits closer to the sample than population mean μ and so understates the population's spread.

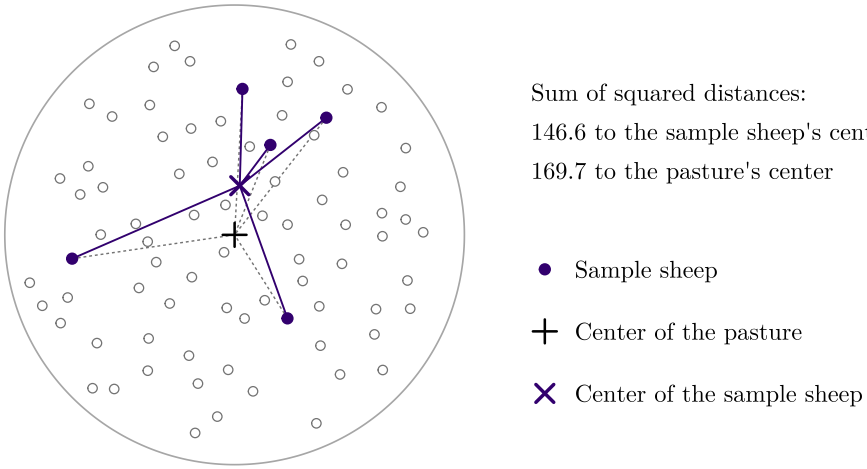


Figure 2.5: Eighty sheep on a round pasture, placed so that their mean position is exactly the center of the pasture. Each draw picks five sheep at random; their own center almost never falls on the center of the pasture.

Example 2.4. Some samples are drawn from a population whose true variance is known (horizontal line). Dividing the squared deviations ($\sum_{i=1}^{n}(y_i-\bar{y})^2$) by n underestimates the true variance. The deviations are measured from the sample's own mean, which sits closer to its own sample than the box mean does. Dividing by n - 1 corrects the bias.

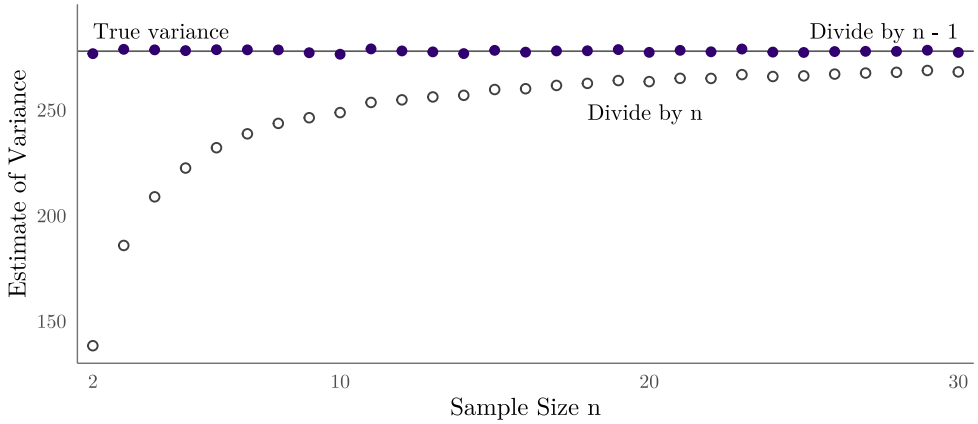


Figure 2.6: Averaged over many samples from one population, dividing by n - 1 lands on the true variance; dividing by n falls short, most for small samples.

Population and Sample Variance Proof OPTIONAL

Let $Y_1, Y_2, \ldots, Y_n$ be a random sample of size n drawn from a population. The sample variance should be a unbiased estimator, which means $E(s^2) = \sigma^2$ (expectation of sample variance should be equal to population variance).

Each $(y_i - \bar{y}) = (y_i - \mu) - (\bar{y} - \mu)$; so that: $\sum_{i=1}^{n}(y_i - \bar{y})^2 = \sum_{i=1}^{n}(y_i - \mu)^2 - n\,(\bar{y} - \mu)^2$. We know the true variance σ^2:

$$
\begin{aligned}
\sigma^2 &= \frac{1}{n}\,E\left[\sum_{i=1}^{n}(y_i - \mu)^2\right] \\
&= \frac{1}{n}\,E\left[\sum_{i=1}^{n}(y_i - \bar{y})^2 + n\,(\bar{y} - \mu)^2\right] \\
&= \frac{1}{n}\,E\left[\sum_{i=1}^{n}(y_i - \bar{y})^2\right] + \mathrm{Var}(\bar{y}) \\
&= \frac{1}{n}\,E\left[\sum_{i=1}^{n}(y_i - \bar{y})^2\right] + \frac{\sigma^2}{n} \\
(1 - \frac{1}{n})\sigma^2 &= \frac{1}{n}\,E\left[\sum_{i=1}^{n}(y_i - \bar{y})^2\right] \\
\sigma^2 &= E\left[\frac{1}{n-1}\sum_{i=1}^{n}(y_i - \bar{y})^2\right]
\end{aligned}
$$

We proof the sample variance should be divided by $n - 1$.

Measures of Shape

Figure 2.2 is a symmetric distribution. On a **right-skewed** distribution (one with a long tail of large values), the tail pulls the mean above the median, and the gap between the two reflects the length of the tail (Figure 2.7). Planning data are typically right-skewed: income, rent, parcel area, commuting time, house price. You can imagine what left-skewed means: one with a long tail of small values.

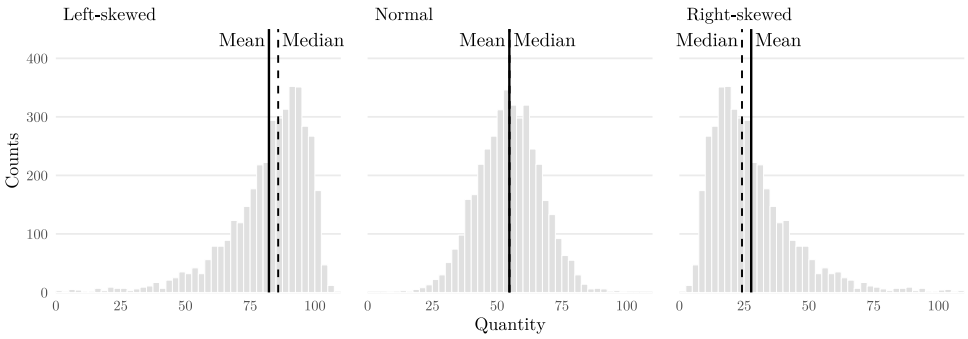


Figure 2.7: Simulated left-skewed, normal, and right-skewed distributions with their means (solid line) and medians (dashed line). A long tail pulls the mean toward it.

Some Dataset Formats

Tabular

The standard data formats is **tabular data** (a *data frame*): one row per **record/item/observation/data point**, one column per **variable/feature/attribute**.[2] Even through there could be some missing cells but we have a fixed structure, we call those **structured data**. So, **unstructured data** lacks a predefined or organized data model, such as text, images, or videos. This course is mainly based on tabular data.

[2] When processing data in R/Python, we should use machine-readable column names: `median_rent`, not `Median Rent`. Spaces in column names break many pipelines.

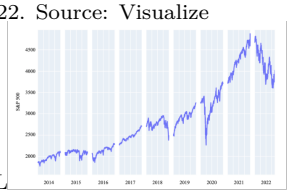
Based on the contents within a tabular data, we can classify by the shapes. For example, each cell below is a home-value index for a metro area in a month, with a population column appended:

Table 2.3: Home-value index and population for five cities

Region	Jan 2000	Feb 2000	Mar 2000	Pop. 2024
New York, NY	220,835	221,773	222,720	19,940,274
Los Angeles, CA	222,016	222,842	223,942	12,927,614
Chicago, IL	156,058	156,202	156,478	9,408,576
Dallas, TX	128,590	128,647	128,713	8,344,032
Houston, TX	124,446	124,469	124,382	7,796,182

One row read across the index columns is a **time series**: one unit observed at many points in time. A time series requires temporal order with consistent intervals [3]. Time series data is important for financial and business applications. We can do forecasting, pattern recognition, and trend analysis.

[3] We can find some trends or repeating patterns directly from the visualization. S&P from 2014-2022. Source: Visualize ML



One month's column read down is **cross-sectional data**: many units observed at a single point in time.

The whole grid of index values is **panel/longitudinal data**: every unit followed through every period. This is the most informative shape and is the combination of time series and cross-sectional data.

The most common-used file format for structured data is **Comma-Separated Values (CSV)**. The CSV stores each item in the dataset in a single line. Variable values for each item are listed all in one line, separated by commas (","). The previous table in CSV format:

```
Region,Jan 2000,Feb 2000,Mar 2000,Pop. 2024
"New York, NY",220835,221773,222720,19940274
"Los Angeles, CA",222016,222842,223942,12927614
"Chicago, IL",156058,156202,156478,9408576
"Dallas, TX",128590,128647,128713,8344032
"Houston, TX",124446,124469,124382,7796182
```

Spatial

Data about physical locations and shapes of objects, including both their geographical position and attributes. Broadly speaking, there are two forms of spatial data:

Vector data is composed of discrete geometric locations, including points (a permit address), lines (a bus route), polygons (a tract boundary). The data will be in Shapefile, GeoJSON, etc.

Raster data is pixelated data where each pixel is associated with a specific geographical location. The value of a pixel can be continuous (population) or categorical (land use types). The data will be in GeoTIFF, etc.

> **Tobler's First Law of Geography**
>
> Everything is related to everything else, but near things are more related than distant things.
>
> Waldo Rudolph Tobler (1930-2018) is one of the most influential geographers and cartographers; he is also a UW alumni with undergrad, master and PhD here.

Spatial data and analysis are not the major focus of URBAN 520, we will introduce spatial statistics but for more spatial analysis and GIS software, please consider URBAN 504 and 522 instead.

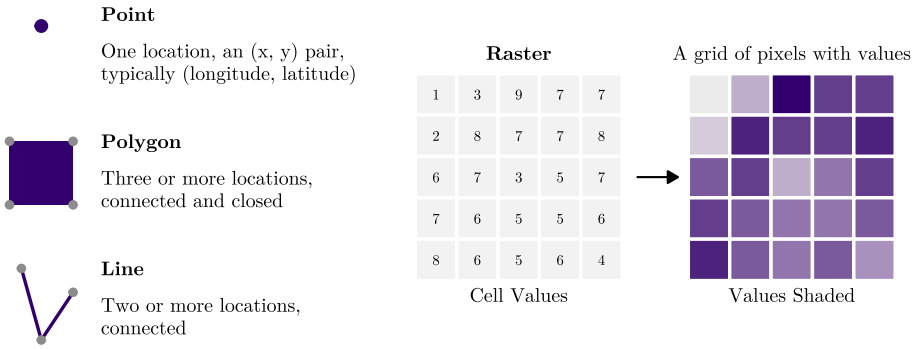


Figure 2.8: The two forms of spatial data: vector data (left) and raster data (right).

Image/Video/Street View

Images and videos can serve as a new data source to extract real-world information. The development of computer vision (CV) provides us new approaches, such as object detection and feature extraction, to identify the objects in images and extract features, such as the building color, building types, and quality.

Source: ImageNet

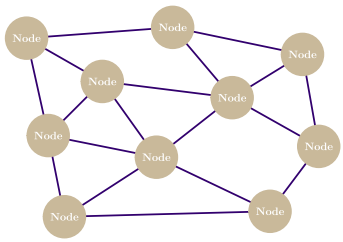
YOLO. Source: Joseph Redmon, Santosh Divvala, Ross Girshick, Ali Farhadi. You Only Look Once: Unified, Real-Time Object Detection (2015) – developed by UW Huskies

Source: Google Street View of UW Campus

Figure 2.9: ImageNet, YOLO and Street View

Network

Data about the entities within a network (called **nodes**) and the connections or interactions between them (called **edges**). Network data is everywhere: social network, migration flow, infrastructure systems, etc.



Node

people, locations, posts, or any entity

Edge

a relationship or interaction between two nodes; directed or undirected

Attributes

both nodes and edges can carry data: population for a node, relationship strength for an edge

Figure 2.10: Network data. Nodes are entities, edges are the relationships between them, and both can carry attributes of their own.

Some interesting statistics we can draw from network data, such as **centrality** (measure how important or influential a specific node is within the network), **average path length** (the average number of steps it takes to get from one node to any other node).

Who Produces Data/Numbers

In planning, data often serves as a description by design. We rely on a **full count** when exact figures are known (e.g., the number of parks in Seattle) and use statistical **estimation** when they are not (e.g., educational levels of Seattle residents). Both these estimates and any **model output** (like I-5 travel demand forecasts) are inherently built on assumptions.

Some numbers are gathered unintentionally. **By-product data** (e.g., transit tap-ins data) and **administrative records** (e.g., building permits applications) provide valuable insights, though they were not explicitly designed as measurements.

Most importantly, planning numbers are more than mere facts or observations. Planning balances current realities with future visions, requiring normative narratives to guide outcomes. This is why we use a **standard** (e.g., Seattle's benchmark of 8 acres of parkland per 1,000 residents) and a **policy target** (e.g., Washington

State's goal to cut greenhouse gas emissions to 45% below 1990 levels by 2030). The following table shows some common data producers in planning.

Table 2.4: Who produces planning data

Producer	Examples
Federal statistical agencies	U.S. Census Bureau; Bureau of Labor Statistics (BLS); Bureau of Economic Analysis (BEA); National Center for Health Statistics (NCHS); Bureau of Transportation Statistics (BTS); National Center for Education Statistics (NCES)
Federal agencies with program data	U.S. Department of Housing and Urban Development (HUD); U.S. Environmental Protection Agency (EPA); Federal Emergency Management Agency (FEMA); Federal Highway Administration (FHWA); Federal Transit Administration (FTA); U.S. Geological Survey (USGS); National Oceanic and Atmospheric Administration (NOAA)
State agencies	Washington State Office of Financial Management (OFM); Washington State Employment Security Department (ESD); Washington State Department of Health (DOH); Washington State Department of Transportation (WSDOT)
Regional agencies (metropolitan planning organizations, MPOs)	Puget Sound Regional Council (PSRC)
Local governments	City of Seattle Open Data Portal; King County GIS Open Data; King County Department of Assessments; Seattle Department of Construction and Inspections (SDCI); Seattle Police Department (SPD); Seattle Customer Service Bureau
Universities and nonprofits	IPUMS (Integrated Public Use Microdata Series); Opportunity Insights; Eviction Lab; Urban Institute
Private companies	Zillow; CoStar; Advan; SafeGraph; Replica; StreetLight Data
Crowdsourced and open communities	OpenStreetMap; PurpleAir; Mapillary

Common Topics of Planning Data

We will work with data from various sectors because urban planning is such an interdisciplinary domain in nature. Please refer to this dataset page on the class site as a resources hub.

Table 2.5: Planning data by topic

Topic	Typical variables
Population	Population count; Age and sex; Race and ethnicity; Nativity and language spoken at home; Households and household type; Household size; Births, deaths, and net migration; Migration flows between places; Population projections

Topic	Typical variables
Economy and employment	Jobs by workplace location; Jobs by industry; Employment and wages by occupation; Business establishments and payroll; Household and per capita income; Poverty status; Labor force participation; Unemployment rate; Gross domestic product (GDP); Consumer prices and cost of living
Housing	Housing units by structure type; Tenure (owner or renter); Vacancy; Home values and sale prices; Rents; Housing cost burden; Housing condition and quality; Building permits and new units; Subsidized housing units; Mortgage applications and loans; Homelessness counts and shelter beds; Short-term rental listings; Projected housing need
Land use and built environment	Parcel boundaries; Land use type; Zoning designation; Zoning rules (lot size, height, parking, allowed housing types); Assessed land and improvement values; Property sales and ownership; Building footprints; Building characteristics (year built, floor area, height); Density and land use mix; Points of interest (shops, services, amenities, etc.); Parks and green space; Land cover and impervious surface; Elevation
Transportation	Commute mode; Commute time; Home-to-work commuting flows; Vehicles available per household; Trips by mode, purpose, and time of day; Vehicle miles traveled (VMT); Road network and road condition; Traffic volume (AADT); Traffic speed and congestion; Transit routes, stops, and schedules; Transit ridership; Bicycle and pedestrian counts; Walkability and transit access; EV charging stations; Traffic crashes, injuries, and fatalities
Environment	Air pollutant concentrations (PM2.5, ozone); Air quality index (AQI); Pollution sources and toxic releases; Temperature and precipitation; Land surface temperature and urban heat; Tree canopy cover; Noise exposure; Greenhouse gas emissions
Hazards and climate	Flood zones; Hazard risk scores (flood, wildfire, earthquake, heat); Expected annual losses from natural hazards; Disaster declarations; Storm events, deaths, and damage; Flood insurance claims; Precipitation frequency (design storms); Sea level rise inundation; Climate projections (temperature, precipitation)
Health	Chronic disease prevalence (asthma, diabetes, obesity); Health behaviors (smoking, physical activity); Disability; Health insurance coverage; Access to health care; Births; Deaths and causes of death; Life expectancy; Food access
Equity and vulnerability	Social vulnerability index; Area deprivation index; Economic mobility (adult outcomes by childhood neighborhood); Child opportunity index; Social capital and economic connectedness; Displacement risk; Cumulative environmental burden; Local equity indices

Topic	Typical variables
Education and public services	School locations and district boundaries; School enrollment; School performance; School staffing and finance; Educational attainment; College enrollment and completions; Broadband availability; Energy use and expenditures; Energy burden; Proximity to public services
Public safety	Reported crimes by offense type; Arrests; Calls for service; Crime victimization; Accidents and injuries
Finance and governance	Budgets and expenditures; Capital improvement program (CIP) projects; Tax revenue; Property taxes; Government debt; Public employment and payroll; Election results; Voter registration and turnout
Emerging data	Mobile device locations and trips; Visits to points of interest (foot traffic); Origin-destination flows; Street-view imagery; Satellite and aerial imagery; Machine-learned building footprints; 311 service requests; Sensor readings (air quality, traffic, bicycle counters); Online listings (homes, rentals, short-term rentals); Online job postings; Social media data

Data Quality

When using some data, it would be better if:

- Use the most recently published version of the data.
- Use data sets from as unbiased a producer as possible.
  - Good sources include data collected or produced by government agencies, such as the statistics compiled by the U.S. Census Bureau or the Department of Labor.
  - Other top-tier data sources can include industry white papers, surveys conducted by reputable research organizations, or findings published in academic publications, such as Brookings, Urban Institute, Puget Sound Regional Council...
  - Note that surveys conducted by polling agencies or think tanks, while usable, often have a political agenda, so always use discretion.
- Understand the data before everything!
  - Especially for non-public access data: find out more about the data, such as how it was gathered, how old it is, and how many people were surveyed.