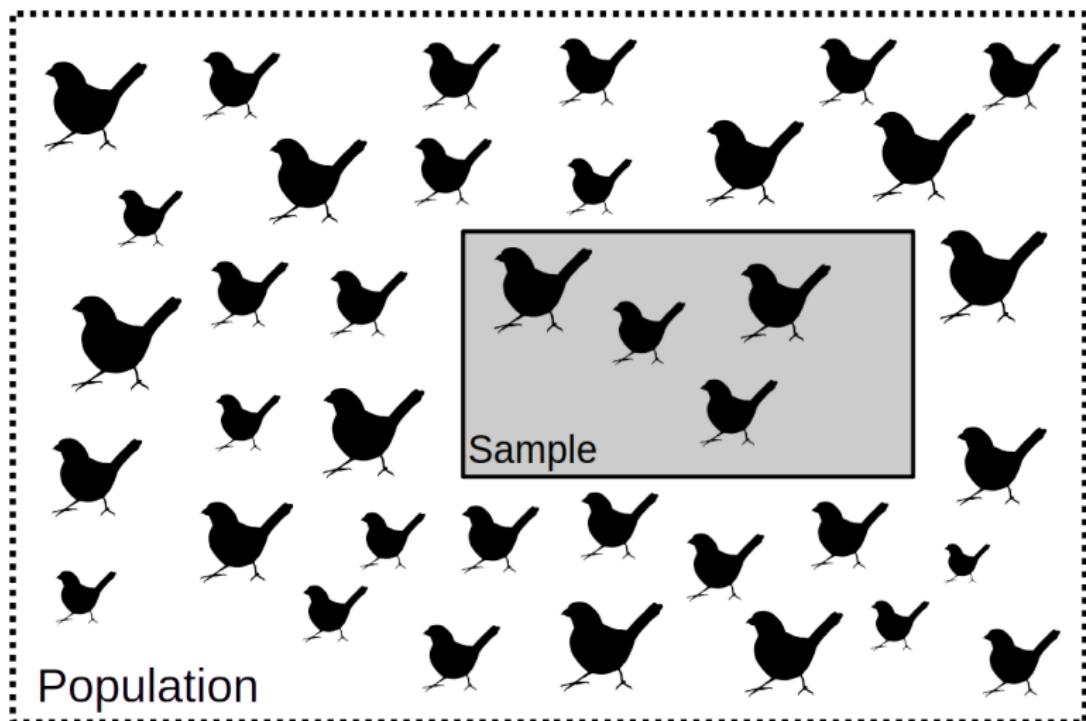


SCIU4T4: Populations, variables, units, uncertainty

Populations and samples



Types of variables: definitions

- ▶ **Categorical:** Fixed number of options
 - ▶ Nominal: No inherent order
 - ▶ Ordinal: Inherent order
- ▶ **Quantitative:** Numbers meaningful
 - ▶ Discrete: Limited number of values
 - ▶ Continuous: Any real number

All of these measurements have uncertainty

Metrology: The science of measurement

Metrology focuses on measurement accuracy, precision, and units¹

- ▶ **Measurement:** Determination of the properties of a unit of observation
- ▶ **Measurand:** The unknown *true* value of what we want to measure
- ▶ **Measurement error:** Difference between the measurement and the measurand

¹Rabinovich, SG. 2013. Evaluating Measurement Accuracy: A Practical Approach. Springer Science & Business Media. [10.1007/978-3-319-60125-0](https://doi.org/10.1007/978-3-319-60125-0)

Metrology: The science of measurement

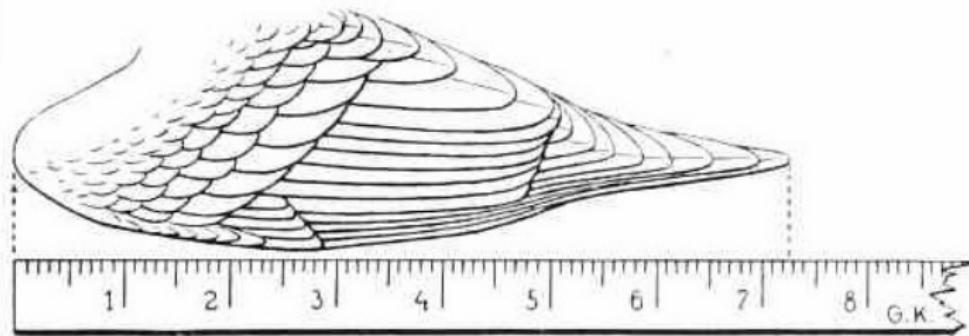
Metrology originally for economic activities¹

- ▶ Need standardised measurements for trade
- ▶ Standardised to a measurement **unit**:
 - ▶ Unit of length (e.g., cm)
 - ▶ Unit of mass (e.g., mg)
 - ▶ Unit of time (e.g., seconds)
- ▶ The ‘unit’ defines what is 1

¹Fanton, JP. 2019. International Journal of Metrology and Quality Engineering. 10:5.

Metrology: The science of measurement

Measuring wing length in centimetres (cm)



- ▶ Measure 7.28 *units* of length (cm)
- ▶ Measurand is the *true* wing length
- ▶ Repeated measures estimate *error*

¹Image: Reichenow, A. 1913. ([Public domain](#)).

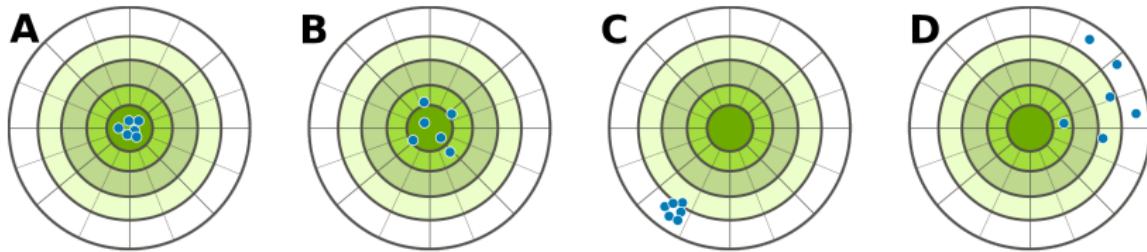
Accuracy and precision

- ▶ **Accuracy** is how close a measurement is to the *true* value we want to measure.¹
- ▶ **Precision** is how consistent a measurement will be if replicated multiple times.²

¹Rabinovich, SG. 2013. Evaluating Measurement Accuracy: A Practical Approach. Springer Science & Business Media. [10.1007/978-3-319-60125-0](https://doi.org/10.1007/978-3-319-60125-0)

²Wardlaw, AC. 1985. Practical Statistics for Experimental Biologists (p. 290). John Wiley & Sons, Chichester, UK.

Accuracy and precision



Measurements can be as follows:

- ▶ **A:** Accurate and precise
- ▶ **B:** Accurate but not precise
- ▶ **C:** Not accurate but precise
- ▶ **D:** Not accurate nor precise

¹**Image:** Willighagen, E. 2014. ([Public domain](#)).

Units of measurement

Units of *measurement* different from units of *observation*

- ▶ Measurement unit is a defined measurement quantity
- ▶ Standardised units of measurement ensure accuracy¹
- ▶ Ideally based on fundamental constants of nature²
- ▶ Measurement units can be base or derived
- ▶ Seven standardised base units

¹Quinn, T.J. 1995. Metrologia, 31:515–527. [10.1088/0026-1394/31/6/011](https://doi.org/10.1088/0026-1394/31/6/011)

²Stock, M, et al. 2019. Metrologia, 56:[022001](https://doi.org/10.1088/0026-1394/ab3e0d)

Kilogram was *defined* by a mass of metal



¹**Image:** National Inst. of Standards & Technology. 2021. ([Public domain](#)).

Kilogram was *defined* by a mass of metal

Standardising mass to a physical object problematic

- ▶ If object changes, so does the unit of mass
- ▶ Base unit affects all other measurements

Kilogram redefined in 2019¹:

- ▶ Atomic transition frequency ($\Delta\nu_{Cs}$)
- ▶ Speed of light (c)
- ▶ Planck constant (h)

$$1 \text{ kg} = (1.4755213 \times 10^{40}) \frac{h\Delta\nu_{Cs}}{c^2}$$

¹Stock, M et al. 2019. Metrologia 56:022001.

Base units of SI measurements

Measured Quantity	Name of SI Unit	Symbol
Mass	kilogram	kg
Length	metre	m
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Amount of a substance	mole	mol
Luminous intensity	candela	cd

Derived SI measurements

Measured Quantity	Name of Unit	Symbol	Definition in SI Units
Area	square metre	A	m^2
Volume	cubic metre	V	m^3
Speed	metre per second	v	m s^{-1}
Force	newton	N	m kg s^{-2}
Pressure	pascal	Pa	$\text{m}^{-1} \text{kg s}^{-2}$
Energy	joule	J	$\text{m}^2 \text{kg s}^{-2}$

Derived units of measurement built from base units

Units versus labels

- ▶ **Unit** defines a magnitude of a quantity
 - ▶ 1 kilogram
 - ▶ 1 metre
- ▶ **Label** describes the data type
 - ▶ soil mass
 - ▶ flight distance
- ▶ **Counts** do not have units
 - ▶ 20 glaciers
 - ▶ 800 seeds

Measurement uncertainty propagation

Nothing measured with perfect accuracy

- ▶ Noise in the measuring environment
- ▶ Mistakes made in measurement
- ▶ Limitations of measuring device

Measurement errors accumulate!



¹Image: Perkins, D. 2015. ([Public domain](#)).

Measurement uncertainty propagation

Suppose we measured 2 stones separately



Each measurement has a \pm error

¹Image: Nijaki, N. 2011. ([Public domain](#)).

Measurement uncertainty propagation

Combined measurement error

- ▶ Stone 1: $40 \pm 1.2 \text{ kg}$
- ▶ Stone 2: $36 \pm 1.1 \text{ kg}$

Combined mass:

$$40 \text{ kg} + 36 \text{ kg} = 76 \text{ kg}$$

Combined measurement error?

Measurement uncertainty propagation

Stone example:

$$\text{Combined mass} = \text{Mass 1} + \text{Mass 2}$$

More generally:

$$Z = X + Y$$

With error (E):

$$(Z \pm E_Z) = (X \pm E_X) + (Y \pm E_Y)$$

Measurement uncertainty propagation

$$(Z \pm E_Z) = (X \pm E_X) + (Y \pm E_Y)$$

If we solve for E_Z ,

$$E_Z = \sqrt{E_X^2 + E_Y^2}.$$

For our two stones,

$$E_Z = \sqrt{1.2^2 + 1.1^2} = 1.63.$$

Measurement uncertainty propagation

- ▶ Morning run: $4.5 \pm 0.3 \text{ km}$
- ▶ Evening run: $3.8 \pm 0.2 \text{ km}$

Combined error (E_Z) for total run length?

$$E_Z = \sqrt{E_X^2 + E_Y^2}.$$

Measurement uncertainty propagation

$$Z = X \times Y$$

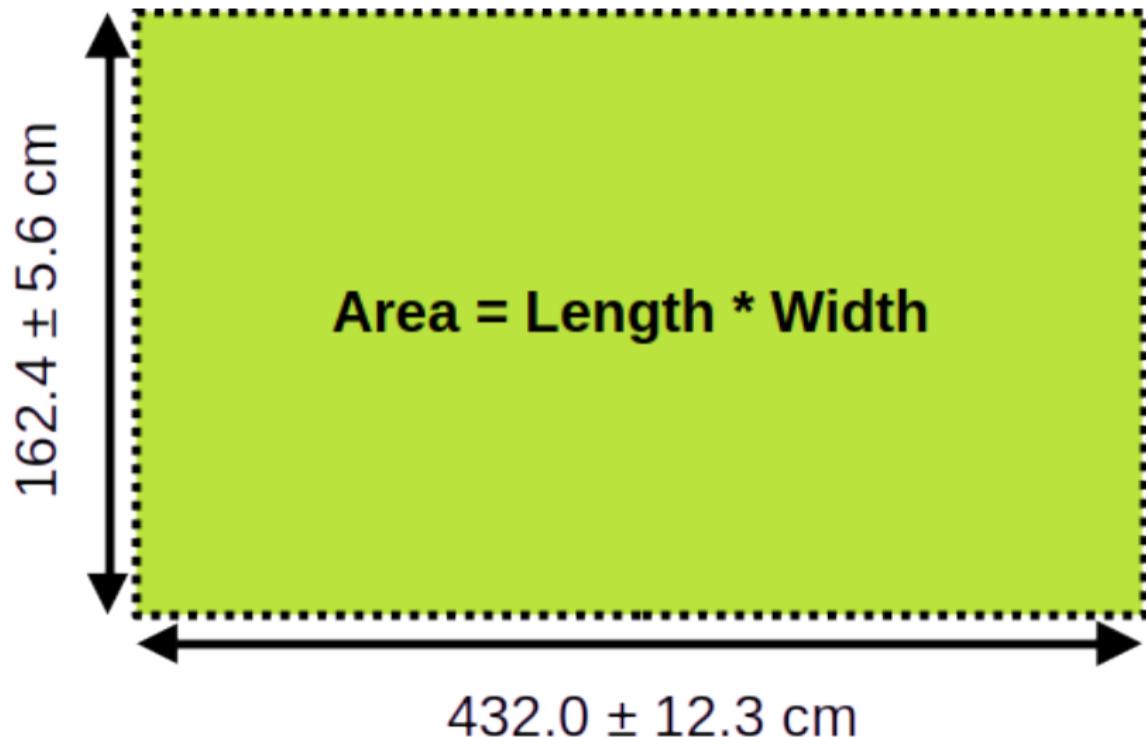
Combining errors different for multiplication

$$Z \pm E_Z = (X \pm E_X)(Y \pm E_Y).$$

If we isolate E_Z ,

$$E_Z = Z \sqrt{\left(\frac{E_X}{X}\right)^2 + \left(\frac{E_Y}{Y}\right)^2}.$$

Measurement uncertainty propagation



Calculating uncertainty

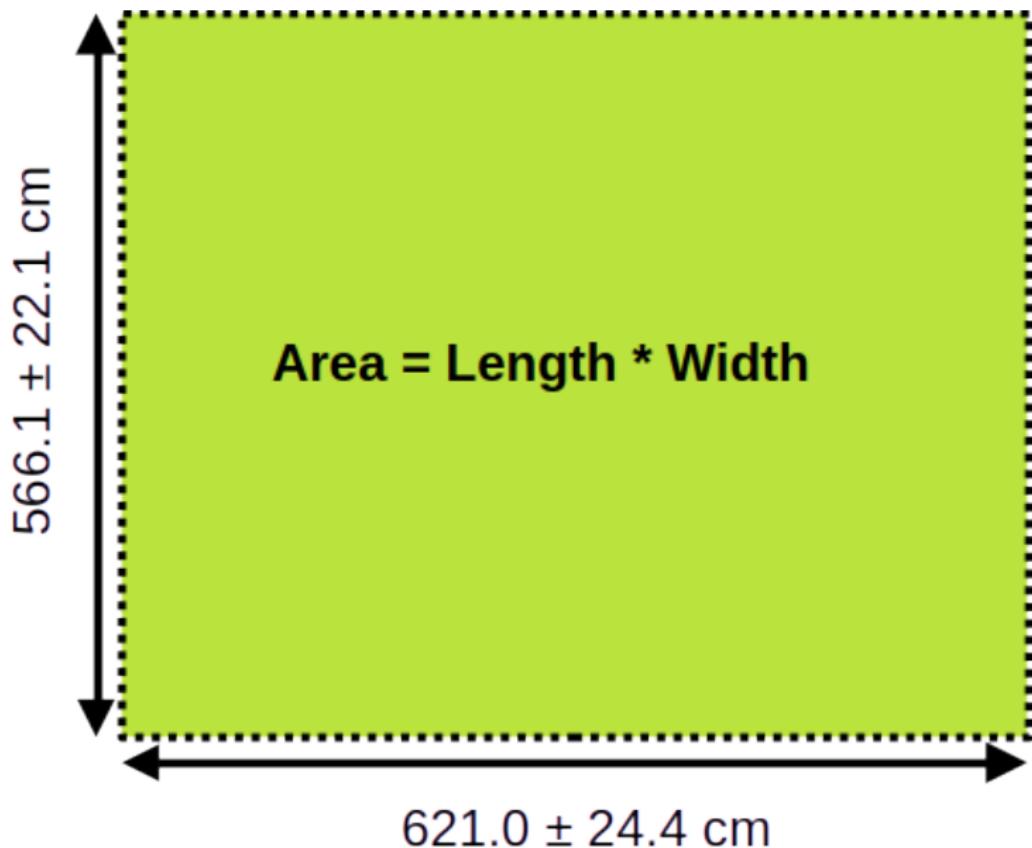
$$E_Z = Z \sqrt{\left(\frac{E_X}{X}\right)^2 + \left(\frac{E_Y}{Y}\right)^2}.$$

- ▶ $X = 432$
- ▶ $Y = 162$
- ▶ $E_X = 12.3$
- ▶ $E_Y = 5.6$

Calculating uncertainty

$$E_Z = Z \sqrt{\left(\frac{E_X}{X}\right)^2 + \left(\frac{E_Y}{Y}\right)^2}.$$

Measurement uncertainty propagation



Calculating uncertainty

$$E_Z = Z \sqrt{\left(\frac{E_X}{X}\right)^2 + \left(\frac{E_Y}{Y}\right)^2}.$$

Working with jamovi

The screenshot shows the jamovi software interface. The title bar says "bumpus". The top menu bar has tabs: "Variables", "Data", "Analyses" (which is highlighted in blue), and "Edit". Below the menu are several analysis icons: Exploration, T-Tests, ANOVA, Regression, Frequencies, Factor, and DISTRACTION. On the far right, there is a "Modules" icon. The main workspace contains a data table with the following columns: surv, totlen, wingext, wgt, head, humer, and femur. The "wingext" column is currently selected, indicated by a blue border around its header. The data rows show values for 20 observations, all labeled "alive". The bottom status bar provides information about the data: "Ready", "Filters 0", "Row count 136", "Filtered 0", "Deleted 0", "Added 0", and "Cells edited 0". To the right of the main window, there is a logo for "version 2.6.44".

	surv	totlen	wingext	wgt	head	humer	femur
1	alive	154	241	24.5	31.2	0.687	
2	alive	160	252	26.9	30.8	0.736	
3	alive	155	243	26.9	30.6	0.733	
4	alive	154	245	24.3	31.7	0.741	
5	alive	156	247	24.1	31.5	0.715	
6	alive	161	253	26.5	31.8	0.780	
7	alive	157	251	24.6	31.1	0.741	
8	alive	159	247	24.2	31.4	0.728	
9	alive	158	247	23.6	29.8	0.703	
10	alive	158	252	26.2	32.0	0.749	
11	alive	160	252	26.2	32.0	0.741	
12	alive	162	253	24.8	32.3	0.766	
13	alive	161	243	25.4	31.8	0.721	
14	alive	160	250	23.7	29.8	0.730	
15	alive	159	247	25.7	31.4	0.729	
16	alive	158	253	25.7	31.9	0.743	
17	alive	159	247	26.5	31.6	0.733	
18	alive	166	253	26.7	32.5	0.767	
19	alive	159	247	23.9	31.4	0.752	
20	alive	160	248	24.7	31.3	0.752	

Ready Filters 0 Row count 136 Filtered 0 Deleted 0 Added 0 Cells edited 0

version 2.6.44

Working with jamovi

The screenshot shows the jamovi software interface with the following details:

- Top Bar:** The title "bumpus" is displayed. The menu bar includes "Variables", "Data", "Analyses", "Edit", and "Modules".
- Analyses Tab:** The "Analyses" tab is selected, showing icons for Exploration, T-Tests, ANOVA, Regression, Frequencies, Factor, and a "distraction" icon.
- Data View:** On the left, a data grid titled "surv" shows 20 rows of data with columns "alive" and "totlen".
- Descriptives Dialog:** The main window displays the "Descriptives" dialog. It lists variables: surv, wingext, wgt, head, humer, femur, tibio, skull, and stem. The variable "totlen" is selected in the "Variables" list. A "Split by" field is empty. Below the dialog are tabs for "Descriptives" (selected) and "Variables across columns", along with "Frequency tables" and "Plots" buttons.
- Results Panel:** On the right, the "Results" panel shows the "Descriptives" section with the following statistics for "totlen":

	totlen
N	136
Missing	0
Mean	159.54412
Median	160.00000
Standard deviation	3.56083
Minimum	152
Maximum	167

Working with jamovi

The screenshot shows the jamovi software interface. At the top, there's a menu bar with 'Variables', 'Data', 'Analyses', 'Edit', and 'Modules'. Below the menu is a toolbar with icons for Exploration, T-Tests, ANOVA, Regression, Frequencies, Factor, and a distribution plot. The main window title is 'bumpus'. On the left, there's a data grid showing 20 rows of data with the first column labeled 'alive'. The 'Analyses' tab is selected. On the right, the 'Modules' panel is open, showing the 'Available' tab. It lists three modules:

- scatr 1.2.0** by Ravi Selker. Description: Allows you to produce several types of explorative plots such as scatter plots and pareto charts. You can find it under the 'Exploration' menu. Status: INSTALLED.
- Rj - Editor to run R code inside jamovi 2.6.0** by Jonathan Love, Maurizio Agostini. Description: Provides an editor allowing you to enter R code, and analyse your data using R inside jamovi. Status: INSTALL.
- pamlij - Power analysis for linear models 0.6.3** by Marcello Galucci. Description: (beta) A suite for power analysis for linear models. At the moment, it allows for power analysis of. Status: Available.