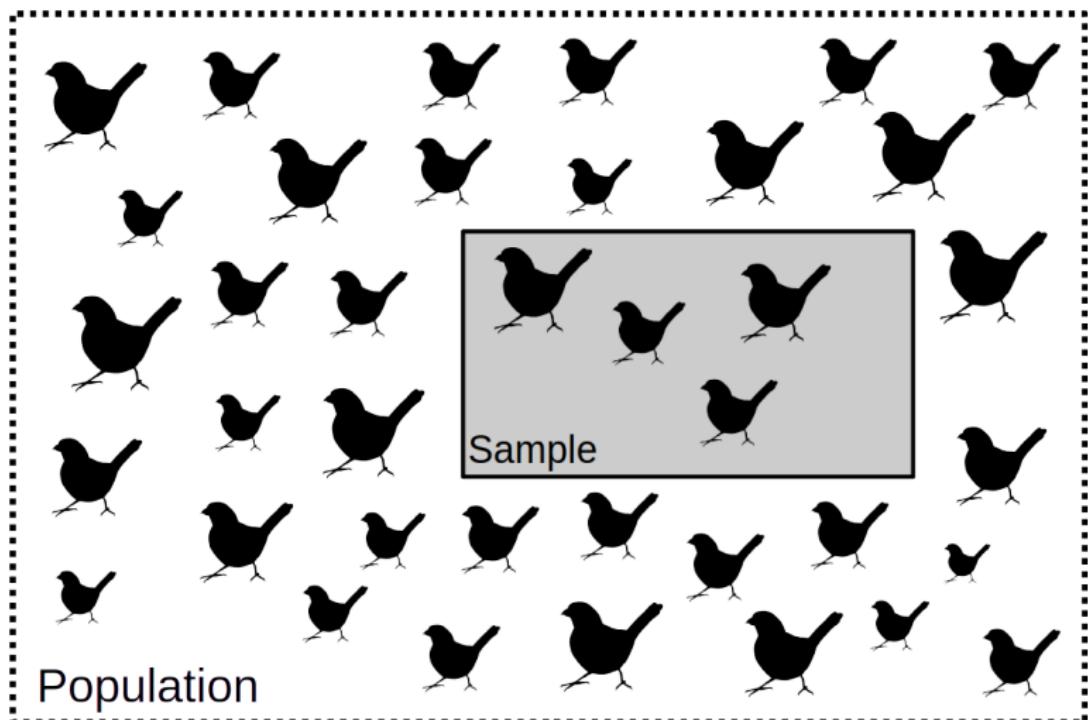


SCIU4T4: Populations, variables, units, uncertainty

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

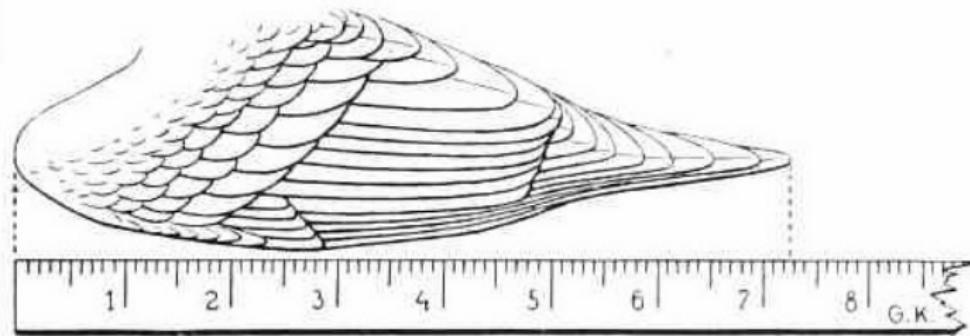
Metrology originally for economic activities¹

- ▶ 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*

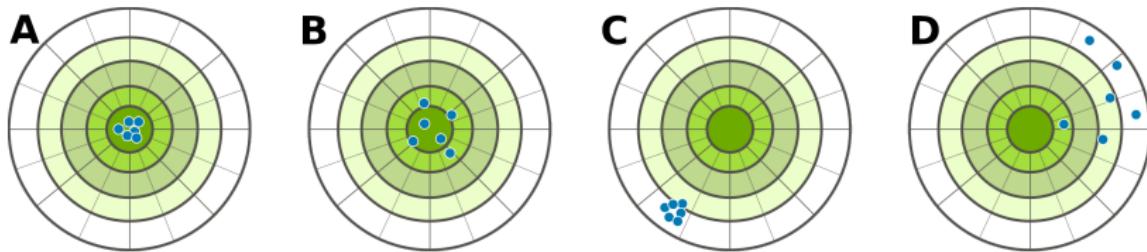
¹Image: Reichenow, A. 1913. ([Public domain](#)).

- ▶ **Accuracy** 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/ab3333)

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

$$Z = X \times Y$$

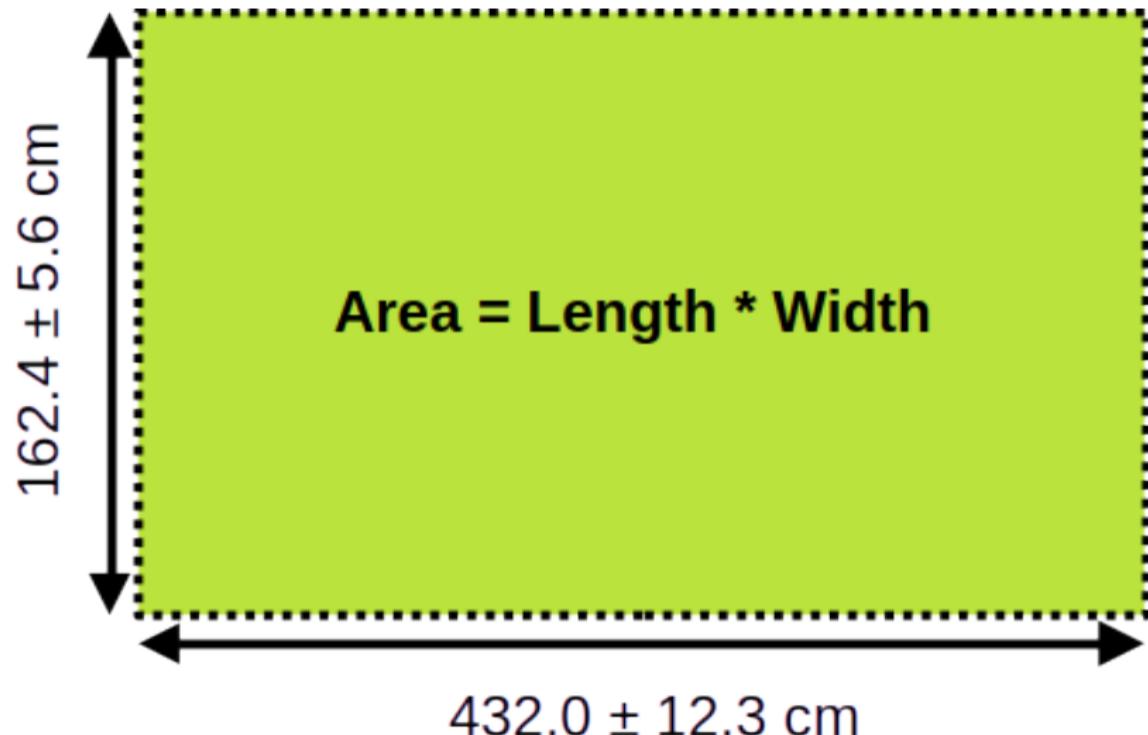
Combining errors different for multiplication

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

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

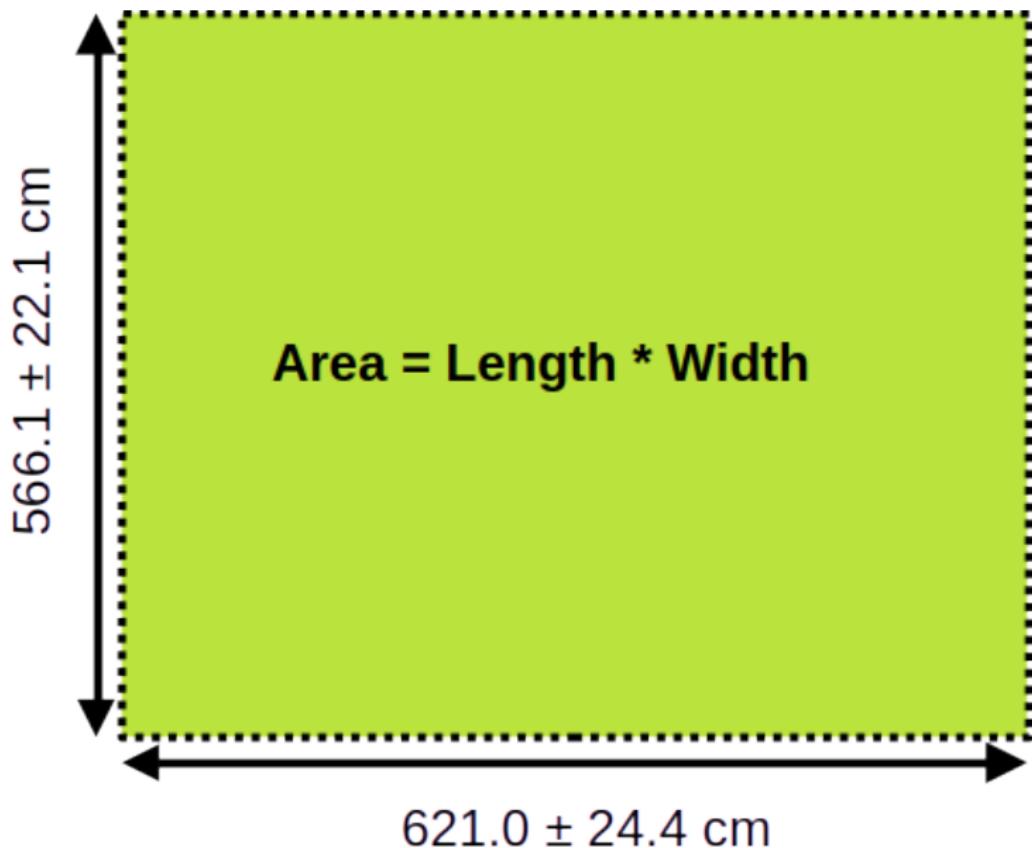
$$E_Z = Z \sqrt{\left(\frac{E_X}{X}\right)^2 + \left(\frac{E_Y}{Y}\right)^2}.$$

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

Calculating uncertainty

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

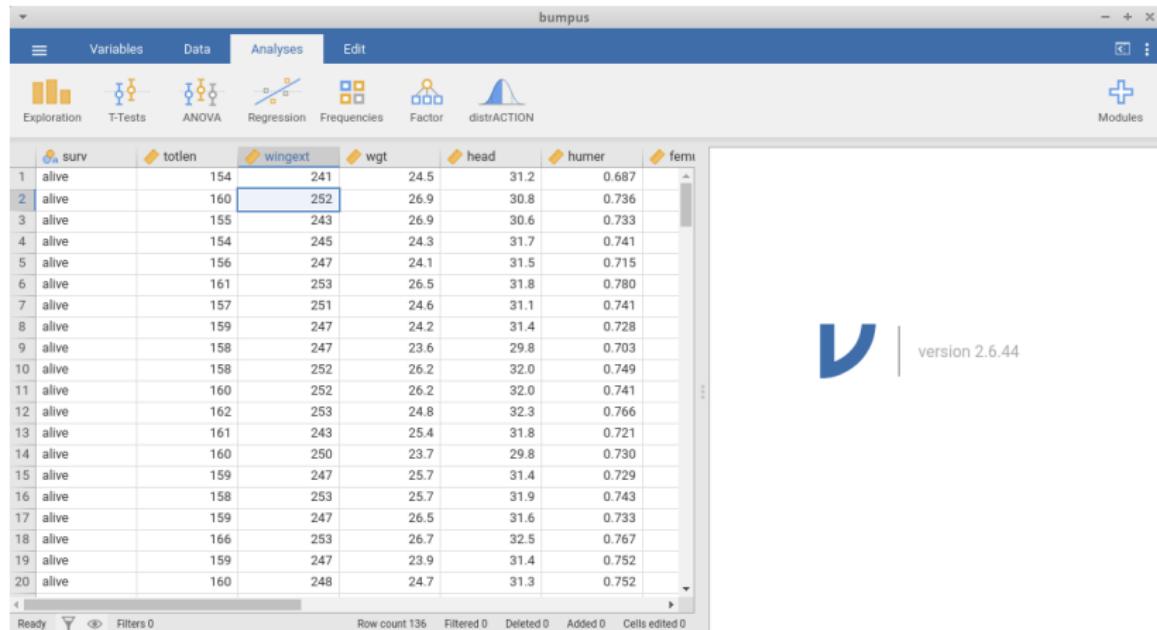
Measurement uncertainty propagation



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 top navigation bar includes 'Variables', 'Data', 'Analyses' (which is the active tab), and 'Edit'. Below the navigation bar are icons for Exploration, T-Tests, ANOVA, Regression, Frequencies, Factor, and a 'distRACTION' icon. On the right side, there is a 'Modules' icon. The main area displays a data grid with 20 rows and 7 columns. The columns are labeled: surv, totlen, wingext, wgt, head, humer, and femur. The 'wingext' column is highlighted with a blue border. The data grid contains the following values:

| | 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 | |

At the bottom, the status bar shows 'Ready', 'Filters 0', 'Row count 136', 'Filtered 0', 'Deleted 0', 'Added 0', and 'Cells edited 0'. The 'version 2.6.44' logo is located in the bottom right corner.

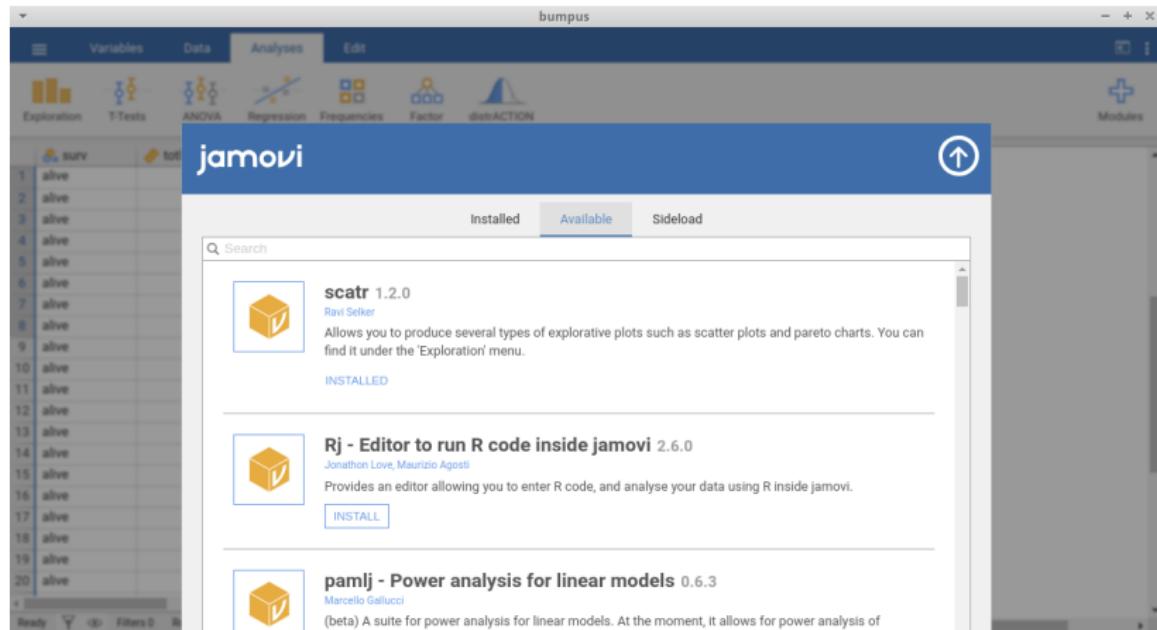
Working with jamovi

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

- Top Bar:** The title "bumpus" is displayed. The "Analyses" tab is selected, showing icons for Exploration, T-Tests, ANOVA, Regression, Frequencies, Factor, and a highlighted "descriptives" icon.
- Left Panel (Data View):** A table titled "surv" is shown with 20 rows of data. The columns are "surv" (alive) and "totlen" (total length). The data shows values ranging from 15 to 16.
- Central Panel (Descriptives Dialog):**
 - Descriptives:** The analysis type is selected.
 - Variables:** The variable "totlen" is selected.
 - Split by:** An empty box for specifying a split variable.
 - Output Options:** "Frequency tables" is checked.
 - Statistics and Plots:** Buttons for "Statistics" and "Plots" are shown.
- Right Panel (Results View):**
 - Results:** The "Descriptives" section is expanded.
 - Descriptives Table:**

| | 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. The top menu bar includes 'Variables', 'Data', 'Analyses', 'Edit', and 'Modules'. The 'Analyses' tab is active, showing icons for Exploration, T-Tests, ANOVA, Regression, Frequencies, Factor, and a 'distrACTION' icon. The 'Modules' tab is also visible. The main window displays the 'Available' tab of the module manager, which lists three available 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