
mousestyles Documentation

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2016 UC Berkeley MA students

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PROJECT REPORT

1.1 Overview

1.1.1 1. Statement of Problem

For this project, our primary data source is mouse behavioral data from the Tecott Lab at UCSF.¹ The lab has recently developed a method for continuous high-resolution behavioral data collection and analysis, which enables them to observe and study the structure of spontaneous patterns of behavior (“Lifestyles”) in the mouse [Tec03][TN04][GSJ+08][AP14]. They have found that using this method: 1) reveals a set of fundamental principles of behavioral organization that have not been previously reported, 2) permits classification by genotype with unprecedented accuracy, and 3) enables fine dissection of behavioral patterns.

1.1 Project Goal

The goal of this project is to explore the effects of genetics on behavior in mice and extrapolate these findings to improve treatment of psychiatric diseases in humans.

1.2 Computational Ethology

Ethology is the study of animal behavior, and it generally follows one of two approaches. The first approach was developed by B.F. Skinner and relies heavily on laboratory experiments. Skinner postulated that since behavior is predictable, it should be controllable. His most prominent experiment involved training pigeons through *operant conditioning*. He found that the pigeons had the ability to learn new behaviors under a reward system. However, the setting of the experiment was incredibly artificial and controlled. In contrast, Konrad Lorenz believed that the only way to truly understand animal behavior is to observe them in their natural context as behavior induced by an artificial environment may not reflect animal behavior in their natural environment. Lorenz’s most prominent experiment discovered that a young goose will instinctively bond with the first moving object that it perceives in order to better recognize its own species. This experiment was conducted in a more natural setting to minimize human manipulation.

This project adopts Lorenz’s approach—observing the whole spectrum of animal behavior in their natural state. Previous approaches relied on human observation to score animal behavior. However, slow data collection, low dimensional data, imprecise and subjective measurements, and human visual and language limitations impeded data collection and analysis. Using modern quantitative tools for measurement, description, and analysis, the field of *computational ethology* has emerged to solve these issues. Together, modern mathematics, engineering, and computer science have the potential to establish a causal relationship between genetics and behavior.

¹ <http://www.neuroscience.ucsf.edu/neurograd/faculty/tecott.html>

1.3 Why Mice?

Although the human genome was first sequenced over a decade ago, the relationship between genetics and behavior is still not well understood. For ethical reasons, genes cannot be systematically manipulated in humans. Therefore, the familiar scientific testing approach must be edited—enter mice. There are several reasons the mouse has become the mammal of choice in human behavioral studies. Chief among them is the fact that “approximately 99% of mouse genes have human counterparts—conversely, mouse versions (orthologs) can be identified for 99% of human genes.” Additionally, the brain organization and behavioral responses of humans and mice display many similarities. For example, both mammals display complex processes like hunger and fear. This allows scientists to more easily identify and track these behaviors. In addition, the extreme similarities of intra-strain mice, the space efficiency of maintaining their caged environments, and the speed of reproduction make mice a logical alternative to testing on humans.

1.1.2 2. Methodology Description

The traditional technology to analyze behavior is time-intensive and labor-intensive. For example, recording data requires researchers to track behavior uninterrupted. This experiment utilized a method for continuous high-resolution behavioral data collection and analysis. The *home cage monitoring (HCM)* system utilized is a network of photobeam feeding detection, drinking detection, and activity platform sensors that records mouse *active states* and *inactive states* automatically and incessantly over 24-hour periods where 1 hour per day was reserved for HCM maintenance. This facilitates objective, multi-dimensional computer tracking, providing a higher degree of accuracy compared to human observation.

In this project, the HCM system tracked 170 mice, representing 16 *strains* or approximately 94% of the genome, logging 500,000 behavioral events per mouse per day over 12 days of data collection after 5 days of acclimation. The scope of the study was limited to male mice as females tended to display cyclical changes in behavior. Mice within each strain display strong homogeneity and low variability in genetic composition. This is in part due to high levels of inbreeding which decreases the randomness between individual mouse samples. By studying the behaviors of these 16 different strains – each strain with their own unique genetic makeup – we can begin to understand the importance of genetic makeup on mice behavior. We can then extrapolate to humans thanks to the remarkable genetic similarity between the two species.

1.1.3 3. Statement of Statistical Problems

This project utilized sophisticated statistical methods to process data, including machine learning algorithms and statistical inference. The whole project can be divided into 6 sub-projects:

- *Behavioral Model*
- *Exploration & Path Diversity*
- *Dynamics of AS Patterns*
- *Ultradian Analysis*
- *Classification and Clustering of Mice*
- *Power Laws & Universality*

1.1.4 4. Glossary

- **Active State (AS):** The active state in this model is when the mouse is using energy, such as foraging, patrolling, eating, or drinking. Active states are energetically costly and can be dangerous in a natural environment.
- **Computational Ethology:** The use of mathematics, engineering, and computer science to overcome the difficulties that come from using humans to score animal behavior.

- **Ethology:** The study of animal behavior, including the phenomenological, causal, genetic, and evolutionary aspects.
- **HCM System:** The system used in this experiment to track variables of interest. The HCM System included photobeam sensors at the feeding stations, capacity based sensors at the drinking station, and an activity platform for position detection using an (x,y) system.
- **Home Environment:** The home environment is the cage of each mouse containing a home base, a food station, and a water station.
- **Inactive State (IS):** The inactive state in this model is when the mouse is in a state of energy conservation, such as sleeping or resting at the home base.
- **Operant Conditioning:** Altering of behavior through the use of positive reinforcement which is given to the subject after eliciting a desired response.
- **Phenotype:** The set of observable characteristics of an individual resulting from the interaction of its genotype with the home environment.
- **Strain:** A strain here is a genetic variant or sub-type of of the more general mouse population.

1.1.5 5. Data

The data includes two directories, intervals and txy_coords, and a npy file named all_features_mousedays_11bins. The all_features_mousedays_11bins.npy contains a 9*1921*11 matrix, which represents 9 features among 1921 mouse days in 11 2 hour bins for a day, the 9 features are:

- **Food (F):** records the food consumption (g) for a certain mouse day and a certain time bin.
- **Water (W):** records the water consumption (g) for a certain mouse day and a certain time bin.
- **Distance (D):** records the movement distance for a certain mouse day and a certain time bin.
- **ASProbability (ASP):** records the AS time proportion in the certain time bin.
- **ASNumbers (ASN):** records the numbers of AS in the certain time bin.
- **ASDurations (ASD):** records the total duration of AS in a certain bin.
- **ASFoodIntensity (ASFI):** equals F/ASP.
- **ASWaterIntensity (ASWI):** equals W/ASP.
- **MoveASIntensity (ASMI):** equals D/ASP.

The intervals directory has 6 sub-directories, all sub-directories have about 33 files for 3 strains, and for each strain there are 11 days data:

- **F:** records start and stop time of eating behaviors for a certain strain and a certain day.
- **W:** records start and stop time of drinking behaviors for a certain strain and a certain day.
- **AS:** records start and stop time of AS for a certain strain and a certain day.
- **M_AS:** records start and stop time of movements in AS for a certain strain and a certain day.
- **IS:** records start and stop time of IS for a certain strain and a certain day.
- **M_IS:** records start and stop time of movements in IS for a certain strain and a certain day.

The txy_coords directory has 5 sub-directories,all sub-directories have about 33 files for 3 strains, and for each strain there are 11 days data:

- **CY,CX,CY:** records the position (x,y) in time t for a certain strain and a certain day.
- **C_idx_HB:** indicates whether the mouse is in HB or not at time t.

- **recordingStartTimeEndTime:** records the start and stop time of tracking (x,y,t) for a certain strain and a certain day.

1.2 Behavioral Model

1.2.1 Statement of Problem:

In order to differentiate mice, we need to create a detailed behavior profile to describe:

1. how they drink, feed or move (locomotion) and
2. how they translate between active state or inactive state.

We have the following key background information from the paper:

- **Home Cage Monitoring System(HCM)** HCM cages were spatially discretized into a 12 x 24 array of cells and occupancy times for each MD were computed as the proportion of time spent within each of the 288 cells. To determine whether animals establish a Home base, HCM cages were spatially discretized into a 2 x 4 array of cells, and occupancy times for each mouse day were calculated as above. In the experiment, 56/158 animals displayed largest occupancy times in the cell containing the niche area, which was considered to be their Home base location.
- **Active and Inactive State** Mice react differently during Active state and Inactive states and all behavioral record should be classified into 2 mutually exclusive categories, Active States (ASs) and Inactive States (ISs). To designate ISs, we examined all time intervals occurring between movement, feeding, and drinking events while the animal was outside the Home base. Those time intervals exceeding an IS Threshold (IST) duration value were classified as ISs; the set of ASs was then defined as the complement of these ISs. Equivalent mathematically, ASs can also be defined as those intervals resulting from connecting gaps between events outside the Home base of length at most IST; ISs are then defined as the complement of these ASs. (*Active State Organization of Spontaneous Behavior Patterns*, C. Hillar et al.)

1.2.2 Statement of statistical problems:

The above flowchart shows the key metrics that are required by the study to capture the behavioral profile:

The main focus is 3 key states of the mice i.e. [*Drinking* | *Feeding* | *Locomotion*]

Each of these metrics can be seen visually in the slides referenced below. Each metric is a tree, decomposed into two child node metrics, whereby when the child nodes are multiplied together, they yield the parent metric.

- AS [*Drinking* | *Feeding* | *Locomotion*] Intensity
- *A note about intensity:* We are not entirely sure what the Tecott Lab's meaning of "intensity" is. Our current hypothesis is that intensity is defined as quantity over active state time. E.g. for drinking, intensity is the quantity consumed divided by the total amount of time the mouse is in an active state.
 - [*Drinking* | *Feeding* | *Locomotion*] Bout Size
 - * [*Drinking* | *Feeding* | *Locomotion*] Bout Duration
 - * [*Drinking* | *Feeding* | *Locomotion*] Bout Intensity
 - [*Drinking* | *Feeding* | *Locomotion*] Bout EventRate
 - [*Drinking* | *Feeding* | *Locomotion*] Event Size
 - [*Drinking* | *Feeding* | *Locomotion*] Bout Rt

Additionally the following needs to be calculated for Inactive /Active State:

Project 1: Behavioral Model

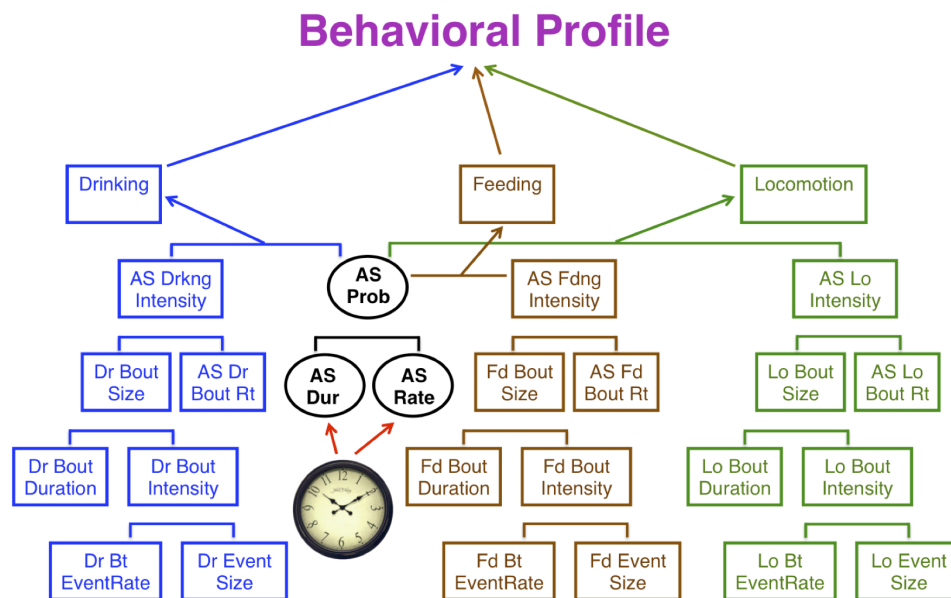


Fig. 1.1: Behavioral Profile (image courtesy of Tecott Lab)

- AS Probability: the probability of AS among all time period
- AS Duration: the length of time of AS
- AS Rate: the reciprocal of average length of time of AS

1.2.3 Data Collection:

The data we have:

- the observations of location for each mice, (x, y, t) with t small.
- the aggregated time binned features about each event and its intensity.

The data we need:

- the observation of consumption size and moving distance with each event.

1.2.4 Exploratory Analysis

Based on the data requirements being provided, we will need to start plotting the following metrics:

For Event

- Event Consumption or Distance: Already in basic time bin features.
- AS Event Intensity: Already in basic time bin features.
- AS Bout Routine: Use *txy_coords* within each event intervals to generate the path.
- Event Bout Size or Distance: Use observation of consumption size and moving distance data.
- Event Bout Duration: Use event intervals data.
- Event Bout Intensity: Use Event Consumption or Distance over minute of AS time
- Event Size: Use interval to get the number of event happened in binned time
- Event Bout Rate: Use Event Size over AS time.

For In/Active State

- AS Probability: Already in basic time bin features.
- AS Duration: Already in basic time bin features.
- AS Rate: Use AS Number over AS Duration.

1.2.5 Data Requirements Description

The data we have:

- a dataframe of observations of location for each mice, (x, y, t) with t small.
- The above dataframe with a classification of strain number and mouse number at each time t (if available)

The data we require:

- The above dataframe with AS/ IS properly classified at each point t for each mouse
- The above dataframe with a classification of drinking, feeding and locomotion for each mouse at each time t
- The above dataframe with a classification of consumption size and moving distance with each event at each time t

A graphic view of the above is as below:

strain	mouse	time	IS/AS	D/F/L/S*	Consn.
0	1	1.1	IS	S	0
0	1	1.4	AS	F	4
1	2	1.1	AS	D	5
1	2	1.3	AS	D	3
1	2	1.6	IS	S	0

*“D/F/L/S” above is a flag for Drinking/ Feeding/ Locomotion/ Stationary

1.2.6 Methodology/ Approach Description

We wish to create a single function that should be able to return all of the above metrics as a list:

Key inputs are:

- mouse/ strain as string
- starting time
- ending time
- a dictionary containing the rectangular vertices marking the area to restrict the movement to i.e. x_lower, x_upper, y_lower, y_upper.
- [Drinking | Feeding | Locomotion] state specification
- The main output is a list containing the key metrics stated in Statement of statistical problems section
- Key idea is that if we have the most granular dataframe in Data Requirements Description then the Python code is really just a SQL (in pandas form) filtering/ grouping query to generate the required output metrics (from flowchart) in the form of a list

An example of a metric calculation for *Drinking* is as follows: $\frac{Drinking}{Total\ Time} = \frac{Drink\ Consumed}{AS\ Time} \times \frac{AS\ Time}{Total\ Time}$

1.2.7 Testing Framework Outline

1.2.8 Additional Remarks

- It is not clear exactly how the specified required metrics are to be calculated in the form of a single query or multiple queries. We need more clarification on what intensity means.
- Not sure yet whether the required dataframe at the most granular level can be easily constructed. This would be really useful for all projects to use so we should really consider developing it for the wider team.
- Some of the required data metrics like consumption of food/ water at each time t may not be easy to obtain as they are provided for each interval. These may have to be prorated across each time t in some stable way in the construction of the required dataframe
- We also believe that the metrics provided at each point are single point statistics i.e. means. We should consider outputting the actual histogram of values at each point for the given metric rather than just the single-valued mean metrics
 - For example, we may not only be interested in the average amount of active time spent in locomotion, but the distribution of locomotion. This is a more complicated metric than those outlined in the work by the Tecott Lab’s papers referenced below. With this information, we could potentially see interesting trends:

the proportion of a mouse-day spent in locomotion could be the same in two time chunks, but the types of movements (distances) could form a more nuanced distribution.

- Not sure if this is feasible, but if we had to produce the mean value we could output the time series mean value over the given interval rather than *just* the overall mean from the given interval

1.3 Exploration & Path Diversity

1.3.1 Statement of Problem

The background of this problem is that the movements of each mouse, defined by “path”, should be affected by some other relevant quantity including strain, time-of-day, day-of-week, physical status, or neural psychological attributes. These important relationships enable us to use the movement of mice to implement statistical analysis including prediction or classification. Generally speaking, our aim in this subproject is to use mouse locomotion patterns to make inference about the mouse’s daily behavior. This behavior involves how many times did the mouse eat in that day and how long did it eat. As we think that mice locomotion patterns are fundamental aspects of behavior, we will expect that these are good features of strains.

1.3.2 Statement of Statistical Problems

Our statistical problems are essentially classified into 2 categories; the definition of path and statistical inference. How to define the path should depend on what we want to do by these paths since the concept of path could be very broad and obscure. If we employ classification in our analysis, we need to discretize the continuous paths. Also we might be able to quantify the paths itself by introducing some ‘scores’ of each path, which is supposed to be a representative summary of the whole path (e.g. “efficiency score” or “exploration score.” Details are in the following sections). Classification could be certainly one of our statistical interests. We are primarily interested in the link between the spatial habits and strain, so for example we can use the following as the response variable for classification:

- Path: given the strain and certain key attributes about the mice (ex: time of day, time of last meal, aggregate distance traveled, etc.), we want to be able to predict the future movement or “path” of the mice. It may be possible to identify types of commonly traveled paths (ex: path towards food, path towards water, exploratory path, etc.) and use these for prediction.
- Strain: By using the path patterns as one of key features to predict strain, we can reveal the important relationship between those.

Ideally the results of those classification should be interpretable to us. That is, for example, the results would show that mice strains which are heavier tend to travel less frequently and less distance throughout the day.

1.3.3 Exploratory Analysis

As we begin our analysis, we would like to explore the following points:

- Daily plots of densities for each strain of mice to distinguish locomotive patterns amongst strains and to get a sense of day-to-day variations in mouse locomotive behavior or possibly detect anomalies. We can measure the ‘distance’ between two densities by the KL divergence in probability.
- Summary statistics of locomotive patterns for each strain. This includes total distance traveled per set intervals (daily, hourly, etc.)
- How different strains allocate their time on each path.
- The impact of changing the grid size (note: the authors have used 1 cm).
- Identify paths that are structurally similar by exploiting rotational invariance

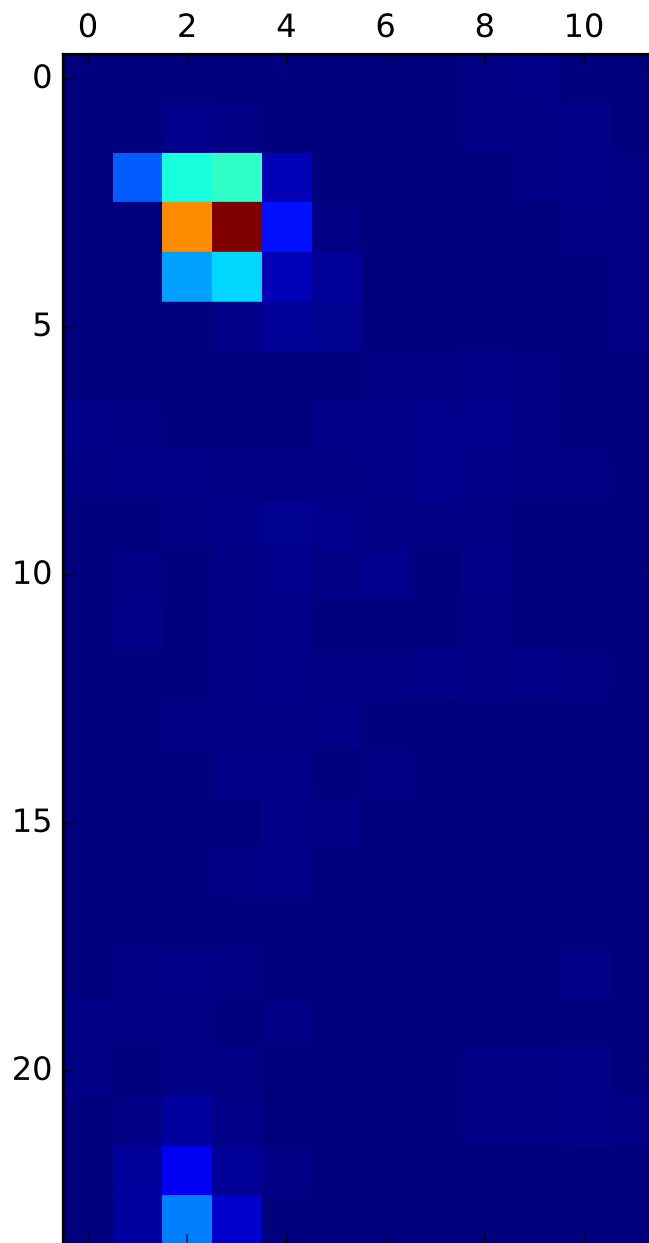


Fig. 1.2: A heatmap of a mouse movement.

1.3.4 Data Requirements

We would require the $\langle x, y, t \rangle$ coordinates for the mice. We require active states (“AS”) and inactive states (“IAS”) to be clearly defined and possibly flagged within the dataset. Additionally, we require behavioral attributes about the mice to be defined and flagged (ex: eating event, drinking event, etc.)

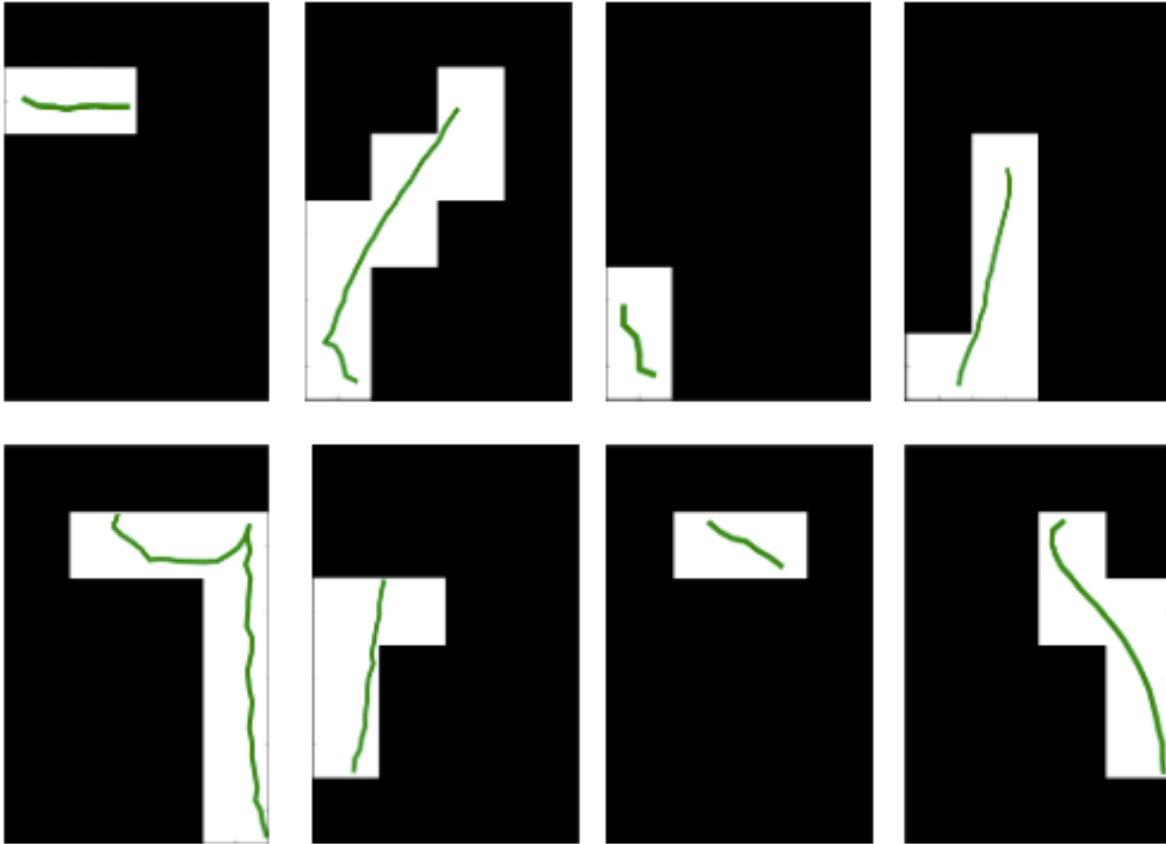


Fig. 1.3: Path (image courtesy of Tecott Lab)

As we define the path, we will also need to consider how each path will be labeled. One possibility is to assign a number to each grid square and to define the path as a sequence of numbers. As an alternative, we can use binary classification to indicate if the mouse traveled on a particular grid square, resulting in a matrix of 0s and 1s.

1.3.5 Methodology/Approach Description

Step 1 : Define “Path”

Definition of path should clearly answer the following questions: - Whether we use raw paths or chunk those into a grid. If we want treat paths as discrete patterns, we need to set appropriate grid size so that the paths are not too chunky or too jittery categorical variables. What is the good measurement here? Which criteria will we follow e.g. stability? - Functions possibly needed in this step: - Obtain_grid: creates grid information based on input of grid size - Chunk_path: chunks paths into a grid by the outputs of Obtain_grid - Eval_chunk: evaluate chunked paths by certain measurement - Whether or not we use time dimension. If yes, how to distinguish a stop or a progression in a path? And how to consider speeds of each path? - Functions possibly needed in this step: - Take_timediff: takes time difference b/w neighboring timestamps - Eval_stops: distinguish a stop or a progression - Obtain_speed: calculates the speed in

each path - How to cut out paths from location data? Should it be divided by equal time length? Or should it start from a certain point e.g. nest? - Functions possibly needed in this step: - Cut_paths: cuts out paths into several smaller paths - Possibility of defining “score” of a path to summarize it. For example, if one mouse goes to food directly and back to the nest immediately, we can evaluate this path as “very efficient,” in a sense that he is very efficient in getting a food. Also it is possible to define an “exploration score” which takes a high value if a mouse goes every part of the cage before going back to the nest. - Functions possibly needed in this step: - Cut_paths: cuts out paths into several smaller paths

Step 2: Choose Key Features

The examples of the key features would include the following: - The stain of the mouse - The time of day - Some pre-defined “score” of a path e.g. efficiency - How frequently a mouse visits/stays at a location - How long it stays at a specific location (ex: nest or food) - The last time the mouse ate - The last time the mouse drank water - The total distance on average a mouse travels per day - How fast on average a mouse travels

We need to construct the functions to generate those features.

Step 3: Classification: Machine Learning Technique

We might be able to use several machine learning methods, including random forest, SVM, gradient boosting. Each method should have following steps: - Cross validation: divide the data into train, validation, and test set - Tune the parameters: Based on the train and validation set, tune the parameter to maximize some pre-defined measurement. - Fit on the test set: Evaluate the performance of the classification on the test set.

Step 4: Interpretation

Hopefully we might employ the different model like logistic regression to get a sense of the effect size of each features on the response variables.

1.3.6 Testing Framework Outline

- Run simulations of machine learning algorithm with a set seed to ensure reproducibility
- Correct warning message or error message.
- Develop tests for python functions in methodology section above

1.3.7 Additional Remarks

We note that the locomotive observations of the mice are recorded at unevenly spaced intervals (i.e., delta-t varies from point to point). Based on exploration of the data, we assume that observations are recorded whenever the mouse is in motion, and during large delta-t intervals, we assume the mouse is stationary. This is an important point we would like to confirm and understand before moving forward with the analysis.

According to the authors, a mice ‘movement event’ was measured as numbered in the tens of thousands per day. Each event was described by a location and time stamp when the distance from the prior recorded location exceeded 1 cm. Despite this, we note an instance in the data where the coordinates from (t) to (t+1) did not change, but resulted in a new observation.

1.3.8 Reference reading:

- Spatial memory: the part of memory that is responsible for recording information about one’s environment and its spatial orientation
- [Wikipedia](#)
- [Mouse Cognition-Related Behavior in the Open-Field: Emergence of Places of Attraction](#)

1.4 Dynamics of AS Patterns

1.4.1 Statement of Problem

The objective of Dynamics Analysis is to analyze and characterize the behaviors of different strains of mice using Markov Chain model. We could use the MC models to further explore the discrepancy between different strains and even simulate a particular mouse day for a particular strain.

1.4.2 Statement of Statistical Problems

The statistical problems in this project are mainly naturally divided into two parts, the modeling part and the simulation of the model part. The modelling part consists of estimating the probability of events transition using the raw data of mouse's spatial and temporal data, and once we've got the model, we could use this model to do predictions and simulate a fake mouse day.

For the estimation, the statistical problems include:

- Define the states of interest.
- Estimate the transition probability matrix given the data we have
- Expand the capacity of our model to take into account the effect of time in our estimation. We want our model to be time-dependent (non-homogeneous) and could also model some of the time series structure of the behaviors of the mice during one typical mouse day

1.4.3 Data Requirements Description

- We need labels of states of interest with respect to the time intervals in a specific mouse day to extract the structure of the Markov Chain.

1.4.4 Methodology/ Approach Description

1. Defining states of interest: which behaviors of the mouse are we interested in?
 - Feeding: labeled by event F
 - Drinking: labeled by event W
 - Other active state behaviors: This could possibly include all other movements in the AS state of a mouse besides drinking and eating.
 - Inactive State: labeled by event I.
2. Data Preprocessing: convert the data we had into strings of the events chosen. This could be done by checking out the states of a typical mouse day at a lot of equally spaced time points and store the states and the time points in the same order. In order to perform this task, we need basically do the following two steps:
 - Data cleaning: Clean the raw intervals given by the measurements in the experiment into interval data that makes more sense and consistent. Also need to check if any of our states overlapped.
 - Data reformatting: Convert the cleaned interval data into strings of events or matrices containing both information from timestamps and the events at those timepoints.
3. Estimating Transition Probability: Estimate the transition probability matrix of the Markov Chain using the data given. One of the key challenges to estimate the transition matrix is that our model is actually time continuous

non-homogeneous Markov Chain, and the parameters are too difficult to estimate given the data we have. Instead, we figured out a way to make our model a composite of small homogeneous discrete time Markov Chains, so that we could perform a rough estimation of the original time continuous non-homogeneous Markov Chain. We followed the following steps to achieve our goal:

- Divide each mouse day into small time intervals, say 5 minutes
 - For each of the small time intervals, aggregate the data from all mice in the same strain for all mouse days and estimate the transition probability matrix of a discrete homogeneous Markov Chain model just for this small time interval. - each of these transition probability matrices is estimated by MLE method, where e.g.: $P(F_{t+1} | W_t) = \frac{N_{WF}}{N_W}$ where N_{WF} indicates the counts of transitions from W to F and N_W indicates the counts of transitions starting from W, no matter where it ends.
 - Build the whole model by compositing the models for each small time intervals.
4. Simulation: Use previous estimated model to simulate a typical mouse day for a typical strain. This part could also be used to evaluate the length of the time interval chosen in the previous step.

1.4.5 Remarks:

Testing for each function should be done by the person who wrote the function.

1.4.6 References:

<http://scikit-learn.sourceforge.net/stable/modules/hmm.html>

<https://github.com/hmmlearn/hmmlearn>

https://en.wikipedia.org/wiki/Hidden_Markov_model

1.4.7 Project Details:

- Data Preprocessing: Hongfei
- Modeling: Jianglong
- Simulation: Chenyu
- Evaluation of length of small time interval chosen: Weiyan, Lynn, Mingyung
- Final Report writeup: Weiyan, Lynn, Mingyung

1.5 Ultradian Analysis

1.5.1 Statement of problem

Ultradian rhythm is widely observed in mammalian behavioral patterns. Ultradian analysis aims to find the time-specific patterns in behavioral records, without specifying the length of cycle in advance (but need to be within 1 hour to 1 day). Typical ultradian period for rats includes 4, 12 and 24 hours. For example, we expect rats to be inactive in the nighttime. Ingestions and movements mostly happened in the daytime. It would be informative to study the ultradian cycle of the behavior of mouse and we need to answer the following questions for this study:

What is the variable of interest for the periodic patterns?

- Summary of activity: Food and water ingestion, distance traveled , movement intensity, AS probability.
- Spatial variable: Spatially discrete the data to cells each with its primary functions such as food cell, water cell, etc. Examine ultradian cycle of the spatial probability densities of the occupancy time in each cells.

How to subset the data?

- Basic subset: 16 strains.
- Strains may not be the primary influence for the variation of ultradian rhythms. We may look into the cycle for each mouse and detect the most important factors influencing the ultradian rhythms.

How to choose the frequency or period ?

- The Lomb-Scargle (LS) periodogram spectral analysis technique, a widely used tool in period detection and frequency analysis.

What is the connection with other subprojects?

- Ultradian rhythms could be treated as one feature for clustering the 16 strains. We may also subset the data using the results of the cluster and analysis the rhythm similarities and differences across clusters.

1.5.2 Statement of statistical problem

How to determine the optimal bin intervals for constructing the time series?

- The bin interval may vary according to the frequency. Bin interval examples: 5 min, 30 min, 1 hour etc. Need to look into the data.

How to test the autocorrelation coefficient for the data and assess the model?

- Use the AIC to select best time lags for the time series model and the K statistics to test the goodness of fit.

For longitudinal data analysis, how to build the model? Which is the fixed effect or random effect?

1.5.3 Exploratory Analysis

Data investigation

- Think about known/expected cycles - time to digest, IS/AS cycle, etc.
- Try to investigate cycles that are greater than 24 hours to avoid missing cycles.
- During the acclimatization period, investigate difference in cycles.

Plots

- Plots for determining optimal bin intervals for constructing the time series.
- Plots for discovering the frequency or period.
- General time series plots for getting intuitions for each variables.

Models

- Usage of Lomb-Scargle (LS) periodogram spectral analysis technique, a widely used tool in period detection and frequency analysis

1.5.4 Data Requirements Description

Input: records for each strains (total of 16), each feature of interest (food, water, distance, active_state probability, ...), in a duration of 12 days (excluding 4 acclimation days).

Processed: using one-minute time bins of movement records to binary score the activity into 0 (IS: inactive state) and 1 (AS: active state); using thirty-minute bins of food records to calculate the amount of chows consumed by mice; using LS periodogram technique to select the appropriate time bins for above.

Output: different patterned visualization for each feature, with the appropriate time bins that presents the most significant ultradian pattern.

1.5.5 Methodology/Approach Description

Seasonal decomposition. Seasonal decomposition is a very common method used in time series analysis. One of the main objectives for a decomposition is to estimate seasonal effects that can be used to create and present seasonally adjusted values.

Two basic structures are commonly used:

1. Additive: $x_t = \text{Trend} + \text{Seasonal} + \text{Random}$
2. Multiplicative: $x_t = \text{Trend} * \text{Seasonal} * \text{Random}$

The “Random” term is often called “Irregular” in software for decompositions.

Basic steps:

1. Estimate the trend
2. "De-trend" the data
3. Estimate seasonal factors by using the "de-trended" series
4. Determine the "random" term

Longitudinal data analysis.

- Attempts for mixed models
 - The mixed model is frequently used for longitudinal analysis. We should specify the random effects and fixed effects first, such as the IS/AS condition, the purpose of the active: like food or water and any other important features. Then we can use linear mixed model to get the pattern of the movements in different time period.
 - Statsmodels.api package can be used to decompose the dataset we have.

Autocorrelation analysis.

- Implement numpy.correlate functions to investigate autocorrelation in several variables for features of interest (food, water, distance, active_state probability ...)
- Explore different kinds of autocorrelation models (spatial analysis, regression analysis) on variables generated by other subprojects.

1.5.6 Testing Framework Outline

Step 1: Generating random samples for testing:

- Split the data based on the Mouse Day Cycle

- Number the splits and use `numpy.random` to subset from these splits

Step 2: Conduct Lomb-Scargle (LS) test to detect the period. Implement the three different models onto the certain period and get the patterns/ estimated coefficients for the model.

Step 3: Compare the result with our hypothesis.

1.5.7 Reference

- Lloyd, David, and Ernest L. Rossi, eds. *Ultradian rhythms in life processes: An inquiry into fundamental principles of chronobiology and psychobiology*. Springer Science & Business Media, 2012.
- Stephenson, Richard, et al. "Sleep-Wake Behavior in the Rat Ultradian Rhythms in a Light-Dark Cycle and Continuous Bright Light." *Journal of biological rhythms* 27.6 (2012): 490-501.

1.6 Classification and Clustering of Mice

1.6.1 Statement of overall problem

The mouse style research investigates mouse behaviors of different genes. The researchers hope to gain insight to human behaviors using mouse data, since experimenting directly on human is difficult.

The important concern is whether we can classify different strains of mice based on mouse behaviors through machine learning algorithms. Important features in classification models will be extracted for future study. Another question of interest is on whether genetic affects (different strain effects) psychological disorders such as depression, or overeating. The fundamental hypothesis is that different mouse strains have different behaviors, and we are able to use these behaviors as features to classify mice successfully.

1.6.2 Statement of statistical problems

The researchers design the experiment as follow: they have 16 different strains of mice, and each strain has 9 to 12 almost identical male mice in terms of genetic.

We need to firstly verify the assumption that mouse of different strains do exhibit different behaviors. One way to do this is to perform hypothesis testing based on the joint distribution of all the features. A simpler alternative is to perform EDA on each of the features. If we observe that each mouse behaves very similarly to its twins, but differently from other strains of mice, we can conclude that genetic differences affect mouse behaviors and that behavioral features might be important for classification. Notice that here we can evaluate the difference by assessing the classification performance of models based on behavioral features.

Based on the assumption, the problem is inherently a multiclass classification problem based on behavioral features either directly obtained during the experiment or artificially constructed. Here we have to determine the feature space both from the exploratory analysis and biological knowledge. If the classification models performed well, we may conclude that behavioral differences indeed reveal genetic differences, and dig into the most important features needed seeking the biological explanations. Otherwise, say if the model fails to distinguish two different strains of mice, we may study that whether those strains of mice are genetically similar or the behavior features we selected are actually homogeneous through different strains of mice.

1.6.3 Exploratory Analysis & Classification Models

In 1D, box plots of each feature, say food consumption or sleeping time, of each strain can be plotted. In 2D, PCA can be preformed on the feature data set and the data are then plotted along the first and the second principal axes colored

in different strains. These plots are useful in verifying assumptions. For instance, we could box-plot different strains of mice against food consumption to see whether different strains of mice eat distinctly. If the number of variables needed to be evaluated is large, we might also use five number summaries to study the distributions.

Example boxplots:

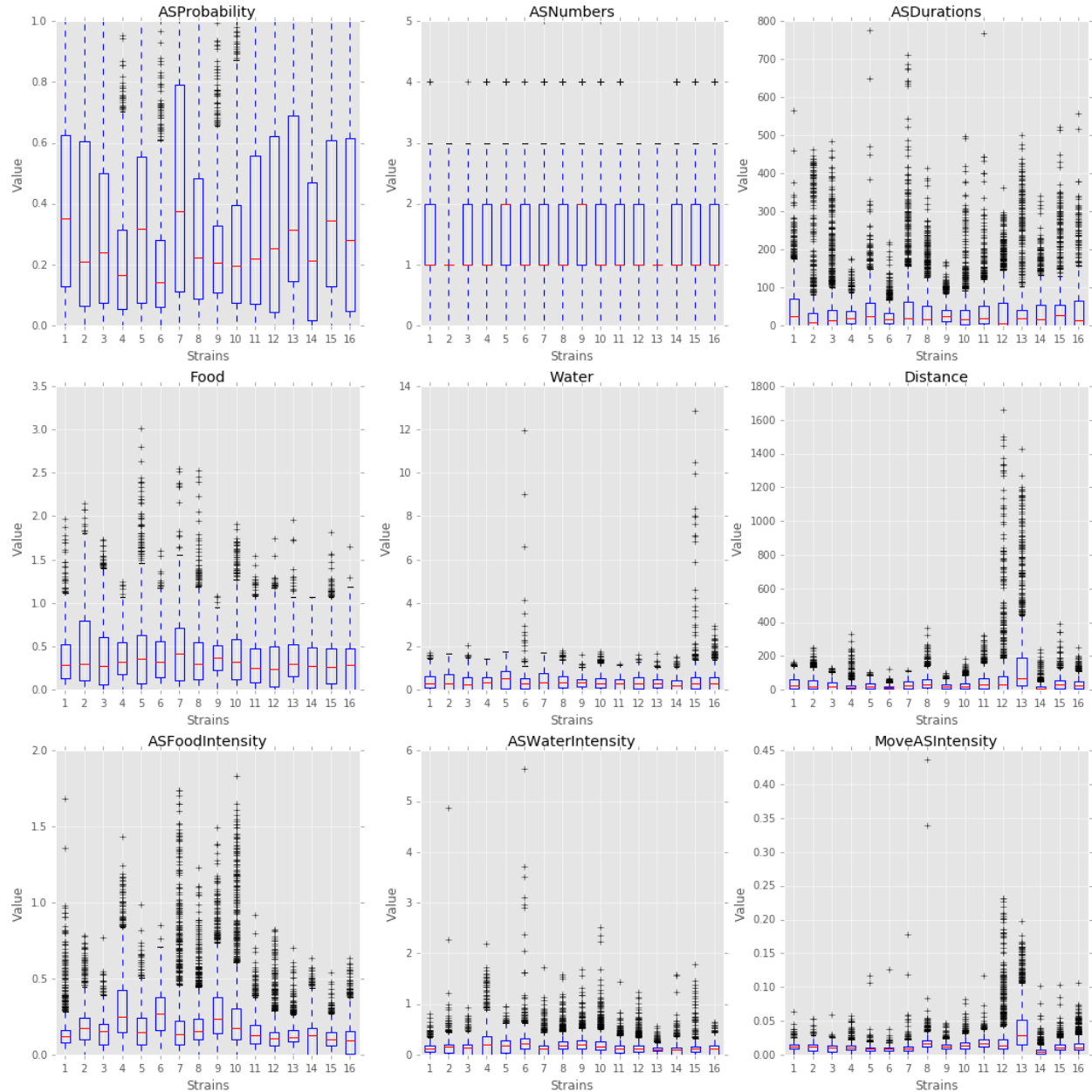


Fig. 1.4: Example boxplots

Since each strain (each class) only has 9 to 12 mice, inputting too many features to the classification model is unwise. The exploratory data analysis will be an important step for hypothesis testing and feature selection. The process will also help us to find outliers and missing values in each behavioral variable, and we will decide how to handle those values after encountering that.

1.6.4 Data Requirements Description

We dispose of a labeled data set of 16 different strains of mice. Behavioral features are recorded for each mouse and each day. One example can be the time spent eating or drinking, and the amount ingested.

The researchers record the daily activities of each mouse, for example the time it spends eating, drinking, sleeping, and wondering around its habitats. Therefore, every behavioral features should be averaged to the same time period (one mouse day) for each mouse. For example, the food consumed variable at each timestamp will be aggregated to the average food consumption.

Notice that the final dataset should be a clean and well formatted dataframe (in numpy array or pandas dataframe) aggregating the features of mice so that it can be directly used to train classification models.

Besides, the detailed explanation for each variable and strain type might be needed for further interpretations of models.

1.6.5 Methodology/ Approach Description

1.Supervised Classification: Supervised classification algorithms (logistic regression, random forest, KNN) will be used to detect the relationship between strain of mice and behavioral features. If we gain good model performance, we can conclude different mouse behaviors actually indicate different genetic differences. K-fold cross-validation might be used to tune model parameters, and a proportion of data would be used as test data to evaluate the model performance. Notice that we may manually manipulate so that the both the training data and the test data cover all strains of mice.

2.Unsupervised clustering In addition, we can use unsupervised machine learning models (e.g. K-means) to cluster the daily mouse activities into clusters that correspond to the genes. This means we will not use the given strain label, instead we will create new labels for mice purely based on its behaviors by clustering. This can highlight an even stronger relationship between genes and mouse behaviors.

The step after model fitting is to assess the important behavioral features in the classification and clustering models. A smaller set of feature space containing only top features might be used to gain better interpretations of the model.

1.6.6 Testing Framework outline

- The first step to test the reproducibility is to test the stability of classification models. Since we randomly split the dataset to be the test set and the training set, we can train and test the model over different seeds and plot the accuracy against different trials. We should also see if the important features are stable over different trials.
- From our limited understanding, the results of this research might have a meaningful implication on the way we treat psychological disorders. If it turns out that nature does influence these disorders, we can probably conclude that psychological disorders is not much different than physical disabilities. Otherwise, if nature has little influence over these disorders, we can try to find way to prevent these disorders from happening.

1.6.7 Initial tasks

1. Clean up the existing strain_classification.py: create functions and objects.
2. Adding new models: knn, random forests, neural networks, logistic regressions.
3. Doing unsupervised learning: k-means.
4. Compute confidence interval for the accuracy of each model.
5. Give insights about how mice behavior is related to their genetic heritage (strain difference).

1.6.8 References

1.7 Power Laws & Universality

1.7.1 Statement of Problem:

To take a closer look at the tail property of locomotion, we analyze the moving distance distribution for home based mice and non home based mice.

1.7.2 Statement of Statistical Problem:

The major statistical question is how to choose fitted distribution family. Based on conventions and data we have, we propose two distributions: law decay distribution and gamma distribution: - In statistics, power law, also known as a scaling law, is a functional relationship between two quantities, where a relative change in one quantity results in a proportional relative change in the other quantity, independent of the initial size of those quantities: one quantity varies as a power of another. $F(x) = kx^{-a}$. This power law decay only works for monotone decreasing distribution. - If the distribution is not monotone decreasing, power function may not be realistic. In this case, the distribution is left skewed with one peak (see exploratory analysis). Thus we can make more general assumption, gamma distribution.

1.7.3 Exploratory Analysis

- The difference between “home base” and “non home base”: “home base”, which means a favored location at which long periods of inactivity (ISs) occur, is a post defined characteristic of the mouse.
- The definition of inter-event distance: literally, inter-event distance is the distance within one single event. Investigating the data of the distance between each two consecutive points recorded by the detector of one mouse day, we found the shape of the histogram is similar to the plot on the slide, except the value of frequency is bigger. This inconsistency gives us the motivation to calculate the inter event distance instead of the distance between each two points. For this purpose, we need a vector of the index of events for each mouse day. In particular, the mapping vector is connected by time since xy coordinates are recorded according to time and the event is defined based on time.
- Preferred choice of distribution: the power law is a monotone decreasing, however our plot indicates a peak, in which gamma distribution may fit better.

1.7.4 Data Requirements Description

- Label of “home base” or “non home base”: generated in the process of data pre-processing by the definition
- Event index corresponding to the time: a vector mapped the time indicating the events.
- Inter event distance: calculated by the square root of the sum of the difference x,y coordinates

1.7.5 Methodology/ Approach Description

Given the estimated parameter for each distribution, we can learn more about its distribution and the information lies mainly in the decay rate of the tail.

Here are our algorithms:

- Draw the histogram for our data. Observe the distribution and intuitively figure out whether our distribution assumption makes sense.

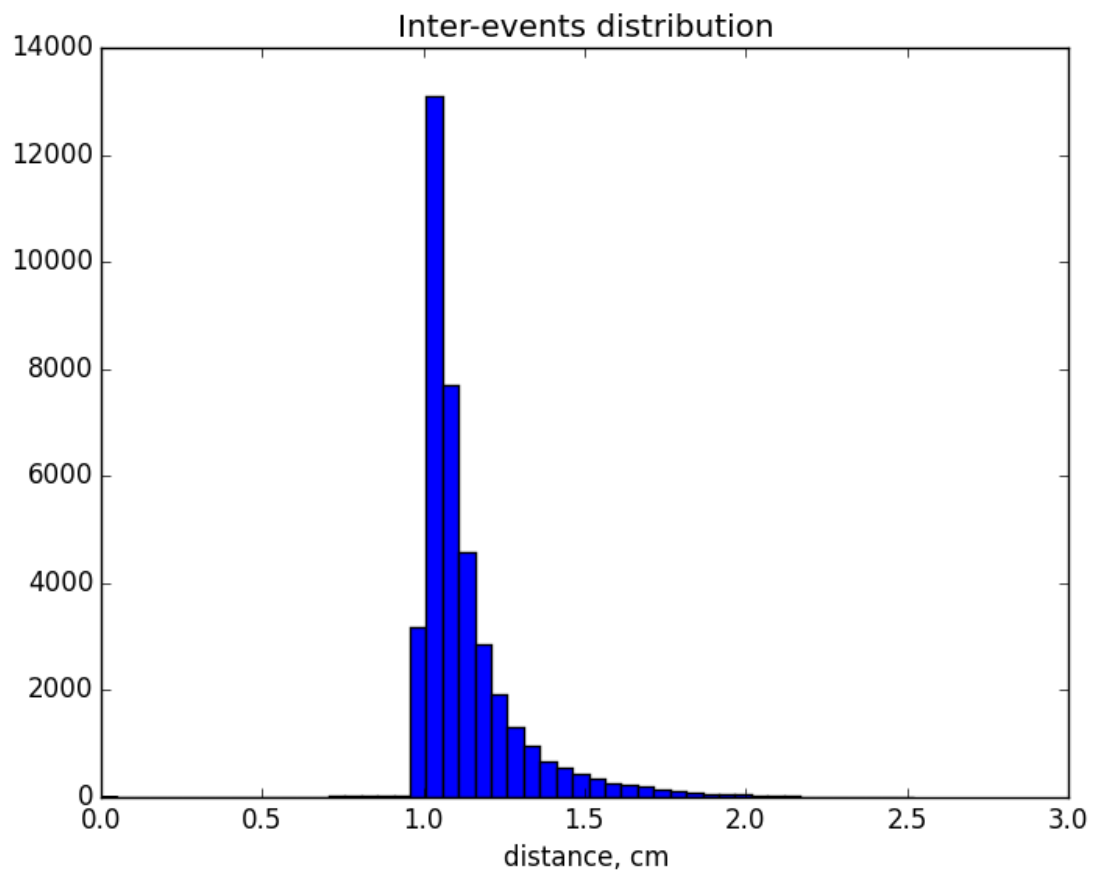


Fig. 1.5: Distribution

- Estimate parameters based on MoM or MLE.
- Add the density function to our histogram, see the fitness of our distribution.
- Conduct statistical test to quantitatively analysis the fitness (Pearson chi square test). For testing the hypothetical distributions of a given array, there are several existing commonly used methods. However, each approach has their pros and cons. Following is a short overview of these testing framework. We recommend that all the methods are to be tried to get a comprehensive understanding of the inter-event step distributions.
- Pearson Chi-square test
- Fisher's exact test
- KS test

1.7.6 Testing Framework Outline

The potential functions are recommended to implement:

- Retrieve data function (*retrieve_data*): Given the number of mouse and the date, create a data frame containing follow variables. 1) position: x,y coordinates 2) time: detecting time stamp for each pair of coordinates, time interval label for events, time interval label for active state and inactive state.
- Retrieve event function (*retrieve_event*): Given an event label (e.g. Food), subset respective part of data from the data frame we got in *retrieve_data*
- Compute the distance (*compute_distance*): Given event label, compute the distance between each time stamp. As we already know the x, y coordinates from the dataframe in *retrieve_event*, the simplest way to implement this function is that:

$$distance = ((x_{t2} - x_{t1})^2 + (y_{t2} - y_{t1})^2)^{1/2}$$

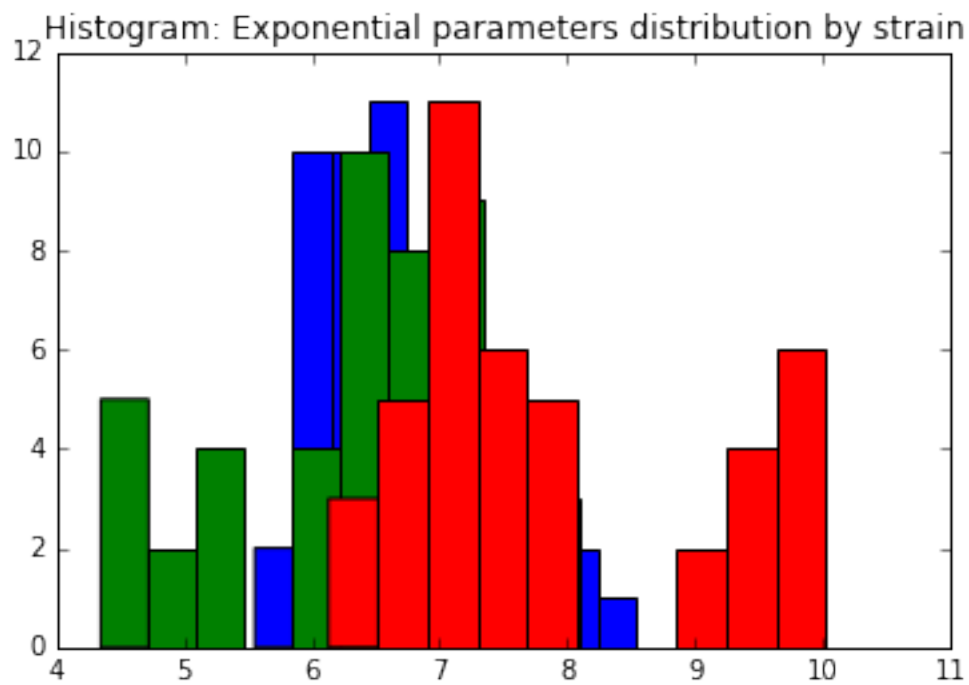
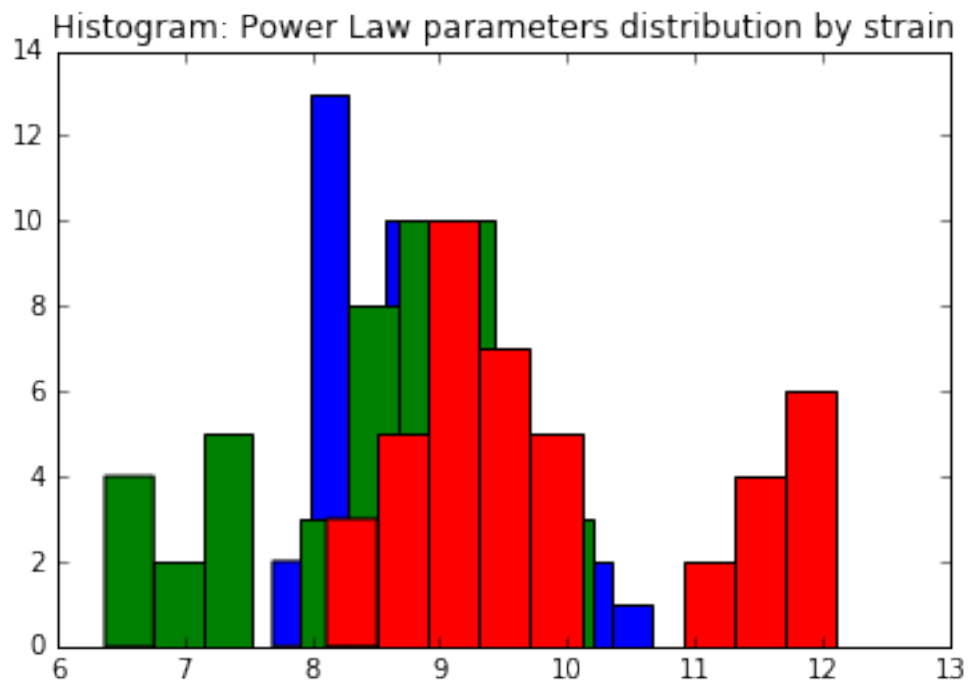
- Draw histogram (*draw_histogram*): Given a sub-array, using the plt built-in histogram function to draw the plot.
- Test distribution (*fit_distr*): Given the testing methods (e.g. "ks"), implement the corresponding fitting methods. The potential output could be p-value of the hypothesis test.

Based on the potential functions to be implemented, the following is the guide of testing:

- *test_retrieve_data*: attain a small subset of data from x,y coordinate and t, and feed in the function. Compare the results with the counted number.
- *test_retrieve_event*: Use the small data frame we get in *test_retrieve_data*, given different events/state. Compare the results with our counted number.
- *test_compute_distance*: Given x = 3, y =4, the output should be 5.
- *test_fit_distr*: randomly draw samples from widely used distributions (e.g. uniform). Test it with right(e.g. uniform) and wrong(e.g. gamma) distributions. Compare the p-values with given threshold (e.g. alpha = 95%)

1.7.7 Result

- The histogram of estimators from powerlaw:
- The histogram of estimators from exponential:
- The histogram of data and fitted curve for strain 0, mouse 2, day 5:
- Fitting power law distribution and gamma distribution for strain 0, mouse 0, and day 0; fitting by Maximum Likelihood, and by minimizing Kolmogorov CDF distances:



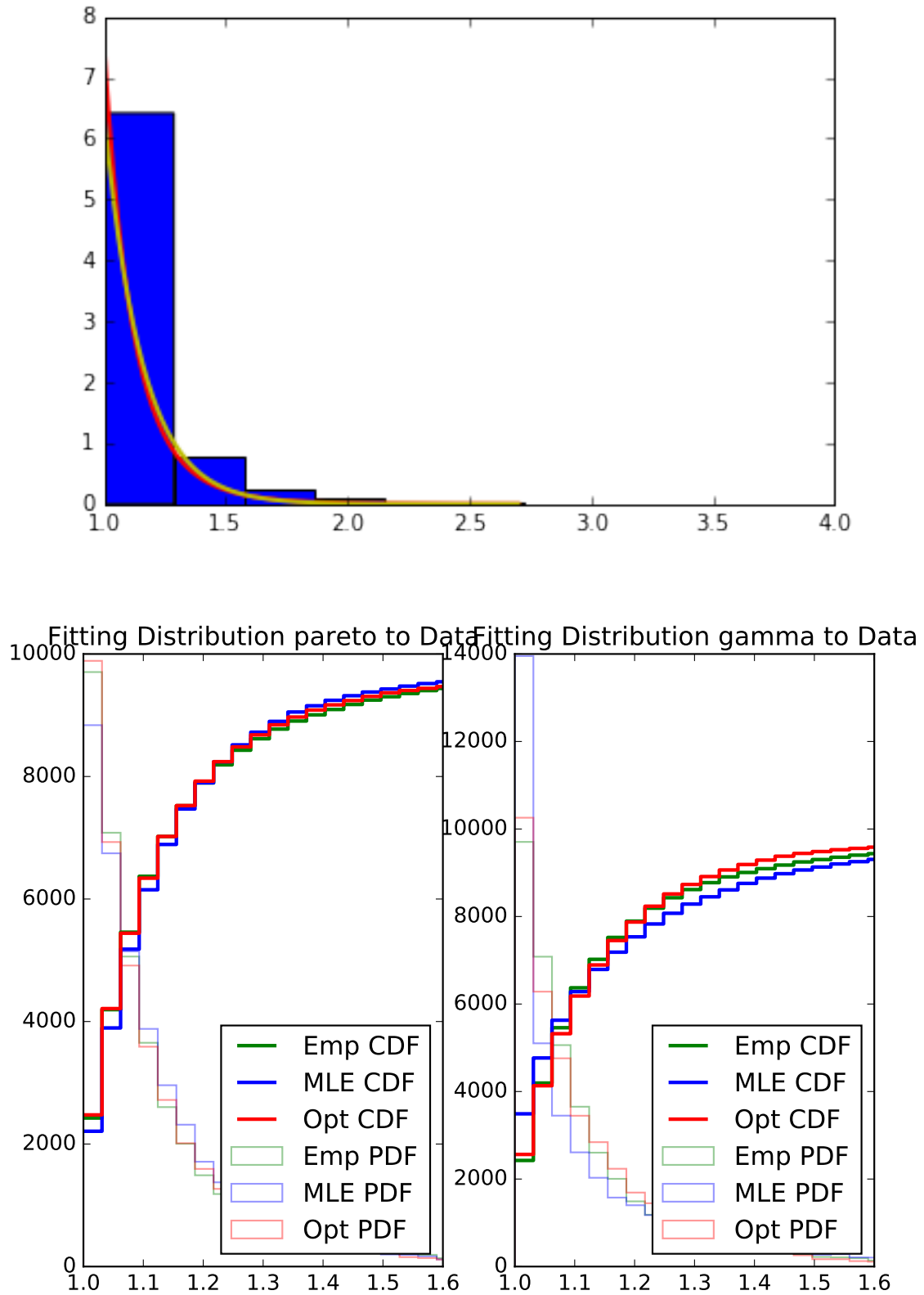


Fig. 1.6: Histogram of distances travelled in 20ms by strain 0, mouse 0, day 0.

1.7.8 Reference reading:

- https://en.wikipedia.org/wiki/Power_law

DEVELOPER DOCUMENTATION

2.1 Contributing

2.1.1 Development process

Here's the long and short of it:

1. If you are a first-time contributor:

- Go to <https://github.com/berkeley-stat222/mousestyles> and click the “fork” button to create your own copy of the project.
- Clone the project to your local computer:

```
git clone git@github.com:*your-Github-username*/mousestyles.git
```

- Add the upstream repository:

```
git remote add upstream git@github.com:berkeley-stat222/mousestyles.git
```

- Now, you have remote repositories named:
 - upstream, which refers to the `berkeley-stat222/mousestyles` repository
 - origin, which refers to your personal fork

2. Develop your contribution:

- Pull the latest changes from upstream:

```
git checkout master  
git pull upstream master
```

- Create a branch for the feature you want to work on. Since the branch name will appear in the merge message, use a sensible name based on the feature you want to improve or add such as `'feature-issue#number'` (e.g. `git checkout -b contributing-issue#14`):

```
git checkout -b contributing-issue#14
```

See *tools/bash-and-git.sh*, which contains useful configurations for visualizing and keeping track of branches more easily.

- Commit locally as you progress (`git add` and `git commit`). It is highly recommended that you use the provided pre-commit hook (described in the [tools README](#)), which automatically runs tests and style checks before every commit. This way, you can see if Travis (described below) will fail before you push.

3. To submit your contribution:

- Push your changes back to your fork on GitHub:

```
git push origin contributing-issue#14
```

- Go to GitHub. The new branch will show up with a green Pull Request button - click it.
- If you want, comment on the [issue posting in Github](#) to explain your changes or to ask for review.

4. Review process:

- Reviewers (the other developers and interested community members) will write inline and/or general comments on your Pull Request (PR) to help you improve its implementation, documentation and style. Every single developer working on the project has their code reviewed, and we've come to see it as friendly conversation from which we all learn and the overall code quality benefits. Therefore, please don't let the review discourage you from contributing: its only aim is to improve the quality of the project, not to criticize (we are, after all, very grateful for the time you're donating!). See [here](#) for some nice code review guidelines.
- To update your pull request, make your changes on your local repository and commit. As soon as those changes are pushed up (to the same branch as before) the pull request will update automatically.
- [Travis-CI](#), a continuous integration service, is triggered after each Pull Request update to build the code, run unit tests, measure code coverage and check coding style (PEP8) of your branch. The Travis tests must pass before your PR can be merged. If Travis fails, you can find out why by clicking on the "failed" icon (red cross) and inspecting the build and test log.

5. Document changes

Before merging your commits, you must add a description of your changes to the release notes of the upcoming version in `doc/release/release_dev.rst`.

Note: To reviewers: if it is not obvious, add a short explanation of what a branch did to the merge message and, if closing a bug, also add "Closes #14" where 14 is the issue number.

2.1.2 Divergence between upstream master and your feature branch

Do *not* ever merge the main branch into yours. If GitHub indicates that the branch of your Pull Request can no longer be merged automatically, rebase onto master:

```
git checkout master
git pull upstream master
git checkout contributing-issue#14
git rebase master
```

If any conflicts occur in (e.g. `conflict-file1` and `conflict-file2`), fix the according files and continue:

```
git add conflict-file1 conflict-file2
git rebase --continue
```

Help in resolving merge conflicts is provided [here](#).

In some cases, you'll want to edit your history while rebasing. This can be accomplished with the `-i` or `--interactive` option of `git rebase`. Running `rebase` with this option will open a text editor, where you can choose to remove or edit some commits, or squash several together. This allows you to (for example) edit commit messages, or merge together repetitive small commits like "fixed typo." See this [tutorial](#) for more details.

Note: you should only rebase your own branches and must generally not rebase any branch which you collaborate on with someone else.

Finally, you must push your rebased branch:

```
git push --force origin contributing-issue#14
```

(If you are curious, here's a further discussion on the [dangers of rebasing](#). Also see this [LWN article](#).)

2.1.3 Guidelines

- All code should have tests (see [test coverage](#) below for more details).
- All code should be documented, to the same [standard](#) as NumPy and SciPy.
- No changes are ever committed without review. Ask on the [mailing list](#) if you get no response to your pull request. **Never merge your own pull request.**

2.1.4 Stylistic Guidelines

- Set up your editor to remove trailing whitespace. Follow PEP08. Check code with pyflakes / flake8.
- Use numpy data types instead of strings (`np.uint8` instead of `"uint8"`).
- Use the following import conventions:

```
import numpy as np
import scipy as sp
import matplotlib as mpl
import matplotlib.pyplot as plt

import numpy as cnp # in Cython code
```

2.1.5 Commit message codes

Please prefix all commit summaries with one (or more) of the following labels. This should help others to easily classify the commits into meaningful categories:

- *BUG* : bug fix
- *RFT* : refactoring
- *ENH* : new feature or extended functionality
- *BKW* : addresses backward-compatibility
- *OPT* : optimization
- *BRK* : breaks something and/or tests fail
- *DOC* : for all kinds of documentation related commits
- *TST* : for adding or changing tests
- *DAT* : for adding or changing data files
- *STY* : PEP8 conformance, whitespace changes etc that do not affect function.

So your commit message might look something like this:

```
TST: relax test threshold slightly

Attempted fix for failure on windows test run when arrays are in fact
very close (within 6 dp).
```

Keeping up a habit of doing this is useful because it makes it much easier to see at a glance which changes are likely to be important when you are looking for sources of bugs, fixes, large refactorings or new features.

2.1.6 Pull request codes

When you submit a pull request to github, github will ask you for a summary. If your code is not ready to merge, but you want to get feedback, please consider using `WIP - experimental optimization` or similar for the title of your pull request. That way we will all know that it's not yet ready to merge and that you may be interested in more fundamental comments about design.

When you think the pull request is ready to merge, change the title (using the *Edit* button) to something like `MRG - optimization`.

2.1.7 Test coverage

Tests for a module should ideally cover all code in that module, i.e., statement coverage should be at 100%.

To measure the test coverage, install `coverage.py` (e.g., using `pip install coverage`) and then run:

```
$ make coverage
```

This will print a report with one line for each file in *mousestyles*, detailing the test coverage:

Name	Stmts	Miss	Branch	BrMiss	Cover	Missing
mousestyles	43	6	10	1	87%	72, 77-88
mousestyles.core	55	0	30	4	95%	
mousestyles.data	45	0	2	0	100%	
mousestyles.eda	22	0	8	0	100%	
mousestyles.irr	52	0	20	2	97%	
mousestyles.stratified	44	0	16	4	93%	
TOTAL	261	6	86	11	95%	
Ran 35 tests in 37.199s						
OK						

2.1.8 Bugs

Please [report bugs on GitHub](#).

2.2 Documentation and Coding Standards

2.2.1 Naming Conventions

- Choose short and concise names that reflect usage
- Never use the characters 'l' (lowercase letter el), 'O' (uppercase letter oh), or 'I' (uppercase letter eye) as single character variable names
- *Package and Module Names:*
- Use all-lowercase names

- Use underscores when appropriate in module names but not package names
- *Class Names:*
- Use CapWords convention
- *Function and Variable Names:*
- lower_case_with_underscores
- Use a descriptive verb in function names
- *Constants:*
- Use all capital letters with underscores separating words (e.g. YELLOW_MARINE)

2.2.2 Indentation

- Use 4 spaces per indentation level
- Continuation lines should align wrapped elements vertically using Python’s implicit line joining inside parentheses, brackets and braces

```
# Aligned with opening delimiter
nacho_cheese = not_your_cheese(cheddar, pepperjack,
                               provolone, brie)
```

- The closing brace/bracket/parenthesis on multi-line constructs should line up under the first non-whitespace character of the last line of list

```
six_afraid_of_seven = [
    7, 8, 9,
    1, 0, 1
]
```

2.2.3 Docstrings

- We will be following `numpy` conventions.
- What is a Docstring?
- A docstring is a string literal that occurs as the first statement in a module, function, class, or method definition. Such a docstring becomes the `_doc_` special attribute of that object.
- When do we use docstrings?
- All modules should normally have docstrings, and all functions and classes exported by a module should also have docstrings. Public methods (including the `_init_` constructor) should also have docstrings. A package may be documented in the module docstring of the `_init_.py` file in the package directory.
- Formatting by type of object
- The docstring of a **script** should be usable as its “usage” message, printed when the script is invoked with incorrect or missing arguments. Such a docstring should document the script’s function and command line syntax, environment variables, and files. Usage messages should be sufficient for a new user to use the command properly, as well as a complete quick reference to all options and arguments for the sophisticated user.
- If the stand-alone script uses another module for handling options, such as the `argparse` module, then option information is moved from the docstring to the module’s utilities.

- The docstring for a **module** should generally list the classes, exceptions, and functions that are exported by the module, with a one-line summary of each.
- The docstring for a **package** (i.e., the `_init_.py` module) should also list the modules and subpackages exported by the package.
- The docstring of a **function** or **method** is a phrase ending in a period. It prescribes the function or method's effect as a command ("Do this", "Return that"), not as a description; e.g. don't write "Returns the pathname ...". A multiline-docstring for a function or method should summarize its behavior and document its arguments, return value(s), side effects, exceptions raised, and restrictions on when it can be called. Optional arguments should be indicated. It should be documented whether keyword arguments are part of the interface.
- The docstring for a **class** should summarize its behavior and list the public methods and instance variables. If the class is intended to be subclassed, and has an additional interface for subclasses, this interface should be listed separately. The class constructor should be documented in the docstring for its `_init_` method. Individual methods should be documented by their own docstring.
- Example docstring
- For consistency, always use `"""triple double quotes"""` around docstrings. Use `r"""raw triple double quotes"""` if you use any backslashes in your docstrings. For Unicode docstrings, use `u"""Unicode triple-quoted strings"""`.

```
def foo(var1, var2, long_var_name='hi') :
    r"""A one-line summary that does not use variable names or the
    function name.

    Several sentences providing an extended description. Refer to
    variables using back-ticks, e.g. `var`.

    Parameters
    -----
    var1 : array_like
        Array_like means all those objects -- lists, nested lists, etc. --
        that can be converted to an array. We can also refer to
        variables like `var1`.
    var2 : int
        The type above can either refer to an actual Python type
        (e.g. `int`), or describe the type of the variable in more
        detail, e.g. `(N,) ndarray` or `array_like`.
    long_var_name : {'hi', 'ho'}, optional
        Choices in brackets, default first when optional.

    Returns
    -----
    type
        Explanation of anonymous return value of type `type`.
    describe : type
        Explanation of return value named `describe`.
    out : type
        Explanation of `out`.

    Other Parameters
    -----
    only_seldom_used_keywords : type
        Explanation
    common_parameters_listed_above : type
        Explanation

    Raises
```

```

-----
BadException
    Because you shouldn't have done that.

See Also
-----
otherfunc : relationship (optional)
newfunc : Relationship (optional), which could be fairly long, in which
    case the line wraps here.
thirdfunc, fourthfunc, fifthfunc

Notes
-----
Notes about the implementation algorithm (if needed).

This can have multiple paragraphs.

You may include some math:

.. math:: X(e^{\{j\omega\}}) = x(n)e^{\{-j\omega n\}}

And even use a greek symbol like :math:`\omega` inline.

References
-----
Cite the relevant literature, e.g. [1]_. You may also cite these
references in the notes section above.

.. [1] O. McNoleg, "The integration of GIS, remote sensing,
    expert systems and adaptive co-kriging for environmental habitat
    modelling of the Highland Haggis using object-oriented, fuzzy-logic
    and neural-network techniques," Computers & Geosciences, vol. 22,
    pp. 585-588, 1996.

Examples
-----
These are written in doctest format, and should illustrate how to
use the function.

>>> a=[1,2,3]
>>> print [x + 3 for x in a]
[4, 5, 6]
>>> print "a\n\nb"
a
b

"""

pass

...

```

2.2.4 Comments

- Use complete sentences; if a comment is a phrase or sentence, its first word should be capitalized, unless it is an identifier that begins with a lowercase letter

- Use two spaces after a sentence-ending period
- Indent block comments to the same level as the code below; start each line of a block comment with a # and a single space (unless it is indented text inside the comment)
- Separate paragraphs inside a block comment by a line containing a single #

```
python # How does a mouse feel after it takes a shower? # Squeaky clean.  
# # How do you save a drowning mouse? # Use mouse to mouse resuscitation.  
not_your_cheese(marscapone, maasdam, camembert, roquefort) - Use inline comments  
sparingly
```

```
python not_your_cheese(gorgonzola, munster, limburg, doppelrhamstufel) # Not  
your cheese, my cheese.
```

2.2.5 Blank Lines

- Surround top-level function and class definitions with two blank lines
- Surround method definitions inside a class with a single blank line
- Use extra blank lines sparingly to separate groups of related functions; omit blank lines between related one-liners (e.g. a set of dummy implementations) if desired
- Use blank lines in functions sparingly to indicate logical sections

2.2.6 Whitespace

- Avoid extraneous whitespace:
- Immediately inside parentheses, brackets, or braces
- Immediately before a comma, semicolon, or colon
- Immediately before the open parenthesis that starts the argument list of a function call
- Immediately before the open parenthesis that starts an indexing or slicing
- More than one space around an assignment (or other) operator to align it with another
- Always surround these binary operators with a single space on either side: assignment (=), augmented assignment (+= , -= etc.), comparisons (== , < , > , != , <> , <= , >= , in , not in , is , is not), Booleans (and , or , not)
- If operators with different priorities are used, consider adding whitespace around the operators with the lowest priority(ies); never use more than one space, and always have the same amount of whitespace on both sides of a binary operator

```
python eyes = e + yes cyclops = eyes*4 - 3 c = (a+b) * (a-b) - Do not use spaces around  
the = sign when used to indicate a keyword argument or a default parameter value
```

```
```python
```

```
def not_your_cheese(cheese1=smelly, cheese2=stinky, cheese3=noxious, cheese4=bad) return my_cheese(r=real,
i=imag) """ - Avoid compound statements (multiple statements on the same line) - Never put an if/for/while with a
multi-clause statement on the same line
```

## 2.2.7 String Quotes

- Generally, use double-quotes for strings, but if a string contains a double-quote, then use single quotes
- Keep string quotes consistent for readability

## 2.2.8 Imports

- Put imports on separate lines, e.g.:

python import os import sys from subprocess import Popen, PIPE - Put imports at the top of the file, just after any module comments and docstrings, and before module globals and constants - Avoid wildcard imports ( from import \* ) as they make it unclear which names are present in the namespace, confusing both readers and many automated tools

## 2.2.9 Maximum Line Length

- Limit all lines to a maximum of 79 characters
- Use backslashes when implicit continuation fails

```
python with open("/why/did/the/chicken/cross/the/road") as
chicken, \ open("/to/get/to/the/other/side", "w") as waffles:
waffles.write(chicken.read())
```

For more information, please refer to: [Style Guide for Python Code](#) and [Docstring Guide](#)

## 2.3 Writing tests

We need to create unit tests for each module and test each function of the module.

### 2.3.1 An introductory example

Suppose we have a file called *data\_utils.py* with two functions *func1* and *func2*, we should have a corresponding test file called *test\_data\_utils.py* with two corresponding test functions called *test\_func1* and *test\_func2* and *data\_utils.py* imported.

- Note that we use *pytest* in our framework. Always import *pytest* at the top of the test file.
- Please follow the naming convention: *test\_\*.py* for test file and *test\_\** for test functions.

```
content of mousestyles/mousestyles/utils.py
def func1():
 return 3

def func2(x):
 return x + 1
```

```
content of mousestyles/mousestyles/tests/test_utils.py
from __future__ import (absolute_import,
 division, print_function,
 unicode_literals)

import pytest
```

```
from mousestyles.utils import func1, func2

def test_func1():
 assert f() == 3

def test_func2():
 assert func(3) == 4
```

## 2.3.2 Run all the tests for mousestyles

- For our mousestyles package, you can run all the tests with `make test`. Note that `make test` always run `make install`, thus you do not need to install beforehand.
- Run `make test-fast` for quicker (but less foolproof) development.
- If you want to look at the details, code for `make` command can be found [here](#).

## 2.3.3 Pytest: basic usage

Installation:

```
pip install -U pytest
```

Run all files in the current directory and its subdirectories of the form `test_*.py` or `*_test.py`:

```
$ py.test
```

Or you may run one test file with or without “quiet” reporting mode:

```
$ py.test test_data_utils.py
$ py.test -q test_data_utils.py
```

## 2.3.4 Pytest: writing and reporting of assertions

pytest allows you to use the standard python `assert` for verifying expectations and values. For example:

```
contents of example1.py
def f():
 return 3

def test_function():
 assert f() == 4
```

If we run `example1.py` using `py.test example1.py`, it will fail because the expected value is 4, but `f` return 3.

We can also specify a message with the assertion like this:

```
assert a % 2 == 0, "value was odd, should be even"
```

In order to write assertions about raised exceptions, you can use `pytest.raises` as a context manager like this:

```
import pytest

def test_zero_division():
 with pytest.raises(ZeroDivisionError):
```

```

1 / 0

def test_exception():
 with pytest.raises(Exception):
 x = 1 / 0

```

See [Built-in Exceptions](#) for more about raising errors.

If you need to have access to the actual exception info you may use:

```

def test_recursion_depth():
 with pytest.raises(RuntimeError) as excinfo:
 def f():
 f()
 f()
 assert 'maximum recursion' in str(excinfo.value)

```

Pytest also support expected warnings, see `pytest.warn`

For more about assertions, see [Assertions in pytest](#)

### 2.3.5 What aspects of a function need to be tested:

- check if it returns correct type of object
- check if it returns correct dimension
- check if it returns the correct value, by
  - prior knowledge
  - different implementation: i.e. use R vs Python; use  $Var(X)$  vs.  $E(X^2) - E(X)^2$
  - theoretical derivation
- “regression”: if the function is improved (by speed, efficiency) while has same functionality, check the output is the same with older version.
- assert errors occurred: i.e. when the function takes three arguments while we only give two, make sure the function will throw an error message

### 2.3.6 Reference

Most example above comes from Pytest documentation. See [Pytest Documentation](#) for more detail.

## 2.4 Set up SSH key

SSH, also known as Secure Socket Shell, is a network protocol that provides us with a secure way to access a remote computer. Once you set up your SSH key and add it to your Github account, you don't have to type username and password when you push your commits to the remote repository.

#### 1. Checking for existing SSH keys:

- Go to your local repository and check whether you have SSH key or not:

```
ls -al ~/.ssh
```

- If you already have the SSH key, you will see the one of the following filenames for the public SSH key:

- id\_rsa.pub, id\_ecdsa.pub, id\_ed25519.pub, or id\_rsa.pub

- If you don't see SSH key or don't want to use the one you have, you can generate a new one (see 2).

## 2. Generating a new SSH key and adding it to the ssh-agent:

- Generate a SSH key:

```
ssh-keygen -t rsa -b 4096 -C "your_email@example.com"
```

- After you paste the above command to the terminal, you will get the following message:

- Enter a file in which to save the key (/Users/you/.ssh/id\_rsa) Hit enter to continue.
- Enter passphrase (empty for no passphrase) Add passphrase if you want; otherwise, hit enter to continue.
- Enter same passphrase again Type the passphrase again or hit enter to continue.

- You will see:

- Your identification has been saved in /home/oski/.ssh/id\_rsa.
- Your public key has been saved in /home/oski/.ssh/id\_rsa.pub., which means that you have SSH key now!

- Add it to the ssh-agent:

```
eval $(ssh-agent -s)
ssh-add ~/.ssh/id_rsa
```

- Now, you are ready to add the SSH key to Github.

## 3. Adding a new SSH key to your Github account:

- Copy the SSH key to your clipboard:

```
clip < ~/.ssh/id_rsa.pub
```

- Or you can use and copy the output:

```
cat ~/.ssh/id_rsa.pub
```

- Go to Github and click your profile in the top-right corner.
- Click the SSH and GPG keys on the right panel and click New SSH key.
- Give a label to this SSH key, paste the key into Key field and click Add SSH key.

## 4. Testing your SSH connection:

- Enter:

```
ssh -T git@github.com
```

- You will see

- The authenticity of host 'github.com (192.30.252.1)' can't be established. RSA key fingerprint is 16:27:ac:a5:76:28:2d:36:63:1b:56:4d:eb:df:a5:46:40:26:a1:45:41 Are you sure you want to continue connecting (yes/no)?

- Type yes and you should see:

- Hi username! You've successfully authenticated, but GitHub does not provide shell access.



#### 5. Switching remote URLs from HTTPS to SSH:

- Since you probably already add your remote URL using HTTPS (check by `git remote -v`, you need to change it into SSH:

```
git remote set-url origin git@github.com:USERNAME/OTHERREPOSITORY.git
```

- You can verify again by `git remote -v` and next time you push your commits to the origin, you don't have to type username and password anymore!

For more detailed discussion, read [SSH key documentation](#) on Github.



## API REFERENCE

### 3.1 Data

`mousestyles.data.distances (strain, mouse, day, step=50)`

Return a numpy array object of project movement data for the specified combination of strain, mouse and day.

At regular timesteps, defined by the step parameter, compute the euclidian distance between the positions of the mouse at two consecutive times.

More specifically:

- let  $\Delta t$  be the step parameter.
- let  $t_n$  be the sequence of non negative numbers such that  $t_0 = 0$  and  $t_{(n+1)} = t_n + \Delta t$ . The sequence is defined for all  $n$  such that  $n \geq 0$  and  $t_n \leq \text{time of the experiment}$
- let  $d_n$  be the sequence of non negative numbers such that  $d_0 = 0$  and  $d_n$  equals the position of the mouse at a particular day at time  $t_n$ .  $d_n$  is then defined on the same set of integers as the sequence  $t_n$ .
- The function returns the sequence  $d_n$ .

#### Parameters

- **strain** (*int*) – nonnegative integer indicating the strain number
- **mouse** (*int*) – nonnegative integer indicating the mouse number
- **day** (*int*) – nonnegative integer indicating the day number
- **step** (*float*) – positive float defining the time between two observations default corresponds to 1 second

#### Returns movement

**Return type** numpy array

#### Examples

```
>>> dist = distances(0, 0, 0, step=1e2)
```

`mousestyles.data.distances_bymouse (strain, mouse, step=50, verbose=False)`

Aggregates ‘distances’ for all days of recorded data for one particular mouse.

More specifically:

- let  $d^1, \dots, d^D$  be the sequence of distances for one particular mouse for days 1 to  $D$ .
- The function returns the concatenation of the  $d^i$ .

### Parameters

- **strain** (*int*) – nonnegative integer indicating the strain number
- **mouse** (*int*) – nonnegative integer indicating the mouse number
- **step** (*float*) – positive float defining the time between two observations default corresponds to 1 second

### Returns movement

**Return type** numpy array

### Examples

```
>>> dist = distances_bymouse(0, 0, step=1e2)
```

`mousestyles.data.distances_bystrain(strain, step=50, verbose=False)`

Aggregates `distances_bymouse` for all mice in one given strain.

More specifically:

- let  $d^1, \dots, d^M$  be the sequence of distances for one particular strain for mice 1 to  $M$ .
- The function returns the sequence concatenation of the  $d^i$ .

### Parameters

- **strain** (*int*) – nonnegative integer indicating the strain number
- **step** (*float*) – positive float defining the time between two observations default corresponds to 1 second

### Returns movement

**Return type** numpy array

### Examples

```
>>> dist = distances_bystrain(0, step=1e2)
```

`mousestyles.data.load_all_features()`

Returns a (21131, 13) size `pandas.DataFrame` object corresponding to 9 features over each mouse's 2-hour time bin. The first four columns index each mouse's 2-hour bin:

Column 0: the strain of the mouse (0-15) Column 1: the mouse number (number depends on strain) Column 2: the day number (5-16) Column 3: the 2-hour time bin (e.g., value 4 corresponds to hours 4 to 6)

The remaining 9 columns are the computed features.

**Returns features\_dataframe** – A dataframe of computed features.

**Return type** `pandas.DataFrame`

`mousestyles.data.load_intervals(feature)`

Return a `pandas.DataFrame` object of project interval data for the specified feature.

There are 5 columns in the dataframe: strain: the strain number of the mouse mouse: the mouse number in its strain day: the day number start: the start time stop: the stop time

**Parameters feature** (`{"AS", "F", "IS", "M_AS", "M_IS", "W"}`) –

**Returns intervals** – All data of the specified feature as a dataframe

**Return type** pandas.DataFrame

### Examples

```
>>> AS = load_intervals('AS')
>>> IS = load_intervals('IS')
```

`mousestyles.data.load_mouseday_features` (*features=None*)

Returns a (1921, 3+11\*n) size pandas.DataFrame object corresponding to each 2-hour time bin of the n inputted features over each mouse. The first three columns index each mouse:

Column 0: the strain of the mouse (0-15) Column 1: the mouse number (number depends on strain) Column 2: the day number (5-16)

The remaining 3\*n columns are the values for each 2-hour time bin of the n inputted features.

**Parameters** *features* (*list, optional*) – A list of one or more features chosen from {"AS-Probability", "ASNumbers", "ASDurations", "Food", "Water", "Distance", "ASFoodIntensity", "ASWaterIntensity", "MoveASIntensity"} Default all features when optional

**Returns** *features\_data\_frame* – A dataframe of computed features.

**Return type** pandas.DataFrame

### Examples

```
>>> mouseday = load_mouseday_features()
>>> mouseday = load_mouseday_features(["Food"])
>>> mouseday = load_mouseday_features(["Food", "Water", "Distance"])
```

`mousestyles.data.load_movement` (*strain, mouse, day*)

Return a pandas.DataFrame object of project movement data for the specified combination of strain, mouse and day.

There are 4 columns in the dataframe: t: Time coordinates (in seconds) x: X coordinates indicating the left-right position of the cage y: Y coordinates indicating the front-back position of the cage isHB: Boolean indicating whether the point is in the home base or not

#### Parameters

- **strain** (*int*) – nonnegative integer indicating the strain number
- **mouse** (*int*) – nonnegative integer indicating the mouse number
- **day** (*int*) – nonnegative integer indicating the day number

**Returns** *movement* – CT, CX, CY coordinates and home base status of the combination of strain, mouse and day

**Return type** pandas.DataFrame

### Examples

```
>>> movement = load_movement(0, 0, 0)
>>> movement = load_movement(1, 2, 1)
```

```
mousestyles.data.load_movement_and_intervals(strain, mouse, day, features=['AS', 'F',
 'IS', 'M_AS', 'M_IS', 'W'])
```

Return a pandas.DataFrame object of project movement and interval data for the specified combination of strain, mouse and day.

There are 4 + len(features) columns in the dataframe: t: Time coordinates (in seconds) x: X coordinates indicating the left-right position of the cage y: Y coordinates indicating the front-back position of the cage isHB: Boolean indicating whether the point is in the home base or not Additional columns taking their names from features: Boolean indicating whether the time point is in an interval of behavior of the given feature.

#### Parameters

- **strain** (*int*) – nonnegative integer indicating the strain number
- **mouse** (*int*) – nonnegative integer indicating the mouse number
- **day** (*int*) – nonnegative integer indicating the day number
- **features** (*list (or other iterable) of strings*) – list of features from {"AS", "F", "IS", "M\_AS", "M\_IS", "W"}

**Returns movement** – coordinates, home base status, and feature interval information for a given strain, mouse and day

**Return type** pandas.DataFrame CT, CX, CY

#### Examples

```
>>> m1 = load_movement(1, 1, 1)
>>> m2 = load_movement_and_intervals(1, 1, 1, []) # don't add any features
>>> np.all(m1 == m2)
True
>>> m3 = load_movement_and_intervals(1, 1, 1, ['AS'])
>>> m3.shape[1] == m1.shape[1] + 1 # adds one column
True
>>> m3.shape[0] == m1.shape[0] # same number of rows
True
>>> m3[29:32]
```

	t	x	y	isHB	AS
29	56448.333	-6.289	34.902	False	False
30	56448.653	-5.509	34.173	True	True
31	56449.273	-5.048	33.284	True	True

```
mousestyles.data.load_start_time_end_time(strain, mouse, day)
```

Returns the start and end times recorded for the mouse-day. The first number indicates the number of seconds elapsed since midnight, the second number indicates when the cage is closed for cleaning. In other words, this is the interval for which all sensors are active.

#### Parameters

- **strain** (*int*) – nonnegative integer indicating the strain number
- **mouse** (*int*) – nonnegative integer indicating the mouse number
- **day** (*int*) – nonnegative integer indicating the day number

**Returns times** – the start time and end time

**Return type** a tuple of (float, float)

## INDICES AND TABLES

- `genindex`
- `modindex`
- `search`





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## D

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