

The manual of *LabGym* (v2.1)

1. Installation of *LabGym* (<https://github.com/umyelab/LabGym>)¹

- a. Download Python3 ² (version $\geq 3.9.7$) from its official website

(<https://www.python.org/downloads/>).

Not to download the latest version of Python3 as some Python libraries used in *LabGym* might not be updated yet to be compatible with the latest version of Python3.

- b. Open the Terminal (Mac) or Command Prompt (Windows), type:

```
python3 -m pip install LabGym
```

- c. After *LabGym* is installed, if you want to use its Detectors, the Detectron2 ³

(<https://github.com/facebookresearch/detectron2>) needs to be installed separately. To do so, type:

```
python3 -m pip install 'git+https://github.com/facebookresearch/detectron2.git'
```

for Windows user, you may type:

```
python3 -m pip install git+https://github.com/facebookresearch/detectron2.git
```

If encounter issues when installing Detectron2, please refer to its documentation page

(<https://detectron2.readthedocs.io/en/latest/tutorials/install.html>).

2. Initiate the graphical user interface (GUI) of *LabGym* for each use

- a. Open the Terminal (Mac) or Command Prompt (Windows), activate Python3 interactive shell by typing:

```
python3
```

- b. After the Python3 interactive shell is activated, type:

```
from LabGym import gui
```

- c. After the importing is done, then type:

1 gui.gui()

2 Now the GUI of *LabGym* is initiated and is ready to use.

4 **3. Extended guide on using the GUI of *LabGym***

5 *Put your mouse cursor above each button to see a detailed description for it.*

7 **3.1. 'Preprocessing Module'**

8 Preprocess your videos to make them more appropriate for analysis.

10 **3.1.1. 'Preprocess Videos'**

11 Use this to enhance contrast of the videos, crop frames to exclude unnecessary regions, or trim
12 the videos to only keep necessary time windows.

14 (Button) 'Specify whether to enter time windows to form a trimmed video'

15 When trimming videos, if you want to set different time windows for different videos, use
16 code '_stt_' and '_edt_' in the filename of a video, replacing the last 't' with the start ('st') time
17 point and end ('ed') time point. For example, 'XX_st10_ed20.avi' (the '_' is unnecessary if it is at
18 the end of file name) means the trimming will start at the 10th second and end at the 20th
19 second. You can set multiple time windows for a video, just use multiple '_stt_' and '_edt_'
20 following the time sequence.

22 **3.2. 'Training Module'**

23 The first three buttons in this module can be used to train Detectron2-based

24 (<https://github.com/facebookresearch/detectron2>)³ Detectors, which is the way to teach *LabGym*
25 to recognize animals / objects of your interest. There are two detection methods in *LabGym*.

26 One is the Detector-based, which is slow but versatile in any recording settings. It is also useful

for distinguishing individuals when they have close body contact. The other detection method is background subtraction-based, which is much faster but requires the background to be static and illumination to be stable in a video. This method is your first choice if the videos meet the criteria. Note that this method cannot distinguish individuals when they have body contact and may not be useful for analyzing interactive behaviors when the individual identities are critical.

The last three buttons can be used to train Categorizers, which is the way to teach *LabGym* to recognize behaviors that are defined by you.

3.2.1. 'Generate Image Examples'

To train Detectors, you need to provide training images in which the outlines of animals / objects of your interest are precisely labeled. But first, you need to generate some image examples (extract some frames from videos).

3.2.2. 'Annotate images with Roboflow'

After images are generated, you need to annotate them to train a Detector. The annotation is to label the outline of the animals / objects of your interest. You can do this by using online annotation tools such as Roboflow (<https://roboflow.com>) or CVAT (<https://www.cvat.ai>) or VGG Image Annotator (<https://www.robots.ox.ac.uk/~vgg/software/via/>). Roboflow is recommended because it is easy to use. When annotated images, make sure to select "Instance Segmentation" for the annotation type. When export the annotation file, make sure to select "COCO instance segmentation" format, which will be a "*.json" file.

Typically, 50~150 annotated images are enough for training a Detector with high accuracy. If you use 'Interactive advanced' mode, include images in which animals / objects have close body contact and annotate their outlines well especially in the boundary regions. Individuals' identify-switching can be avoided by including most colliding scenarios in the training images.

3.2.3. 'Train Detectors'

Trained Detectors will be stored in the Detector list in *LabGym* and ready to use.

(Button) 'Specify the inferencing framesize for the Detector to train'

It determines the speed-accuracy trade-off of Detector performance. You can try large size such as 960 or above GPUs are used. If you don't use a GPU, start with small size such as 256 and increase the size if the accuracy is not ideal. If there are many animals / objects to detect in one frame, and they are relatively small compared with the entire frame, you may use larger inferencing size such as 640 or higher. If there is only one animal / object and it occupies large area of the frame, use smaller size such as 320 for faster processing speed. For general scenarios, size that is smaller than 192 or larger than 1600 is not recommended.

3.2.4. 'Generate Behavior Examples'

To teach *LabGym* to recognize behaviors that are defined by you, you need to use sorted behavior examples to train a Categorizer. But first, you need to generate some behavior examples and sort them. **DO NOT** change the file names for the generated behavior examples since they contain the key information for later training steps and the function of 'Sort Behavior Examples' will also be based on these file names.

(Button) 'Specify the mode of behavior examples to generate'

There are 2 modes of interactive behaviors that *LabGym* can generate examples and analyze. "Interactive basic" is faster in analysis and is useful in the scenario when you don't care about which individual does what in an interaction, or all the individuals do the same behavior in an interaction. It analyzes the behaviors of all animals / objects in an interactive pair / group as one and does not distinguish individuals. The behavior examples for this mode

contain all the animals in a frame. The behavioral quantifications in this mode are behavior count, behavior latency and behavior duration.

The “Interactive advanced” is slower in analysis than “basic”, but it distinguishes individuals during close body contact. It can tell which animal does what in an interaction. The behavior examples for this mode contain all “characters” within a “social distance” defined by you, with a spotlight on the main character. The social distance should be an integer, for example, if enter “2”, all animals / objects whose distance from others is within “2 folds of the square root of an averaged animal area” will be included in one behavior example. You can do a rough estimation. If enter “0”, the social distance is set to be infinity and all the animals in a frame will be included. When annotate such examples, you annotate the behavior of the main character. The behavioral quantifications in this mode are behavior count, behavior latency, behavior duration, 3 length parameters, 3 areal parameters, and 4 locomotion parameters.

(Button) ‘Specify the method to detect animals or objects’

There are two options: ‘*Subtract background*’ and ‘*Use trained Detectors*’

‘*Subtract background*’ is the first choice for videos in which the background is static, the illumination is stable overtime, and the total behavior events are more important than animal IDs, because this method is fast and accurate in such videos but cannot distinguish entangled animals and the IDs might switch after they re-separate. When using this method, you need to specify the scenarios of their experiments: ‘*Animal brighter than background*’, ‘*Animal darker than background*’, or ‘*Hard to tell*’. A pop-up option ‘(Optional) load existing background?’ will need to be specified. *LabGym* will output the extracted backgrounds (as images) for each video processed. Therefore, this pop-up option can be used to save the step of background extraction if the background for this video has already been extracted and output. You also need to specify whether the illumination in videos is unstable. If the illumination is very stable overtime, choose ‘No’ to increase the processing speed. Finally, you need to specify a time window for

background extraction. An appropriate time window for background extraction should be a period (typically 10~60 seconds) during which the animals move around. This time window should be as short as possible for increasing processing speed. There are 3 options to specify this time window: (1) '*Use the entire duration of a video*': not recommended if processing speed is critical. (2) '*Decode from filenames: _xst_ and _xet_*': can be used if multiple videos are selected and the time window for background extraction is different for each video. Two code tags '*_xst_ and _xet_*' ('xs' stands for 'extraction start time', 'xe' stands for 'extraction end time', and 't' should be an integer) need to be added into the file name of each video to let *LabGym* decode the time window. For example, if a video name is 'XX.avi', to set the time window for background extraction from the 25th second to the 47th second, rename the video to 'XX_xs25_xe47.avi' (the '_' is unnecessary if it is at the end of file name). (3) '*Enter two time points*': can be used if only one video is selected, or multiple videos share the same time window for background extraction.

'*Use trained Detectors*' is useful in any kind of videos or experimental settings. It is also useful for differentiate individual animals when they entangle. The only caveat of this method is slow.

(Button) 'Specify when generating behavior examples should begin (unit: second)'

- (Pop-up option) 'Illumination shifts?'

This option is only for background subtraction-based detection method. It is useful when there are sudden bright-to-dark or dark-to-bright illumination transitions in videos. If choose 'Yes', there will be 3 options to specify the beginning time: '*Automatic (for light on and off)*', '*Decode from filenames: _bt_*', and '*Enter a time point*'. If choose 'No', only the latter two options can be chosen.

1 *'Automatic (for light on and off)'* is for videos involving lighting on and off (e.g., optogenetics)
2 and the first time point of illumination change will be automatically detected and used as the
3 beginning time to generate behavior examples.

4 *'Decode from filenames: _bt_'* can be used if multiple videos are selected and the beginning
5 time for each video is different. You need to add a code tag '*_bt_*' ('b' stands for 'beginning time'
6 and 't' should be number) into the file name of each video to let *LabGym* decode the beginning
7 time. For example, if a video name is 'XX.avi', to set the beginning time at the 12.35 second,
8 rename the video to 'XX_b12.35.avi' (the '*_*' is unnecessary if it is at the end of file name).

9 *'Enter a time point'* can be used if only one video is selected, or multiple videos share the
10 same beginning time.

12 (Button) 'Specify the number of animals in a video'

13 There are two options: *'Decode from filenames: _nn_'* and *'Enter the number of animals'*.

14 *'Decode from filenames: _nn_'* can be used if multiple videos are selected and the number
15 of animals in each video is different. A code tag '*_nn_*' (the first 'n' stands for 'number of
16 animals' and the second 'n' should be an integer) needs to be added into the file name to let
17 *LabGym* decode the animal number. For example, if a video name is 'XX.avi', to set the number
18 of animals in this video as 8, rename the video to 'XX_n8.avi' (the last '*_*' is unnecessary if it is
19 at the end of file name). If there are multiple kinds of animals / objects in the videos to detect,
20 you can put in multiple '*_nn_*' code. The order should be consistent with that of the 'animal /
21 object name' in the Detector to use (when you select a Detector, the animal / object name will
22 display in order, and you can also specify which ones to detect).

23 *'Enter the number of animals'* can be used if only one video is selected, or multiple videos
24 share the same animal number.

26 (Button) 'Specify the number of frames for an animation / pattern image'

The animations and their paired pattern images in the behavior examples spans a duration (the number of frames, an integer) defined by you, which should approximate the duration of a behavior episode. This duration needs to be the same across all the behavior examples that are used to train one Categorizer. If the duration of different behavior episode is different, use the longest one.

(Button) 'Specify how many frames to skip when generating two consecutive behavior examples'

LabGym generates a pair of behavior example which spans a user-defined duration at a frame. If two consecutively generated examples are too close in time, say, one generated at the 10th frame and the other at 12th frame, suppose their duration is 10 frames, they will have 8 overlapping frames. These two behavior examples are too similar and will impair the training efficiency when training a Categorizer. Generating too many such similar examples will also make the example sorting laborious. Therefore, you can choose to skip certain frames between the two consecutively generated examples. A practical recommendation to achieve a balance between getting the perfect examples that just span the behavior episode and reducing the labor is to set this number equal to the duration you set for a behavior episode.

(Button) 'Start to generate behavior examples'

- (Pop-up option) 'Including background?'

Choose 'No' if the background information is behavior irrelevant.

- (Pop-up option) 'Including body parts?'

Choose 'Yes' if the motion pattern of individual body parts such as limbs or noses are critical for behavioral identification. If choose 'Yes', a 'STD' need to be entered, which should be an integer between 0 and 255. The STD value decides the threshold to show the how many

1 'motion pixels' of the body parts in the pattern images. Lager STD, less motion pixels will be
2 shown.

4 **3.2.5. 'Sort Behavior Examples'**

5 The behavior examples need to be sorted into different folders according to the behavior types
6 they belong to. This is the way how you teach *LabGym* the behaviors defined by you. You can
7 select a number of behavior examples and move them into a folder, or use this button to
8 visualize each behavior example one by one and sort them using shortcut keys. The more
9 behavior examples for each behavior type are included, the higher accuracy of the trained
10 Categorizer; the more diverse (let the Categorizer see as many variations of each behavior type
11 as possible), the higher accuracy of the trained Categorizer. For general scenarios, 100~200
12 pairs of behavior examples for each behavior type are enough for training a Categorizer with
13 high accuracy.

14 Importantly, when you define behavior categories, make the list of categories as complete
15 as possible. For example, if there are 'A', 'B', 'C', and 'D', 4 types of behaviors showing
16 frequently in all experimental sessions, and you only sort behavior 'A' and 'C' because they are
17 the behaviors of your interest. After training, the Categorizer knows there are only behavior 'A'
18 and 'C' in its world and when it sees type 'B' during analysis, it will forcibly categorize the 'B' into
19 'A' or 'C', based on how similar 'B' is to 'A' or 'C'. If a behavior type happens in a low frequency
20 in all experimental sessions, then you don't need to include it since it will not affect the
21 categorization accuracy too much.

22 The behavior examples within the same behavior category should share similar features or
23 patterns that can be visually identified, while those among different behavior categories should
24 possess visually distinguishable features or patterns. *LabGym* distinguishes behavior examples
25 based on visually identifiable features or patterns in them without knowing additional information

from other sources. So, if you cannot distinguish two behavior examples by just watching them, then *LabGym* will not be able distinguish them either.

3.2.6. 'Train Categorizers'

There are two parts: one is for preparing the training examples; the other is for using the prepared training examples to train a Categorizer. The Categorizers are the core of *LabGym*, which identifies behaviors defined by you during analysis. Trained Categorizers will be stored in the Categorizer list in *LabGym* and ready to use. The complexity of Categorizer is customizable. It takes some trial and errors to find the best setting that perfectly fits your behavioral data.

(Button) 'Specify the type / complexity of the Categorizer to train'

- (Pop-up option) 'Categorizer types'

If the processing speed is critical to you, choose the Categorizer with only Pattern Recognizer. If you want to maximize the analysis accuracy and care less about the analysis speed, choose the Categorizer with both Animation Analyzer and Pattern Recognizer.

- (Pop-up option) 'Complexity level'

There are 7 complexity levels (1~7, from simpler to more complex) of either Animation Analyzer or Pattern Recognizer. You can start with simpler levels like 1 ~ 3 and go more complex if the accuracy is not ideal. If the Animation Analyzer is gray scale (animal / object color is behavior irrelevant), you can make the complexity levels of Pattern Recognizer a little higher than that of Animation Analyzer because the Pattern Recognizer analyzes pattern images containing additional color information, which indicates the temporal sequence of a behavior.

- (Pop-up option) Behavior mode'

You need to indicate which mode of behavior examples are used for training the Categorizer. For "Interact basic" and "Interact advanced" behavior examples, you can find the mode information in the filenames of the behavior examples. "_itbs" is "Interact basic" and

“_itadv” is “Interact advanced”. If the behavior mode is “Interact advanced”, you also need to specify a social distance, which can also be found in the filenames of the behavior examples with “_scdtXX_” where “XX” is the number you need to enter for the social distance.

(Button) 'Specify the input shape for Animation Analyzer / Pattern Recognizer'

You can start with the smaller input frame / image sizes such as 16 or 32. If there are many detailed appearance features in the frames that are behavior relevant, go larger size such as 64 or 96 or even 128. And always go deeper (increase complexity level) first, rather than go wider (increase input frame / image size) first.

- (Pop-up option) 'Grayscale Animation Analyzer?'

Choose 'Yes' if the color of animals is behavior irrelevant.

(Button) 'Specify the methods for data augmentation'

Briefly, '*rotation*' will rotate the animal blobs; '*flipping*' will flip the animal blobs; '*brightening*' and '*dimming*' will increase and decrease the brightness of the animal blobs; '*shearing*' will distort the animal blobs; '*rescaling*' will change the width / height ratio of the animal blobs; '*deletion*' will delete one or two frames in the animations (mimic the scenario in which animals are not detected in one or two frames during analysis).

- (Pop-up option) 'Use default augmentation?'

Default augmentation will use '*rotation*', '*flipping*', '*brightening*' and '*dimming*'.

- (Pop-up option) 'Augment validation data?'

If the total number of behavior example pairs used for training a Categorizer is less than 1,000 before augmentation, choose “Yes” for this option.

3.3. 'Analysis Module'

1 Automatically track animals / objects of your interest, identify and quantify their behaviors in
2 videos, and automatically mine the analysis results to display the data details that show
3 statistically significant differences among groups of your selection.

5 **3.3.1. 'Analyze Behaviors'**

6 Will output a raster plot for all behavior events for all videos, an annotated video copy for each
7 video, various spreadsheets storing quantification results for each selected behavior parameter.

8
9 (Button) 'Select a Categorizer for behavior classification'

10 Choose a Categorizer for behavior classification in analysis, or just let *LabGym* track the
11 animals and calculate their motion parameters and body kinematics. If the former, you need to
12 specify a 'Uncertainty level' for the Categorizer. This number in percentage determines the
13 threshold for the Categorizer to output an 'NA' for behavioral classification. For example, when
14 the probabilities of behavior A, B, and C are 60%, 10%, and 30%, respectively. If the uncertain
15 level is set to be 31, the behavior classification will be 'NA', as the uncertainty level exceeds the
16 difference between probability of the highest-likely behavior (A, 60%) and the second highest-
17 likely behavior (C, 30%), which is 30%. Setting uncertainty level can reduce the possible false
18 positives in behavior classification since ambiguous classification will be output as an 'NA'.
19 Higher uncertainty level, higher precision but more false negatives at the same time. If choose
20 to not classify behaviors, you need to specify a time window for calculating the motion
21 parameters and body kinematics.

22
23 (Button) 'Select the video(s) for behavior analysis'

- 24 • (Pop-up option) '(Optional) resize the frames?'

25 Downsizing the frame will exponentially increase the analysis speed. This is **highly**
26 **recommended** especially when using Detector-based detection method and GPUs are not

1 available. The analysis accuracy will not decline if the animal size after downsizing is still larger
2 than the input size of the Categorizer used for analysis. For example, suppose the original size
3 of a video frame is 1000 x 500, the size of an animal is approximately 1/4 to that of a frame, and
4 input size of the Categorizer is 48 x 48. After downsizing the video frames to 500 x 250, the
5 animal size is roughly 125 x 63 and still is larger than the input size of the Categorizer (48 x 48).
6 In this scenario, the analysis accuracy will not decline since the animal blob will be downsized to
7 48 x 48 anyway when input to the Categorizer for analysis.

8
9 (Button) 'Specify the method to detect animals or objects'

10 There are two options: '*Subtract background*' and '*Use trained Detectors*'

11 '*Subtract background*' is the first choice for videos in which the background is static, the
12 illumination is stable overtime, and the total behavior events are more important than animal
13 IDs, because this method is fast and accurate in such videos but cannot distinguish entangled
14 animals and the IDs might switch after they re-separate. When using this method, you need to
15 specify the scenarios of their experiments: '*Animal brighter than background*', '*Animal darker*
16 *than background*', or '*Hard to tell*'. A pop-up option '(Optional) load existing background?' will
17 need to be specified. *LabGym* will output the extracted backgrounds (as images) for each video
18 processed. Therefore, this pop-up option can be used to save the step of background extraction
19 if the background for this video has already been extracted and output. You also need to specify
20 whether the illumination in videos is unstable. If the illumination is very stable overtime, choose
21 'No' to increase the processing speed. Finally, you need to specify a time window for
22 background extraction. An appropriate time window for background extraction should be a
23 period (typically 10~60 seconds) during which the animals move around. This time window
24 should be as short as possible for increasing processing speed. There are 3 options to specify
25 this time window: (1) '*Use the entire duration of a video*': not recommended if processing speed
26 is critical. (2) '*Decode from filenames: _xst_ and _xet_*': can be used if multiple videos are

selected and the time window for background extraction is different for each video. Two code tags ‘_xst_ and _xet_’ (‘xs’ stands for ‘extraction start time’, ‘xe’ stands for ‘extraction end time’, and ‘t’ should be an integer) need to be added into the file name of each video to let *LabGym* decode the time window. For example, if a video name is ‘XX.avi’, to set the time window for background extraction from the 25th second to the 47th second, rename the video file to ‘XX_xs25_xe47.avi’ (the ‘_’ is unnecessary if it is at the end of file name). (3) ‘*Enter two time points*’: can used if only one video is selected, or multiple videos share the same time window for background extraction.

‘*Use trained Detectors*’ is useful in any kind of videos or experimental settings. It is also useful for differentiate individual animals when they entangle. The only caveat of this method is slow.

(Button) ‘Specify when the analysis should begin (unit: second)’

- (Pop-up option) ‘Illumination shifts?’

Specify whether there are sudden bright-to-dark or dark-to-bright illumination transitions. If choose ‘Yes’, there will be 3 options to specify the beginning time: ‘*Automatic (for light on and off)*’, ‘*Decode from filenames: _bt_*’, and ‘*Enter a time point*’. If choose ‘No’, only the latter two options can be chosen.

‘*Automatic (for light on and off)*’ is for videos involving lighting on and off (e.g., optogenetics) and the first time point of illumination change will be automatically detected and used as the beginning time to generate behavior examples.

‘*Decode from filenames: _bt_*’ can be used if multiple videos are selected and the beginning time for each video is different. You need to add a code tag ‘_bt_’ (‘b’ stands for ‘beginning time’ and ‘t’ should be number) into the file name of each video to let *LabGym* decode the beginning time. For example, if a video name is ‘XX.avi’, to set the beginning time at the 12.35 second, rename the video file to ‘XX_b12.35.avi’ (the ‘_’ is unnecessary if it is at the end of file name).

1 *'Enter a time point'* can be used if only one video is selected, or multiple videos share the
2 same beginning time.

3
4 (Button) 'Specify the analysis duration (unit: second)'

5
6 (Button) 'Specify the number of animals in a video'

7 There are two options: *'Decode from filenames: _nn_'* and *'Enter the number of animals'*.

8 *'Decode from filenames: _nn_'* can be used if multiple videos are selected and the number
9 of animals in each video is different. A code tag *'_nn_'* (the first 'n' stands for 'number of
10 animals' and the second 'n' should be an integer) needs to be added into the file name to let
11 *LabGym* decode the animal number. For example, if a video name is 'XX.avi', to set the number
12 of animals as 8, rename the video to 'XX_n8.avi' (the last '_' is unnecessary if it is at the end of
13 file name). If there are multiple kinds of animals / objects in the videos to detect, you can put in
14 multiple *'_nn_'* code. The order should be consistent with that of the 'animal / object name' in
15 the Detector to use (when you select a Detector, the animal / object name will display in order,
16 and you can also specify which ones to detect).

17 *'Enter the number of animals'* can be used if only one video is selected, or multiple videos
18 share the same animal number.

19
20 (Button) 'Select the behaviors for annotations and plots'

- 21 • (Pop-up option) Specify individual-specific behaviors?

22 If the selected Categorizer is for "Interactive advanced" mode, you can select individual
23 specific behaviors to initiate the "behavior-guided" identity correction. For example, behavior A
24 only occurs in a specific individual whose initial ID is "0", if its ID switches with another individual
25 (e.g., ID "1") because of false detection in a frame, after that, when behavior A occurs, its ID will

switch back to “0” because behavior A only occurs in this specific individual “0”. In this way, this individual “0” can correctly maintain its ID during the entire analysis period.

- (Pop-up option) 'Specify colors for behaviors?'

Specify a color to represent a behavior category in the annotated videos and the raster plot for behavior events. In the annotated videos, the value of % confidence of behavior categorization will be shown; in the raster plot, the color intensity indicates the value of % confidence, from 0% of the color intensity (clear) indicating 0% of the confidence, to 100% of the color intensity indicating 100% of the confidence. If choose not to specify the colors, *LabGym* will use the default colors to represent the behaviors.

- (Pop-up option) 'Legend in video?'

Specify whether to show the legend of behavior names in the annotated videos.

(Button) 'Select the quantitative measurements for each behavior'

There are 13 quantitative measurements (parameters) for each behavior for you to choose:

- ◇ The *count* is the summary of the behavioral frequencies, which is the occurrence number of a behavior within the entire duration of analysis. Consecutive single occurrences (at a single frame) of the same behavior are considered as one count.
- ◇ The *latency* is the summary of how soon a behavior starts, which is the time starting from the beginning of the analysis to the time point that the behavior occurs for the first time.
- ◇ The *duration* is the summary of how persistent a behavior is, which is the total time of a behavior within the entire duration of analysis.
- ◇ The *speed* is the summary of how fast the animal moves when performing a behavior, which is the total distance traveled (can be back and forth) (d) (between the two centers of mass of the animal) during the time window (t_w) for categorizing the behavior divided by t_w .
- ◇ The *velocity* is the summary of how efficient the animal's movement is when performing a behavior, which is the shortest distance between the start and the end positions (dt)

(between the two centers of mass of the animal) divided by the time (t) that such displacement takes place.

◇ The *acceleration / velocity reduction* is the summary of how fast the animal's velocity changes while performing a behavior, which is the difference between maximum velocity (v_{max}) and minimum velocity (v_{min}) divided by the time (t_v) that such velocity change takes place.

◇ The *distance* is the total distance traveled of the animal by performing a behavior within the entire duration of analysis.

◇ The *intensity (area) / intensity (length)* is the summary of how intense a behavior is, which is the accumulated proportional changes of the animal body area (a) / length (l) between frames divided by the time window for categorizing the behaviors (t_w) when performing a behavior.

◇ The *magnitude (area) / magnitude (length)* is the summary of the motion magnitude, which is the maximum proportional change in animal body area (a) or length (l) when performing a behavior.

◇ The *vigor (area) / vigor (length)* is the summary of how vigorous a behavior is, which is the magnitude (area) / magnitude (length) divided by the time (t_a or t_l) that such a change takes place.

Details on how they are calculated are in *LabGym* paper ¹.

- (Pop-up option) 'Normalize the distances?'

If choose 'No', all the distances will be output in pixels. The unit of all the distance related measurements will be 'pixel' or pixel related. If choose 'Yes', all the distances (calculated in pixels) will be normalized to (divided by) the size of a single animal (also calculated in pixels). In this scenario, all distance related measurements will be normalized measurements (e.g., normalized speed) and will not have a unit. In this way, you do not need to worry about the ratio of pixel / actual size (length) across different videos with different recoding methods, if the size of animals used in these videos are consistent. The ratio of pixel / actual size (length) is not easy to obtain and is subject to change easily (e.g., when the zoom-in level changes). With the option of normalizing distances to the size of a single animal, you can compare the analysis

1 results across different recordings or experimental sessions without worrying about the changes
2 in the ratio of pixel / actual size (length).

3 4 **3.3.2. 'Mine Results'**

5 Automatically performs parametric / non-parametric statistical analysis among groups that you
6 selected, according to the data distribution, to compare the mean / median of different groups
7 and display the data details that show statistically significant difference.

8 The Shapiro test will be first performed to assess the normality of data distribution. For
9 normally distributed data, if unpaired, unpaired t-test for 2 groups, ANOVA for more than 2
10 groups, with either Tukey (comparing each pair) or Dunnett's (comparing all groups against the
11 control group) posthoc comparison; if paired, paired t-test for 2 groups, ANOVA for more than 2
12 groups, with either Tukey (comparing each pair) or Dunnett's (comparing all groups against the
13 control group) posthoc comparison. For data that is not normally distributed, if unpaired, Mann
14 Whitney U test for 2 groups, Kruskal Wallis for more than 2 groups, with Dunn's posthoc
15 comparison for both comparison of all groups and against control; if paired, Wilcoxon test for 2
16 groups, Friedman for more than 2 groups with Dunn's posthoc. The selections of the tests are
17 consistent with those in GraphPad Prism 9.

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