Investigating perceptual decision making using automatic pose estimation

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Centre de Recerca Matemàtica

Founded by Professor **Manuel Castellet** in 1984, the centre de Recerca Matemàtica or **CRM** is a mathematical research institute. The CRM is the oldest mathematics institute of research in Spain.

One of the biggest roles of the CRM is the organisation of international events and meetings; each year the CRM invites a lot of professors and researchers from around the world not only to present their work, the projects they are working on and the papers they published but also to collaborate with the researchers of the CRM.

CRM created a supergroup of smart hardworking researchers trying to discover the mysteries of maths, neuroscience and other fields related to mathematics.

Nowadays, the CRM is a team effort between the Catalan Government, the Catalan Academy, and the university UAB (Universitat Autonoma de Barcelona), it's a part of the CERCA (centers of research supported by the Catalan Government) and of the EPDI (European Post-Doctoral Institute for the Mathematical Sciences). They are also leading a school for maths called BGSMath(Barcelona Graduate School of Mathematics) And they're connected to the Instituto Español de Matemáticas (IEMath) too. They are connected to all the math clubs actually!

CRM is not just about math-neuroscience research, but they are also into sharing big knowledge and helping students learn a lot of scientific things that gets us more excited and curious about science. They are part of the BAMB! (Barcelona summer school for Advanced Modelling of Behavior) for brain science. They are teaching a lot of things about neuroscience and maths and have hands on tutorials and coding parts to know how to use models for example for neuroscience tasks.

The Centre de Recerca Matemàtica stands out for its commitment to Social and Environmental Responsability(SER) in the mathematical research. They recognize the importance of SER in promoting sustainable science and society and by integrating it into their research. Additionally, CRM implemented eco-conscious practices like curbing the carbon footprint and also by cultivating eco-friendly attitudes.

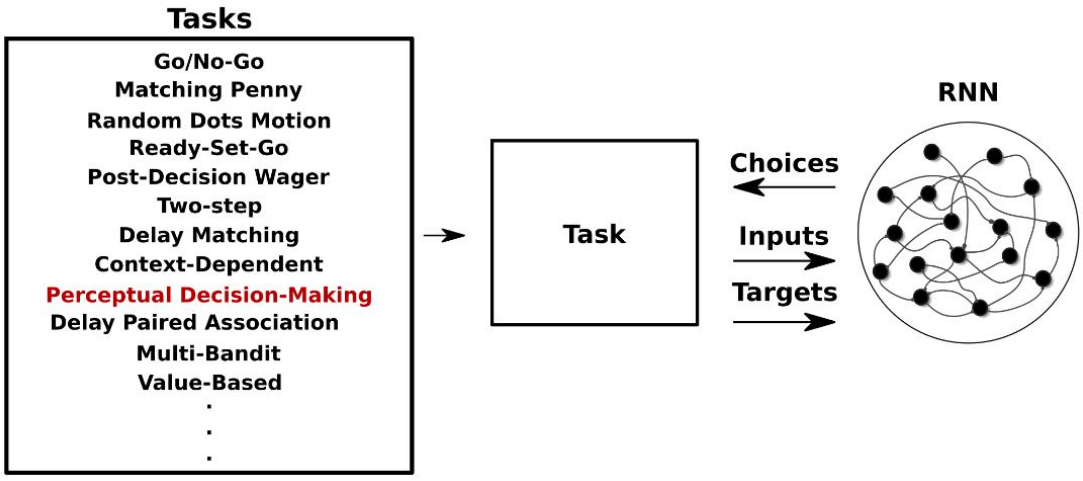

Figure 1: RNN Model for Neurocience Tasks (Source: Github Link)

BARCCSYN

During my internship, I got the chance to participate to the annual Barcelona Computational, Cognitive and Systems Neuroscience (BARCCSYN) meeting. It's an event where all researches from different areas meet and share knowledge. Those who are interested about how the brain works, about the behavior of rats, about memory of monkeys...

This year was the 11th time they've held this BARCCSYN, on May 25 and 26,2023, at the Institut d'Estudis Catalans. Each day, there were talks, poster sessions where people explain the papers are working on and many other things.

I have gained significant knowledge during this event and it introduced me to the fantastic world of research.

Figure 2: BARCCSYN Event Poster

Abstract

My journey at the **CRM** started by understanding the state of the art of different things, especially papers related to my internship topic. For this I have got into the deep of maths and neuroscience. This helped me understanding complex ideas about different topics.

At the **CRM** and in **each Monday**, we had a meeting where someone between us present a research paper or talks about what they are working on. We also do something similar called a **journal club** at **IDIBAPS each Friday**. These presentations have been so helpful for me to gain knowledge about different topics. One thing I discovered through all this, is how curious I am to learn about how our brains works, the more I was discovering new papers, the more I was excited to dig into what's happening inside my (our) heads.

Then I had to get the data from a **cluster** in the clinic hospital **IDIBAPS** where my tutor works, this helped me a lot to learn about using Linux and Ubuntu, also I knew how to connect, use and extract data from a cluster from far away. My data was about 15 different types of rats, each rat had its own and unique way to do things, to behave, understanding their behaviour was so interesting, it made me think about how much the world is so mysterious.

I used **DeepLabCut**, a software tool to make the **pose estimation** and **tracking** of rats. Then due to a python code that I did, I was able to verify if my **Tracking** model is efficient. After that, I tried to implement a **model** for predicting the choices of the rats (center, left or right).

Acknowledgements

I would like to express my sincere gratitude to my tutor **Dr. Manuel Molano** for their invaluable guidance and support throughout this project and to all the administrative staff and researchers at the **CRM**.

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Chapter 1

Understanding of research papers

In order to have a deep understanding of both **Machine Learning** and **Neuroscience** parts of my project, I went deeply into many research papers. I will explain briefly two of them, which are closely related to my project.

1.1 Article 1: Response outcomes gate the impact of expectations on perceptual decisions

This Paper Hermoso-Mendizabal et al. 2020 explain how animals and in particular rats can make their choices based on sensory information and if it can be influenced by the recent decisions the rats did before. It explains the connection and the influence between sensory information and recent expectations.

To do this, the researchers did an experiment where rats were faced to a different stimuli and had to make their choice. What was more interesting in the paper is that the probability of making rat hear the same stimulus was manipulated through different blocks of trials.

What was exciting about it is that the rats developed a habit where they just repeat what they did before or just do the opposite based on how much they think the same sound will come again. It's what they called a "transition bias". What means that our rats can just change their decisions on what they think the next sound will be, the same or not!

And what is more surprising is that this habit disappeared when they messed up a choice, and yes! it came back again when they got it right (it's like humans, when u have a bad mark, you just lose confidence on yourself ...)

As a result, researchers got a new idea about rats, is that when they got something right, it influenced their next choices and the more they got correct choices the more they are paying attention of what it might happen next and vice versa.

In conclusion, rats make their decisions based on not only what they hear (sensory information) but also about their expectations of what it might happen next.

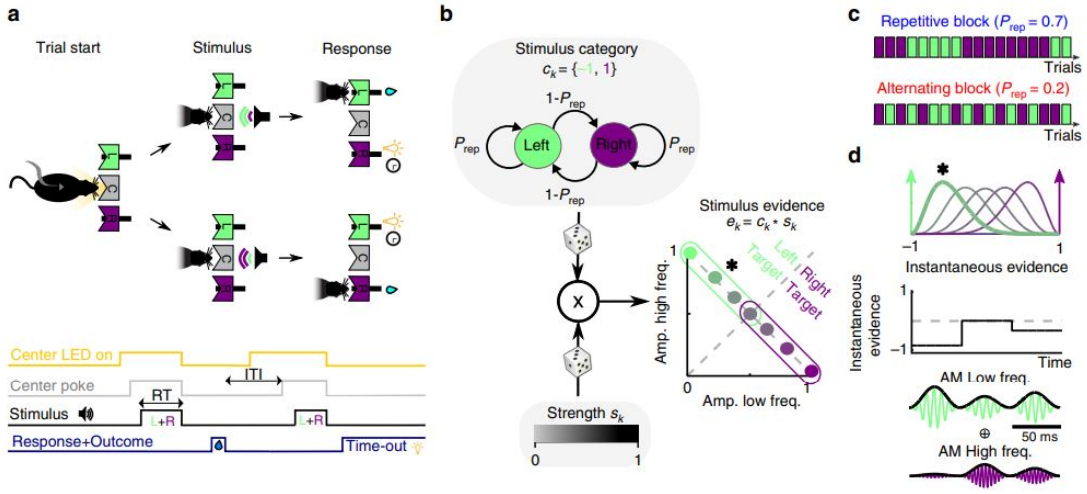

Figure 1.1: Auditory Discrimination Task and Stimulus Sequence Statistics[1]

1.2 Article 2: Proactive and reactive accumulation-to-bound processes compete during perceptual decisions[2]

In this second paper Hernández-Navarro et al. 2021, researchers experiment with rats doing similar auditory tasks.They have to press a button whenever they hear a sound. So Rats are actually waiting for a limit of evidence to make their decision.

The interesting part of this paper is that researchers discovered that sometimes rats aren't waiting for enough evidence that they really heard the sound to press the button, it's like them deciding sometimes to press the button without waiting for the sound.

Actually this is the new challenge that researches faces because before we were thinking that the decision of rats are based only on sensory information but know we discovered that sometimes rats can press the button even before they heard the sound (with no sensory input).

Therefore, the researchers discovered that there are two things: the first is the **Action Initiation** that refers to the rat and his thoughts about pressing the button or not and the second thing is the **Evidence Accumulation** which means the information that the rat collected (the sensory information).

In normal cases, the rat collect information (Evidence Accumulation) and when it reaches certain limits, The Action Initiation starts and the rat press the button. But sometimes what happens is that the rat presses the button too early without collecting information.

To conclude, this research reveals the coexistence of reactive (when the evidence is accumulated to a certain limit) and proactive responses (that happens independently of the stimulus) and shows that how the decisions are made is more complex than we thought it is.

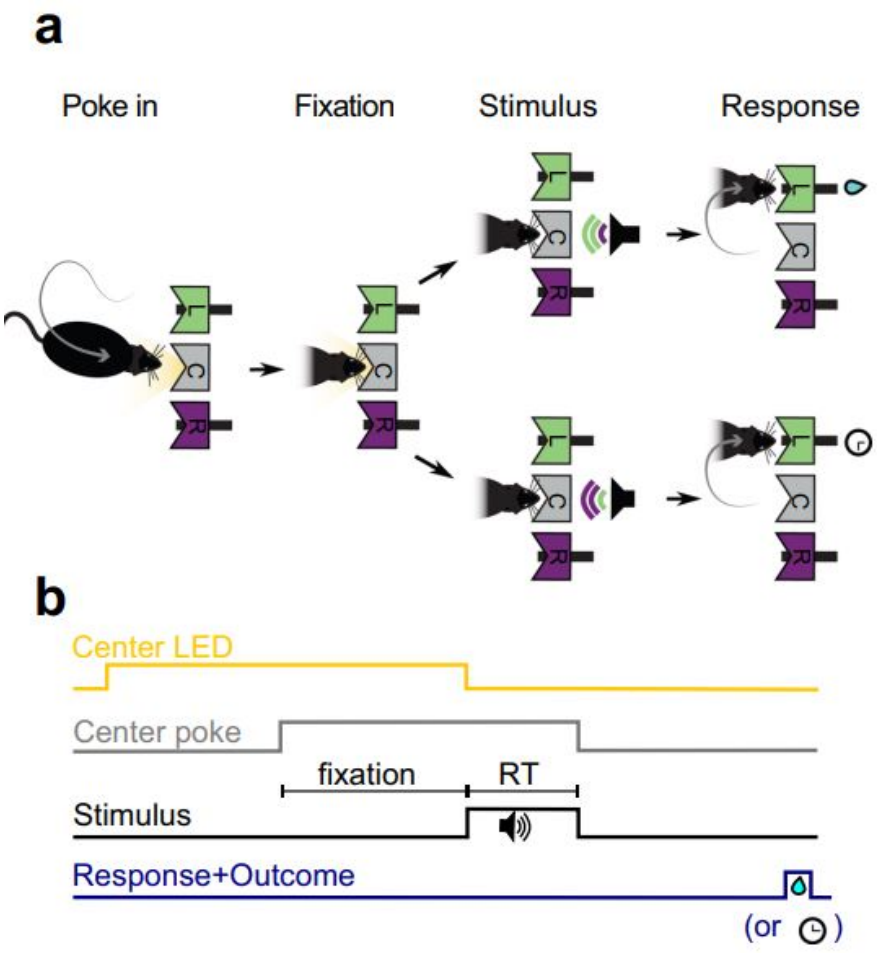

Figure 1.2: Auditory Discrimination Task[2]

Chapter 2

Data Collection

As part of my internship I had the opportunity to collect the essential data for my project on perceptual decision-making from a cluster at **IDIBAPS** Clinical Hospital.

I've got at first problems several using Windows; I was facing problems while attempting to establish an **SSH connection** to the remote server so I decided to try with Linux which allowed me to access to the cluster where there is all the Data i need in a specific folder called rats. Hundreds of types of rats with countless videos.

The Data I was working with consisted of around 3 GB of videos recording, 100 videos of 15 different type of rats, these rats were identified by these codes: **'LE42', 'LE43', 'LE38', 'LE39', 'LE85', 'LE84', 'LE45', 'LE40', 'LE46', 'LE86', 'LE47', 'LE37', 'LE41', 'LE36' and 'LE44'**, in each video of each type, the rat is performing an auditory task and is choosing choosing to go either the center,left or right.

I was carefully selecting videos that aligned with my project, where the rat perform more in making its perceptual decision making.

Figure 2.1: Folder of Rat Videos

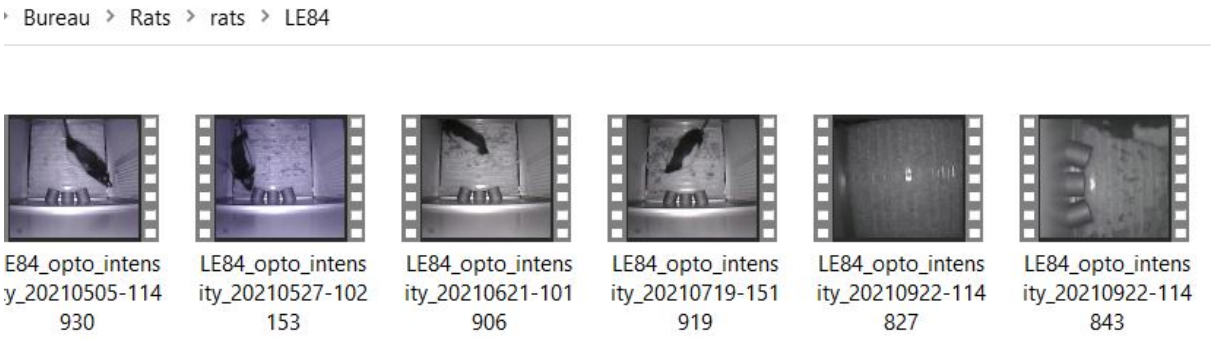

Figure 2.2: Videos of Rat "LE84"

The sections of videos that interest me and that will help me in my project is:

- **Fixation Phase**: In each trial rats get a signal that is a **yellow LED** in the center, they go and follow it and **poke** at the **gray center spot**. After they do, the fixation time period of 300 milliseconds start, it's called the **fixation period**. It's when rats are getting ready to receive sensory information, just waiting.

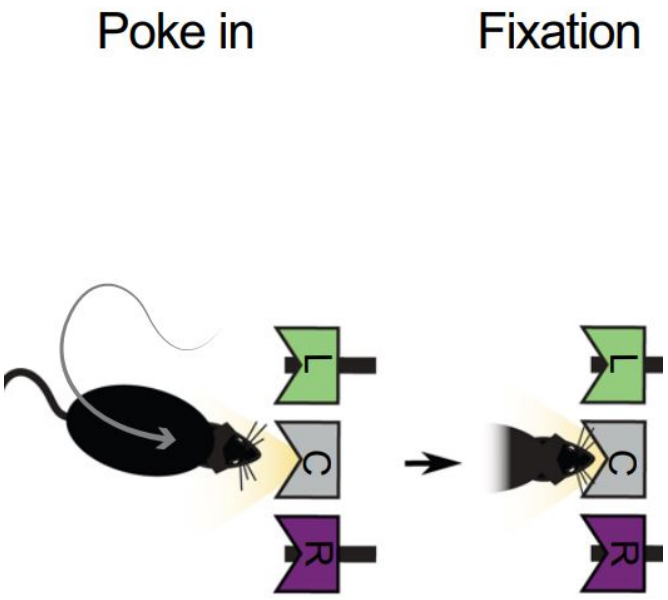

Figure 2.3: Poke-in and Fixation Period

- **Response Time:** When the period of fixation ends, the stimulus appears, it's a mix of two sounds with different frequencies or with different sound sources. Each of these sounds is linked to either the left or the right side. The rats have to figure out if the sound is coming from the left or the right, they do this by listening very carefully to the sound, then the rats can decide to leave the center and choose either the left or the right and this decision is their response. The duration that it takes them to make this decision is called the **reaction time** RT.

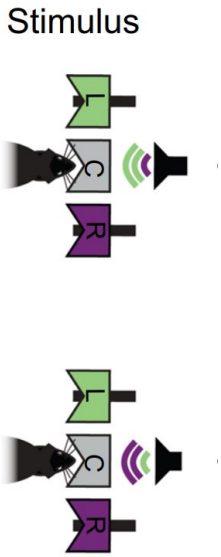

Figure 2.4: Stimulus and Response Time

- **The Response:** it's when finally our rats choose either they will go center, left or right. If rats got their decision right, they were rewarded with water and if they take a wrong decision they were punished by a time-out.

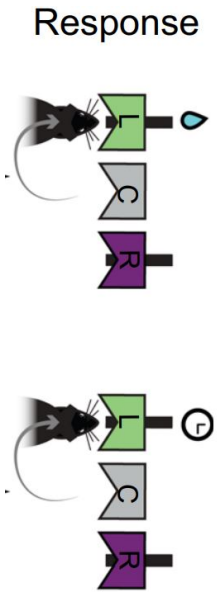

Figure 2.5: Response

In conclusion, our trial is the following: the rat starts by focusing, poke in and waiting to hear the sound in the period of fixation and finally making a decision.These three parts give us a lot of information about how actually rats make choices when they are receiving a **sensory information** or-based on the two articles I explained in the first chapter-make their own decision **before** any sensory input.

Chapter 3

DeepLabCut

During my internship, a big part of my project was devoted to the implementation of **DeepLabCut** or **DLC** [4], a powerful tool used for pose estimation based on transfer learning with deep neural networks, **DLC** and with the help of **neuroscience** and **deep Learning** algorithms we can understand rats behavior.

Quick Pipeline:

DeepLabCut uses deep neural networks to make pose estimation and to track animals,in our case, rats. We feed DLC with videos of rats going into auditory tasks and thanks to Deep Neural Network algorithms we track the body parts of the rat in the video, like the nose, leg, ear of the rat...

DLC uses also a technique called **transfer learning**;the networks that it uses have already been trained on a massive amount of data. These pre-trained networks can recognize already different parts of bodies of rats, which helps a lot and increase the quality of results.

Once we do that, we can track the rat and have the movement of each part of his body over time, which means that we will have what we need to study its behavior.

One of the great thinks, that helps using DeepLabCut, is the interactive interface(Project GUI), it simplifies a lot of tasks as labeling of data, model training...

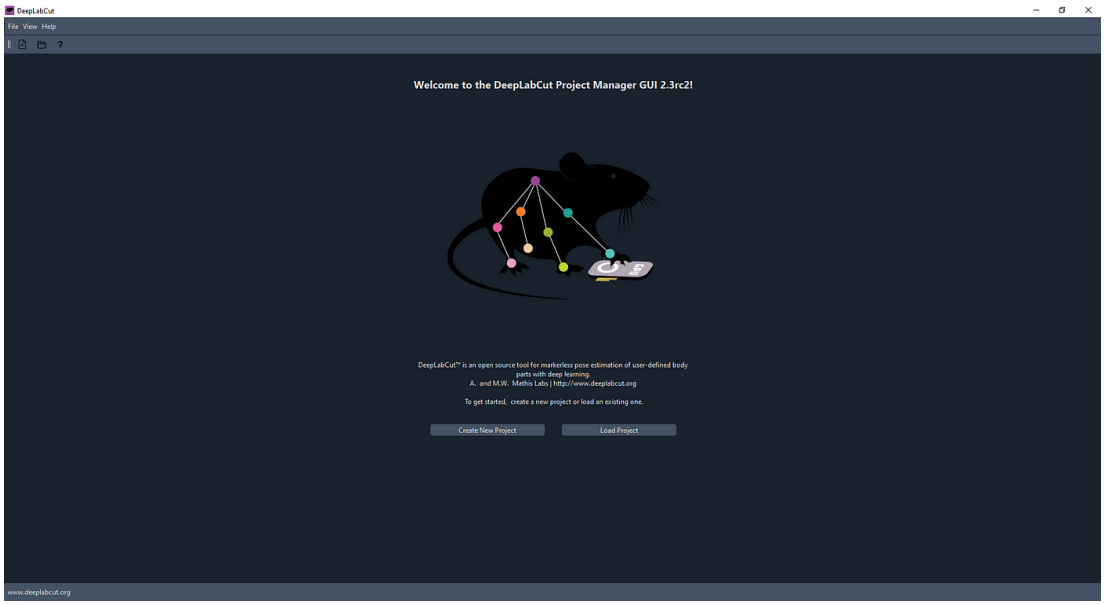

Figure 3.1: Screenshot of the DLC Interface

Machine Learning

After that, I tried to use a Recurrent Neural Network(RNN) model, a type of artificial intelligence model, to predict the responses of rats during decision-making tasks. By training the RNN on the behavior data, we could predict if our rat will choose to go left or right.

Challenges Faced:

I've got a lot of problems while installing DeepLabCut, in the beginning I encountered issues with **TensorFlow** that takes an important part of DLC. **Conda**, the environment manager, didn't want to work well. After this, and thanks to the documentation and tutorials of DLC, I gained a clear understanding of how it works.

Chapter 4

Installation and using of DeepLabCut

Installation of DeepLabCut

To install DLC, I started by installing Anaconda to create all the dependencies in an environment that I called **DEEPLABCUT** in my machine.

I installed deeplabcut from github by cloning it and following the documentation.

Figure 4.1: Screenshot of the deeplabcut Installation

I set up and **activate** the **environment** named **DEEPLABCUT**. Then I start using DLC for each of the 15 rats. This took me a long time, approximately 2 days for each type of rats because of the huge data that I have and the big number (100 000) of iterations that I use in the training of the network.

```
(base) C:\Users\33752\Desktop>activate DEEPLABCUT
```

Figure 4.2: Screenshot of DEEPLABCUT Environment Activation

Here is an example of the pipeline that I followed while using DLC for each type of rats:

I start by launching DLC:

```
(DEEPLABCUT) C:\Users\33752\Desktop>python -m deeplabcut
Loading DLC 2.3.5...
C:\Users\33752\.conda\envs\DEEPLABCUT\lib\site-packages\deeplabcut\__init__.py:80: UserWarning:
        As PyTorch is not installed, unsupervised identity learning will not be available.
        Please run `pip install torch`, or ignore this warning.

  warnings.warn(
Starting GUI...
```

Figure 4.3: Command to Launch DLC

Create a project

I started by making a new DeepLabCut project for a specific type of rats by including the videos of rats:

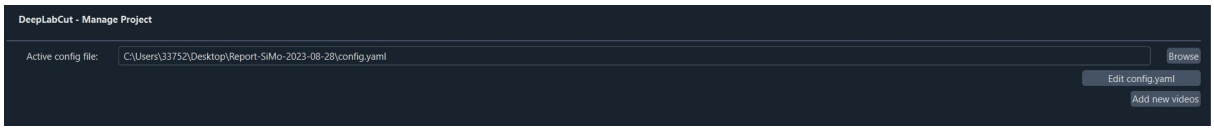

Figure 4.4: Screenshot Showing New DLC Project

this create automatically a folder with all information that I need.

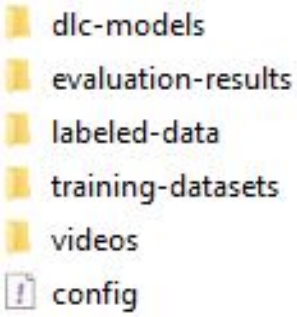

Figure 4.5: Screenshot of Automatically Created DLC Folder

The Folder included a configuration file that I used to mark the points of the body that I want and give them a name to mark them

```
    # Project definitions (do not edit)
Task: simo
scorer: simo
date: Aug28
multianimalproject: false
identity:

    # Project path (change when moving around)
project_path: C:/Users/33752/Desktop/simo-simo-2023-08-28

    # Annotation data set configuration (and individual video cropping parameters)
video_sets:
  C:\Users\33752\Desktop\simo-simo-2023-08-28\videos\le86-p4-opto-ramp-20201114-085722_xGjYgr0U (1).avi:
    crop: 0, 640, 0, 480
bodyparts:
- nose
- rightear
- leftear
- tailbase
```

Listing 4.1: Yaml file configuration of the project

Data Preprocessing

The first step is to do what we called **Frame Extraction**; we take images from the videos we have especially when the rats are making their decisions. Each frame is taken in a different moment/behavior of the rat.

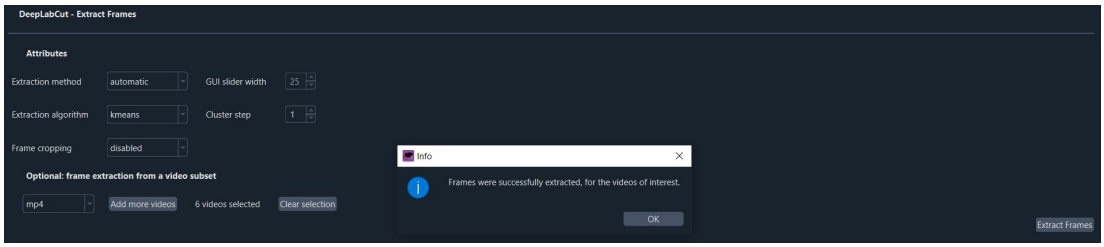

Figure 4.6: Screenshot of Frame Extraction

Now that we have frames, we add labels; we add key points to the parts we

want to track in the body of the rats so that we can help DLC making the pose estimation and track our rats.

Figure 4.7: Screenshot of Data Labeling in DLC

Create the Training Dataset

Once we have labeled the Data by adding the key points to the frames, we create our training data set by pairing each frame with it's labeled key points, so that our network will learn from them.

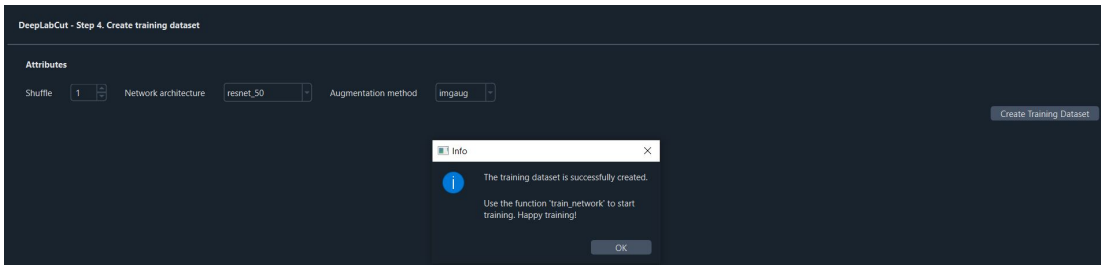

Figure 4.8: Creation of Training Dataset

Training the network

Once we have our training data set created, we start training our network. My configuration of the network training was the following:

- 100 000 iterations
- 5 snapshots to keep
- 50 000 save iterations

with this configuration, the network takes approximately 26 hours to finish training.

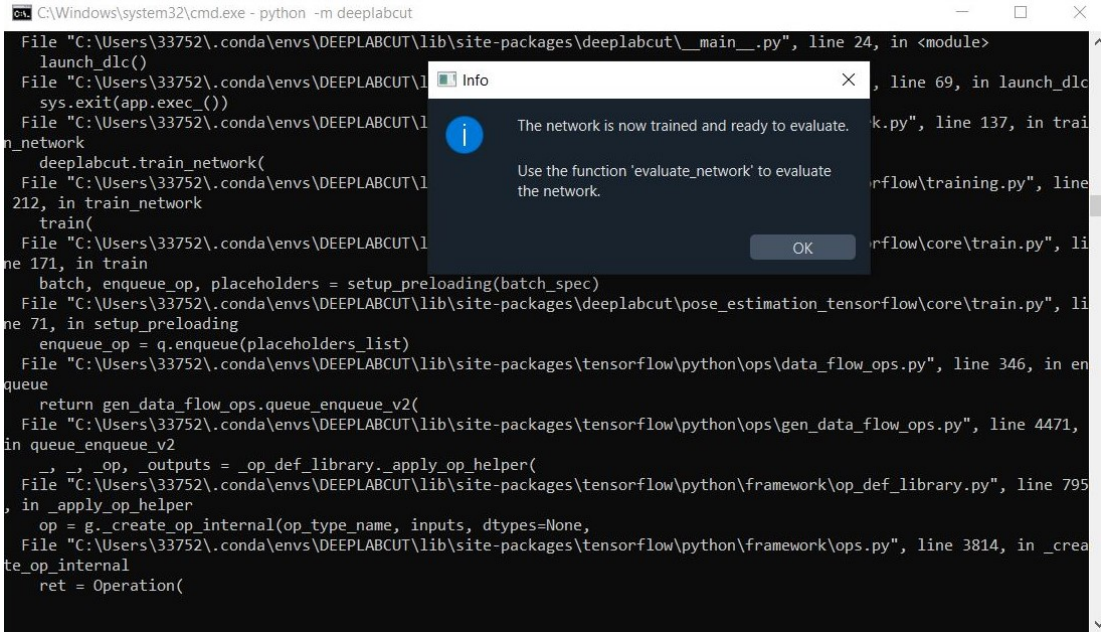

Figure 4.9: Screenshot of Network Training

The neural network learn from the training data set and start recognizing each part of the body of the rat, the more our frames are different (rat in different poses), the better our network perform.

Network Evaluation

After the neural network is trained using the training data set we give it, we evaluate it by seeing how well the network it's learned

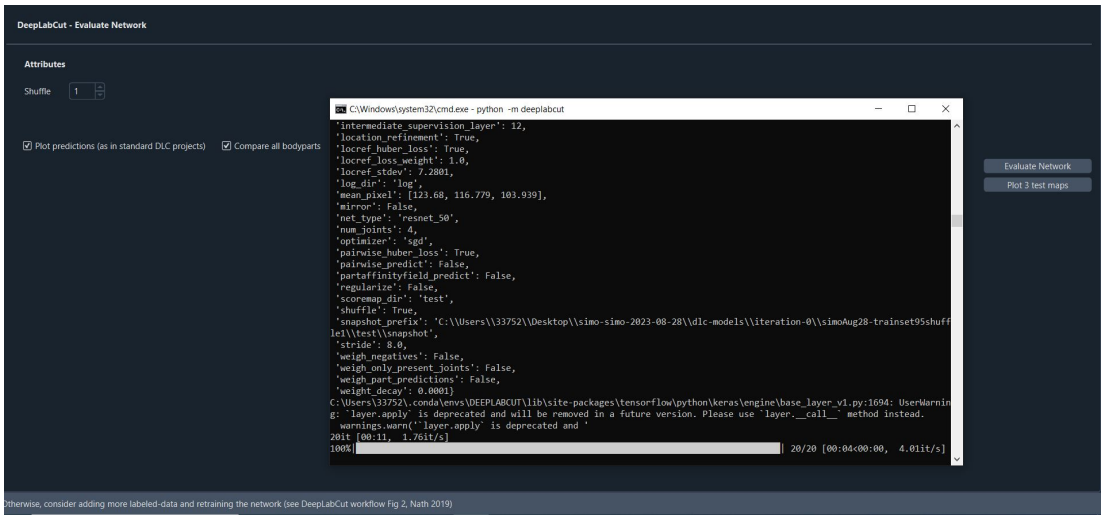

Figure 4.10: Screenshot of Network Evaluation

This is done by taking the videos we didn't label, and comparing their model prediction to the labeled positions of the key points in the training data set, this help us measure how close our model is to reality.

Analyzing,creating videos and extracting outlier frames

In this final part I did the analyzing of videos and I created labeled ones and I extract outlier frames.

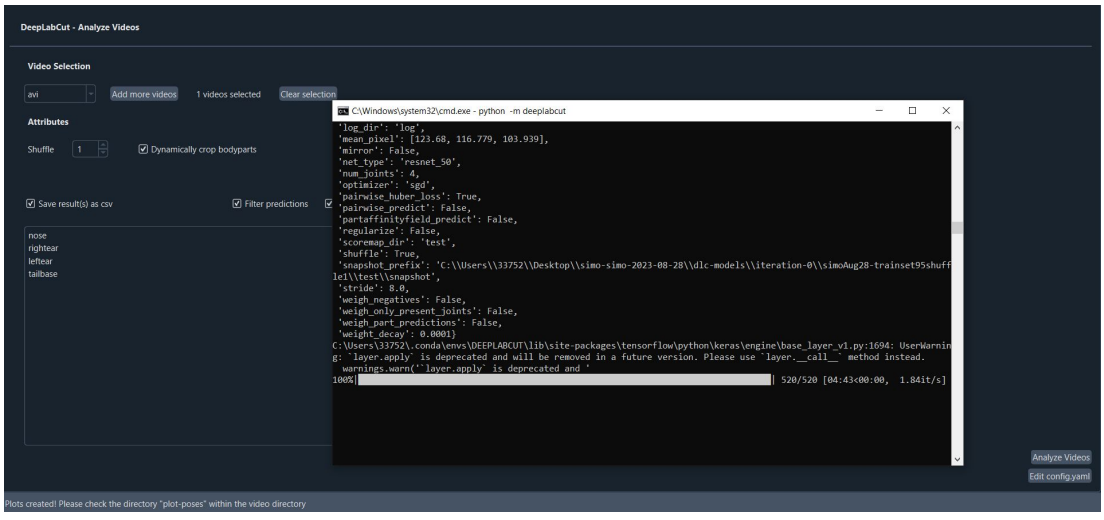

Figure 4.11: Screenshot of Video Analysis

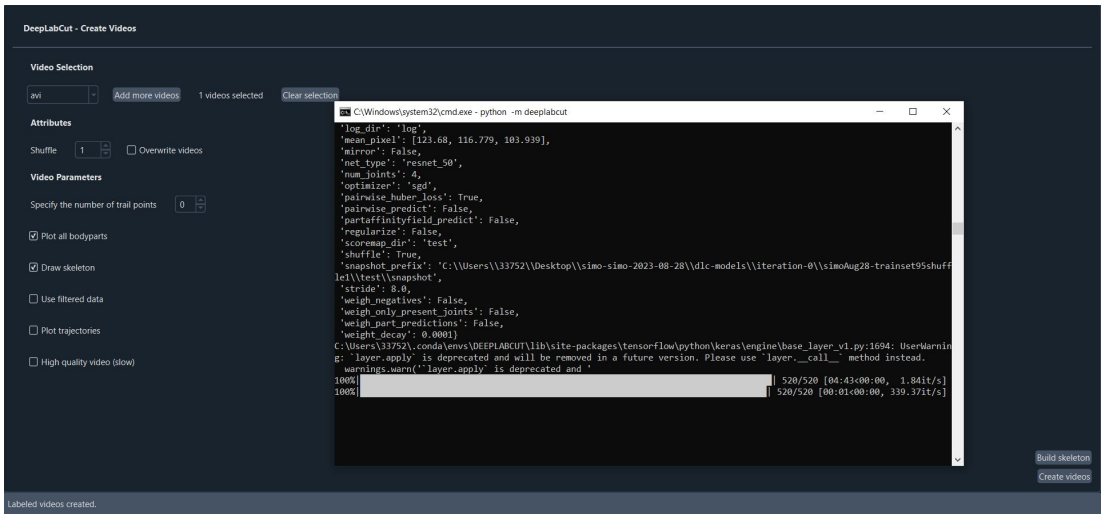

Figure 4.12: Screenshot of Video Creation

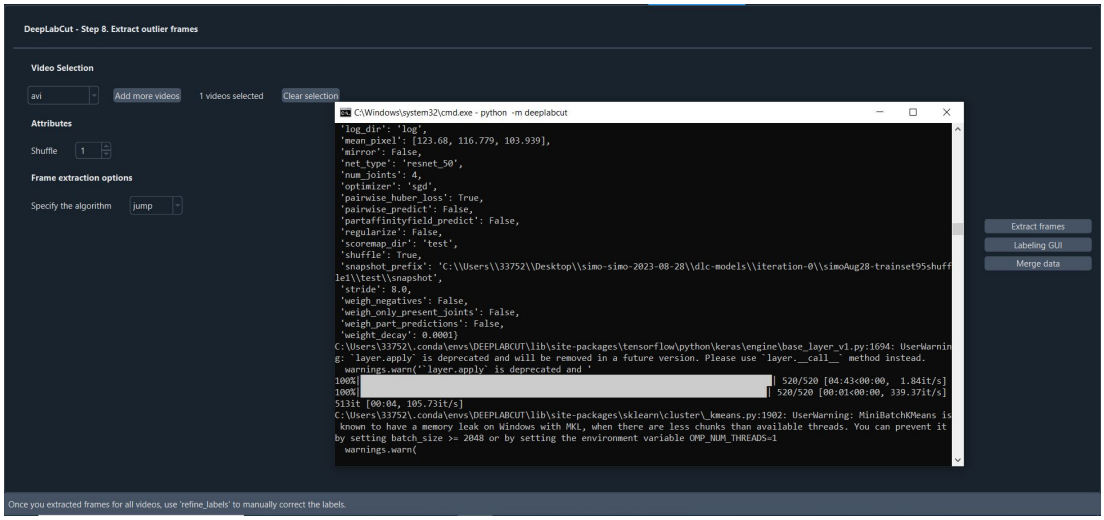

Figure 4.13: Screenshot of Outlier Frame Extraction

- I have obtained a plot of the trajectory of body parts of rats. (Y position in relation of X position).Here is the plots for the nose for example:

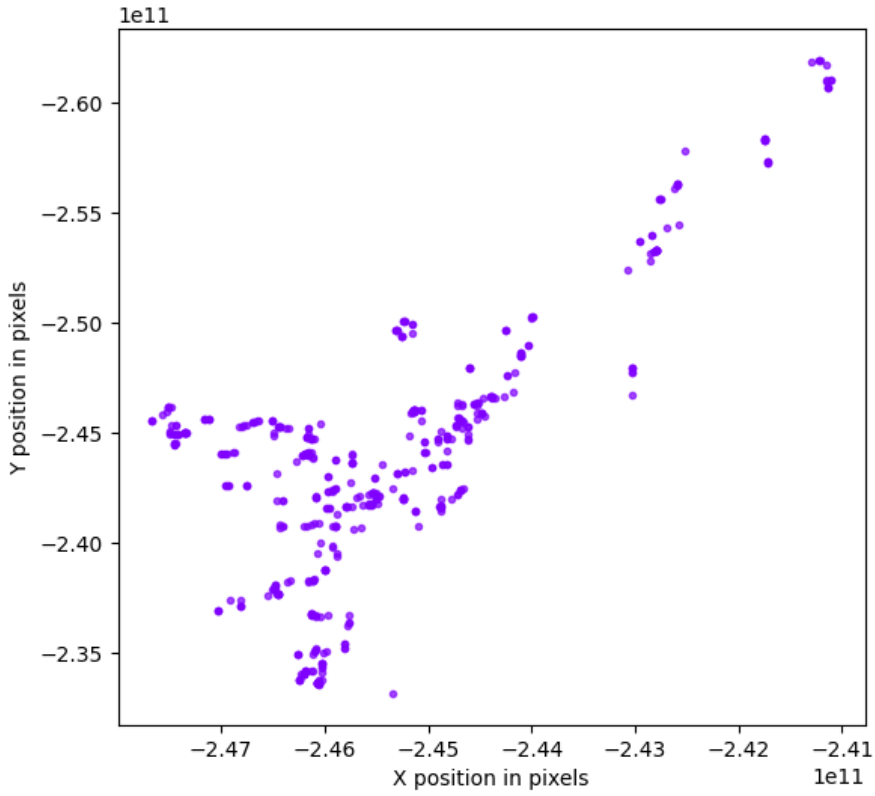

Figure 4.14: Screenshot of Rat Nose Trajectory

- A plot showing the X ad Y positions in function of frame index

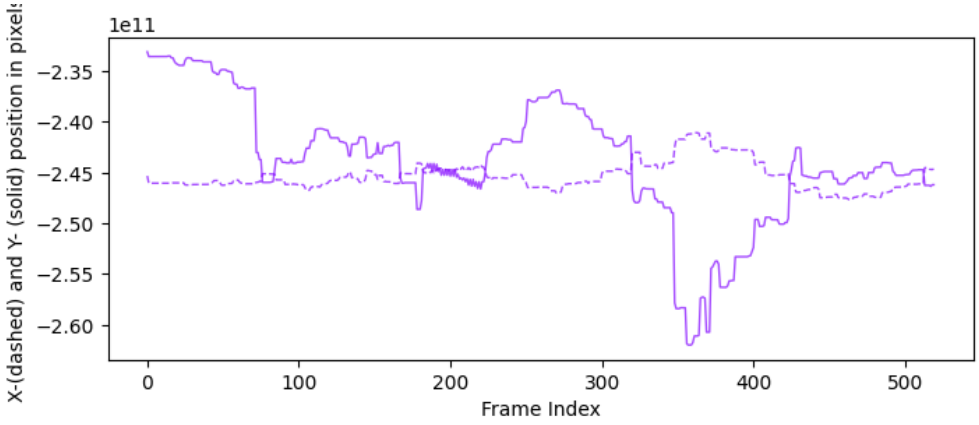

Figure 4.15: X and Y Positions of Rat Nose as a Function of Frame Index

- I also have the results in the form of Excel files containing the coordinates (X and Y) of all the body parts in each frame of the video. Therefore, I

have all the necessary parameters for the final phase, that is the prediction of the rat choice by a model of RNN.

LE36_p4_only_light_20191001-122736DLC_resnet50_LE36Jul3shuffle1_100000.csv

	A	B	C	D	E	F
1	scorer	DLC_resnet50_LE36	DLC_resnet50_LE36	DLC_resnet50_LE36	DLC_resnet50_LE36	DLC_resnet50_LE36
2	bodyparts	nose	nose	nose	leftear	leftear
3	coords	x	y	likelihood	x	y
4	0	247.7570038	231.8122101	0.1968578994	195.2141571	246.2957306
5	1	247.8071289	231.9683685	0.1123726517	194.941803	246.1924133
6	2	246.9979858	232.0157166	0.11557623	195.0130768	245.8887482
7	3	247.3981476	232.2232666	0.1222611889	194.8862762	245.8856659
8	4	247.4055939	232.0276947	0.1152640358	194.7727966	245.957016

Figure 4.16: Subset of the Results from the Dataset

Model Zoo

In my study, I used two different models (trained models, and Model Zoo) to have more choices of results and select the best ones.

The **DeepLabCut Model Zoo** is a pre-trained models using the DeepLabCut software. It containes a range of pre-entrained models of various species, behaviors...Which facilitate the task for researchers; they don't need anymore to add labels and training data.

Here is an example of results using the model zoo:

- The plot of the trajectory of different body parts of rats.

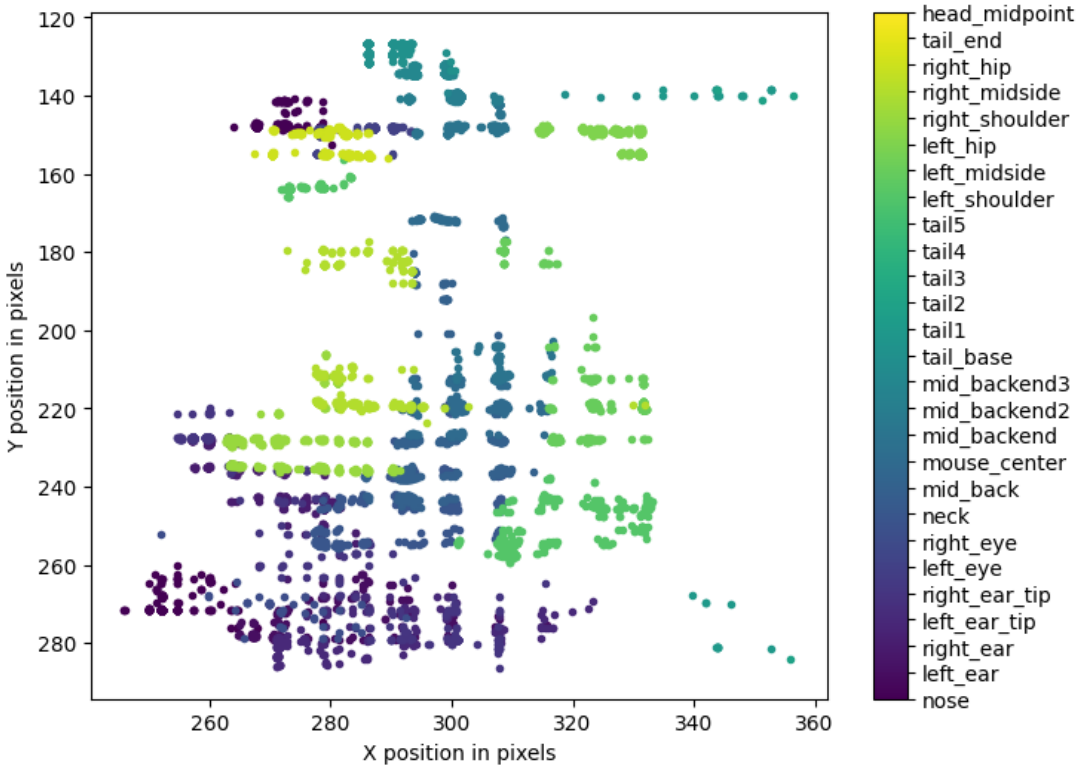

Figure 4.17: Trajectory of Different Rat Body Parts

- Plot of X and Y positions in function of frame index

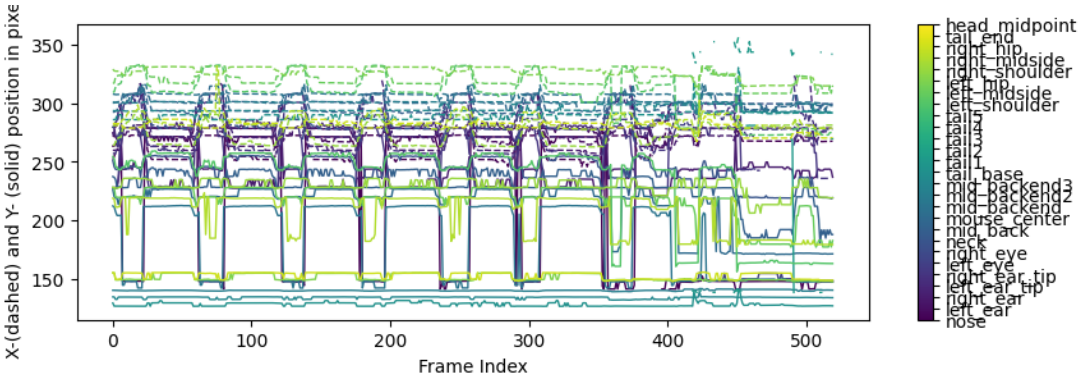

Figure 4.18: X and Y Positions of Various Body Parts as a Function of Frame Index

- A labeled video with a lot of body parts that interest us:

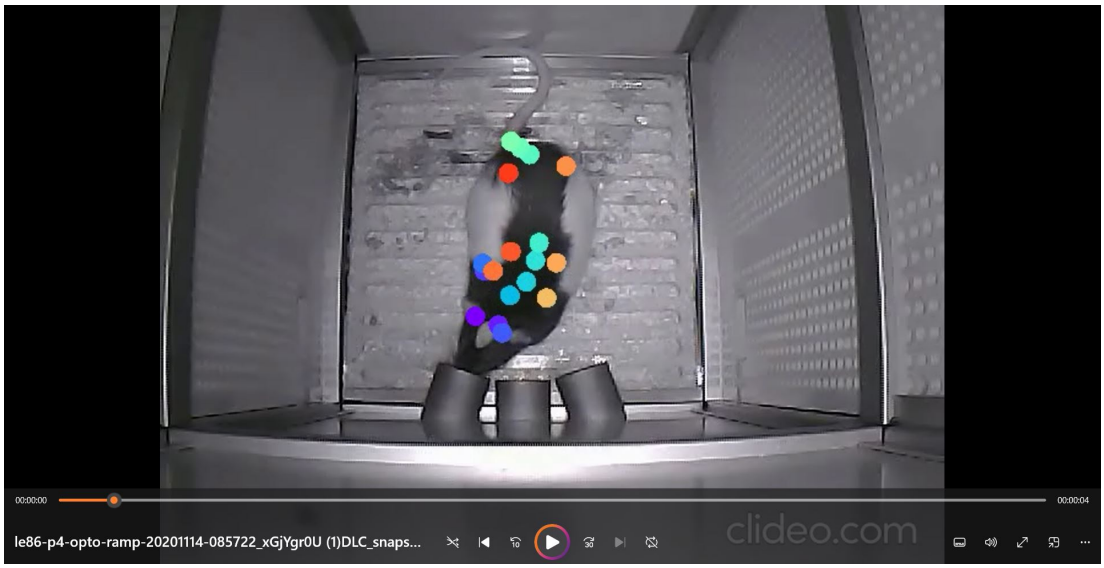

Figure 4.19: Screenshot of Labeled Rat Video

Chapter 5

Failures: Implementation of a Recurrent Neural Network

During this final part, I've tried to implement a Recurrent Neural Network (RNN) model to make a perceptual decision making. Even tough i didn't achieve my desired results due to some obstacles I faced; notably the data preprocessing step.

Nevertheless, I had the opportunity to discover a new toolbox called Neurogym which consists of gathering several neuroscience tasks that can be accomplished through a RNN training. In this context, I gained insights in term of implementation of RNN models using PyTorch, training, testing, adjusting the parameters, and setting experiments to have a full analysis of scenes.

Chapter 6

Future Work

- I wanted to develop the last part (RNN Implementation) where I faced problems and I hope to contribute more to the understanding of how decision-making works.
- I am interested in exploring different situations for example : where rats lack sensory information as input, I wanted to know how will they behave, especially their first reaction (that I assume it to be natural).
- I am also excited about understanding how the mammalian brain works, and how we humans make choices and decide. I am very curious to figure out whether we can predict choices that people make based on different inputs, such as: feelings, as well as other external information, even though the tasks seems to be complicated.

Chapter 7

Conclusion

In conclusion, the internship was a useful experience. I have found out what my strengths and weaknesses are, gained new knowledge and skills and met many new people. I achieved many of my learning goals, but for some the conditions did not permit me to achieve them as I wanted.

My internship at the **Centre de Recerca Matemàtica** has provided me with the motivation to discover more things about neuroscience, in particular the mysterious parts of humans or animals bodies like the brain. And also to pursue a career in Data science and AI.

I also discovered that I should make more efforts with my communication skills so that i can make a bigger network and introduce myself in a better way.

Bibliography

Hermoso-Mendizabal, Ainhoa et al. (2020). "Response outcomes gate the impact of expectations on perceptual decisions". In: *Nature communications* 11.1, p. 1057.

Hernández-Navarro, Lluis et al. (2021). "Proactive and reactive accumulation-to-bound processes compete during perceptual decisions". In: *Nature communications* 12.1, p. 7148.